AEROSPACE REPORT NO.
ATR-2012(5629)-1 REV A

Automated Transit Network Feasibility Evaluation San José Mineta International Airport San José, CA

October 19, 2012

Thomas Paige
Program Development
NASA Programs Division

Prepared for:

San José Department of Transportation
200 E. Santa Clara Street
Tower 8th Floor
San José, CA 95113-1905

Contract No. 09172010

Authorized by: Civil and Commercial Operations

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Approved by:

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Change Notification

This update to the report originally released to the City of San José on October 19, 2012, corrects typographical and grammatical errors, reconciles inconsistent use of notations, and clarifies the presentation of information in certain paragraphs, charts, and graphs. No technical content or findings have been altered.

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1. Executive Summary

Prologue: Forget everything you know about transportation systems. Take all of your expectations regarding their design, operations, cost/performance tradeoffs, user value, and financing/construction risks and throw them out the window. The similarities between automated transit networks (ATNs) and conventional systems are skin deep. Just below the surface is a completely different animal, orders of magnitude more complex.

As envisioned, ATNs would fit well the definition of a truly disruptive innovation, with the ability to change how we live in an urban environment. However, unlike a relatively unobtrusive cell phone tower, a dashboard navigation display, or a handheld device that can be upgraded with the signing of another two-year service contract, ATNs involve large, expensive, and permanent infrastructure that would become part of the fabric of an urban environment and directly involve issues of public safety. They thus require that a high degree of due diligence be carried out prior to their adoption.

A debate over the merits of ATNs and the realistic chances of them being able to perform as envisioned has raged for more than four decades. There is no doubt from a technical standpoint that the movement of some numbers of small vehicles operating on a network can be coordinated. The question is not if ATNs *can* be built and operated, but if they *should*—can they move *enough* people safely, efficiently, effectively, and/or uniquely to make them worth the effort. Proponents hold out the promise of high capacities, an unprecedentedly attractive service model, and a downward bending of the transportation cost curve. Critics contend that this analysis is incorrect—that proposed designs are ill-conceived, their performance *not* worth the effort, and that they therefore will simply never be realized.

These contrasting views have unfortunately been amplified over the years in part by the character of the debate—one that has been and still is being argued at the extremes and from rather dogmatic perspectives. The parties are talking past each other, resulting in a confusing set of claims, counterclaims and conceptual dissonance that's obscuring the ultimate value of ATNs and even the definition of what they *are*, or might be.

In recent years, teams of dedicated innovators have made tantalizing progress toward proving some of their contentions, yet their work is still very much in progress, and the overall debate remains unsettled. Even the focused objective of using ATN technology as a transit connector to and within San José Mineta International Airport (Airport) brings these aspects of the ATN question into sharp relief. This project being contemplated bears the promise of helping to bring into existence a unique and intriguing form of transit service for Airport customers—and the simultaneous reality of having to deal with the uncertainties that are *always* associated with something "new" and largely untried.

Project Context and Summary Findings: Given the state of affairs discussed above, a feasibility assessment of using ATNs to provide Airport transit service takes on a much different meaning than one that would normally be associated with an infrastructure project. In the latter case, one starts with the presumptive knowledge of established technical maturity, a network of knowledgeable, involved stakeholders, and established rules governing their transactions. For example, not only are the performance capabilities of a light rail vehicle known, having been verified through extensive testing and years of operational experience, but also the building codes for the structure that supports it, the regulations governing its design and operations, the design guidelines necessary for effective system planning, the risks that underlie the willingness of government agencies and/or financial institutions to finance construction, the perceptions of the public as to its value, and on and on.

With regard to ATNs, most of this is not in place and is therefore not available to inform a traditional assessment of feasibility. There is no equivalent of, say, the AASHTO Green Book[1][1]. The academic world has not yet produced a pool of ATN system planners. Existing codes, standards, and regulations, while helpful as a starting point, certainly do not cover *a priori* all aspects of this entirely new class of vehicles, structures, and operations—and their misapplication would hinder rather than encourage innovation. What's most in need, of course, is the experience upon which all of the above is based, and that *always* bridges the gap between concept and conventional reality.

This report might therefore be more aptly described as a reality check rather than a feasibility study—very little can have been presumed. Lacking the usual set of system knowledge, planning guidelines, and cost information, the project turned to the development community to provide the necessary information for the City of San José's due diligence. This was a successful effort that shed light on the state of the art and state of the industry and helped inform the following summary results:

1. Recent advances in ATN design and operational experience, and the analyses described herein, lead one to the conclusion that, from a technical standpoint, ATN technology may be able to provide an attractive transit experience for Airport customers. However, this would likely require that "off-the-shelf" designs be modified, matured, and supplemented with additional system elements not encompassed within the current definition of ATNs.

2. ATN technology is far from being fully mature from either a design or a *conceptual* standpoint. ATNs currently exist as essentially prototype designs, having a high degree of uncertainty and many unknowns, including:

    a. the socioeconomic and human factors pros and cons and their influences on design

    b. the technology's cost and environmental effectiveness

    c. the level of current actual performance and practical performance limits (the vehicles, for instance, have about one-tenth the power of a contemporary electric automobile)

    d. the level of test verification and acceptable range of operating conditions

    e. the safety and security of operations, especially with respect to control communications

    f. the range of applications for which they are suitable

    g. the liability and regulatory constraints governing an automated public conveyance

[1] American Association of State Highway and Transportation Officials. The Green Book is the unofficial title for "A Policy on Geometric Design of Highways and Streets."

h. the handling of investment and trade-secret issues for an automated public conveyance

i. the manufacturability of designs and ability to integrate with built environments while simultaneously providing acceptable service; and

j. the current capacity of those in the procurement community, including the City itself, to understand ATNs and thereby effectively plan for any of its potential uses

3. Currently available ATN designs are very rudimentary, suitable for low-speed, low-demand applications. If the City views the Airport application as the cornerstone of eventual expansions, it must be aware that the next steps in ATN evolution will likely call for unprecedented modes of operation having significant regulatory and human factors implications. Fully realized ATN systems will be different not just in scale but also in *kind* from those being made available today.

4. The present uncertainties and unknowns will translate to a high level of performance, cost, schedule, and public acceptance risk should the City choose to immediately move forward with an Airport design/build project modeled along conventional lines.

5. These risks will be multiplied if the City envisions the Airport application as a cornerstone installation that would later be expanded. In order to avoid this risk, the City needs to develop an understanding of both the wider potential and limits of ATNs. This is a broader challenge to the very definition of the ATN concept itself.

6. All of this suggests the unavoidable conclusion that, should the City decide to move forward based on the promise of attractive service noted above, it should first redirect its efforts toward mitigating these risks. It would thereby and unequivocally become involved in a development effort in some way, shape, or form.

7. The City—any city—is not equipped to manage risks of this level and certainly not to underwrite them. Whether the City's goals are limited to the Airport or are more expansive, a considerable multiparty effort will be required to drive risk down to acceptable levels, commensurate with those for conventional civil infrastructure procurement. Although less of an effort would be required in support of the more limited goal, this course of action can only be considered in isolation if the Airport project itself is so considered. Otherwise, it can only be considered the first installment of a much larger effort spanning a much longer time period. And if *this* is to occur, the broader challenge of Item 5 will likely need to be taken up as one of the very first steps.

8. This further suggests that the City envision for itself a role as part of a broader collective effort involving other public-sector agencies, the development and investment communities, regulatory and legal authorities, etc. This effort would itself carry its own set of risks, the principal two being that its extent cannot be predicted with any certainty, and that there can be no *a priori* guarantees of success. This is the definition of development. As such, it would be best planned and accomplished in a phased manner so that *its* risks may be responsibly managed. The framework of one potential approach is discussed in the body of this report.

9. Approaching the issue in this manner would represent an eminently reasonable and responsible course of action by the City, going far beyond the "great idea; needs more study" stopping point at which many proposed innovations arrive. This leads to the final point: The principal ingredient that has been lacking with regard to ATN development has not been lack

of need or technology or desire or money; rather, it has been the absence of a city like the City of San José, a potential customer who has already demonstrated its commitment both to due diligence and the willingness to take reasonable risks on behalf of its constituents. No technology can be developed in a vacuum. Helping to facilitate the development of a mechanism by which risks can be incrementally approached and reduced would be a unique and lasting contribution in the area of civil systems innovation.

2. Introduction

2.1 Purpose

The purpose of this work, as directed by the City of San José Department of Transportation (SJDOT) and its companion stakeholders, was to evaluate the feasibility of utilizing ATN technology to fulfill a range of strategic goals and specific objectives. From a strategic standpoint, the SJDOT articulated a number of principal goals commensurate with the City's Green Vision aspirations and its role as the capital of Silicon Valley. These include:

- Potentially broad application of ATN systems as an element of the Green Vision: a more seamless, less automobile-dependent, and more environmentally sound integration of transportation modes, particularly with respect to implementation of pedestrian and bike-friendly at-grade thoroughfares and the "urban village" concept.

- Pursuit of potential economic opportunities, including those that might be associated with ongoing ATN development, leveraging the considerable technical and financial resources of the area. This also includes the potential of further boosting the attractiveness of the Airport to air travelers and carriers.

As a step toward these goals, the specific objective of the task was to evaluate the performance capabilities and business case of *existing ATN system designs* relative to the requirements associated with the provision of transportation services to/from the Airport and nearby rail transit stations and within the airport proper. This near-term objective was established in response to a line item in the 2000 Santa Clara County Measure A ballot measure that funded the work.

This effort was strictly preparatory. It was intended as a risk identification and mitigation effort in support of City decisionmaking. The principal decision at hand is, of course, whether or not to move forward with consideration of ATNs, principally with a design/build procurement but perhaps in some other fashion. Knowledge gained as a result of the effort would allow the City to interact more effectively with its constituents, companion stakeholders, and the ATN development community for other related purposes. It could position the City to consider other design/build applications and/or to undertake some other type of role with regard to the further development of the technology.

As a preparatory measure and as an effort to fulfill a specific legislative goal, the City specifically prohibited certain lines of inquiry that are more appropriately conducted as part of an actual procurement. Consequently, this work is not a comprehensive analysis of alternatives relative to other potential solutions, it does not compare specific design offerings or make comparisons between the capabilities of suppliers, and it does not inquire into specific cost and contracting arrangements as might be proposed by a supplier. Lastly, it does not analyze the feasibility of ATN technology for any application other than for the City application included in Measure A. However, as we've already discussed, developing a general understanding of the broader issues noted above was unavoidable and, it turns out, essential to the task at hand.

The tasking in support of these goals and constraints was relatively straightforward:

- Understand and delineate the real-world requirements associated with the provision of Measure A.

- Research and characterize the state of the art and the state of the industry relative to these requirements.

- Identify both technical and nontechnical gaps in capabilities, describing areas of uncertainty and risk.

- Identify potential risk mitigation approaches.

- Identify possible roadmaps for defining and continuing to subsequent phases.

The findings here are based on information made available by the ATN development community via a Request for Information (RFI) issued by the City in January 2011, a select review of the substantial body of literature documenting ATN work over the past several decades, and independent research and analyses.

This work was undertaken in collaboration with Arup International, Ltd. (Arup) and managed by SJDOT staff. The rough division of labor was such that The Aerospace Corporation (Aerospace) focused on the evaluation of the systems-level technology and development issues. In response to the information gathered during the effort, Aerospace developed a reference design and estimated its performance in order to highlight the principal issues discovered and serve as a focal point for ongoing dialog. Arup focused on demand and cost estimation, detailed infrastructure layout, business case and financing options development, and public outreach.

2.2 Note to Readers

A number of excellent ATN feasibility studies have been performed in recent years, coming to both favorable and unfavorable conclusions. While some of these conclusions are, at a high level, similar to the findings presented here, the City requested a more comprehensive and detailed investigation than these reports were able to offer.

Therefore, this effort has been directed toward taking a more critical look at ATNs; no presumptions were made about any characteristic of ATNs either conceptually or with regard to any particular performance claims. The intent has been to provide as much additional depth and detail as possible to enable actionable decisions by the City and its companion stakeholders, the development community, and associated third-party organizations such as regulatory authorities.

It is expected that a variety of audiences will take an interest in this report. The reader will appreciate that it is quite difficult for a single style to satisfy everyone. First and foremost, the content and form of this report is intended for convenient use by the leadership of the City of San José and its companion stakeholders in their decisionmaking process and, as importantly, to help the City communicate its efforts to its constituents. Enough technical detail is provided to support findings, but the report is not intended to be a technical treatise of sufficient detail for peer review. And, as mentioned earlier, it was not possible within the bounds of this effort to deliver a definitive assessment of ATNs in the general case. Those in the development community and those who have been following ATNs from a technical perspective will likely find much of the content incomplete, elementary, and perhaps unsatisfactory with regard to the larger issues. It is hoped, however, that it will be found accurate and well-reasoned.

There is a vast repository of technical information available about ATNs specifically and related topics more generally. It seems there is hardly anything that *hasn't* been said on the topic. The focus of this report is on what appeared to be the most significant and fundamental issues at the present time with respect to the Airport project in particular. No claims are made that this work represents a complete review of all the available information, nor of originality. Per the guidance of SJDOT staff, a principal objective was the assessment and integration of various points of view into as comprehensive a perspective as possible within the context of the Airport project. Comments are welcome, especially those that have the potential of altering the findings in any significant way.

The author extends apologies to international readers for this report's exclusive use of foot-pound-second (fps) units.

2.3 ATNs in Brief

For those unfamiliar with the topic, ATNs are, roughly speaking, a cross between taxicabs operating on a grid of one-way streets such as in an urban business district and the familiar Automated People Movers (APMs) commonly found operating at airports. Both ATNs and APMs are variants of the larger category generally known as Automated Guideway Transit (AGT). Other analogies are frequently used to describe ATNs—horizontal elevators and "transit internet," for example. While analogies like these are useful to convey a general feel for how ATNs are constructed and operate, it is important not to let one's experiences of how these other systems work affect *too* much one's expectations regarding ATNs. There are profound differences that have equally profound practical consequences. For now, the basics:

The ATN concept dates back almost a half century, then referred to as Personal Rapid Transit or PRT. Proponents of ATNs promise an unprecedented type of service for a public transit system. Imagine, as many have suggested, a dispersion of taxicab stops throughout a service area, all within convenient walking distance of any particular venue. In the case of the Airport, the airport operator sets this distance at 500 feet or less. Imagine further that the taxicab analogy continues in that the vehicles are small and passengers are able to choose whether or not to travel alone or in small, self-selected parties at a time close to their arrival at a station.

Under these conditions, the time passengers spend waiting to board depends on the availability of empty vehicles, station layout and operations, and the number of other parties also waiting. Parties instruct a coordinator, in this case a computerized system via an interactive device of some type, as to their destination and number in their party. Once the party is directed to an assigned vehicle and confirmed as being aboard, a robotic driver (in the sense that the entire system is robotic—there is no identifiable R2D2) navigates to the destination, choosing from among a number of non-unique routes within a *network* of roadways. In most articulations of the concept, these roadways are segregated from conventional traffic, achieved by elevating the entire system.

The choice of route depends on real-time demand. The system may specify that the robot driver take a slightly longer route or "go around the block" to avoid congestion and coordinate arrivals and departures. This is similar in function to the familiar freeway signs that may suggest alternate routes in the event of some sort of blockage ahead, or an airport traffic officer waving you around for another lap at the Airport because there's no room at the drop-off curb. There are no intersections or stoplights on the network, only merges and splits. The robot drivers all cooperate with each other to execute merging maneuvers and to minimize trip times and avoid congestion en route. In addition to waiting in line for a vehicle to board, passengers may also experience waiting in their vehicle in input and output queues at the stations as arriving vehicles wait for an open berth and departing vehicles wait for an open space on the network. They may also experience waiting while aboard their vehicle before it departs from its berth.

The hoped-for overall goals for ATNs are cost effectiveness, efficient and clean resource utilization, and improved mobility. In other words, ATN designers seek to transport a given number of people using the least amount of materials, energy, real estate—and time. The ATN concept also involves going where no transit system has gone before—a sort of automated paratransit that gets service closer to the sources of demand. A frequent and logical claim is that ATNs arranged in a network dense enough would provide a convenient and personal service model similar to that of an automobile.

With these preliminaries out of the way, the technical heart of the evaluation is next, followed by a concluding section on the options the City faces moving forward and some possible steps that might be taken.

3. Technical Discussion

Assessing the feasibility of a new technology is challenging. All feasibility studies, even those for applications of conventional technologies, involve striking a satisfactory balance between requirements on the one hand and the capabilities of the system being assessed on the other, according to some set of criteria against which multiple options can be measured and compared. The three factors—requirements, capabilities, and criteria—have mutual effects on each other.

For example, a cost criterion can result in a limited service-area requirement; a performance criterion can result in a demand for industry to increase system capabilities; and so on. Physical limits of capabilities can have similar effects; e.g., perhaps also limiting the service area that can be established as a requirement or the wait times that can be specified.

For ATNs, this balancing act is especially interesting. How can one establish requirements *a priori* for a system concept that is not yet fully understood? How can a system even be *developed* without fully understanding requirements? For emerging systems such as ATNs, this trio of feasibility factors is thus more of a moving target than usual. If an assessment is undertaken with the same expectations and approach as for conventional systems, the City runs the additional risk of either dismissing a promising new technology or entering a technological cul-de-sac.

From the beginning of this project, therefore, Aerospace has advised that an inquiry into the requirements, capabilities, and criteria by which the City would judge success be seen more as discovery than as specification, a principal goal being to shed light on and perhaps reduce the number of unknowns with which the City must contend. The overall objective is to begin a dialog between the City, the development community, and third-party stakeholders for the purpose, eventually and if possible, of finding a satisfactory balance of requirements, capabilities, and criteria.

A feasibility assessment can only be made having these three items. Therefore, the first steps in the evaluation were efforts to define requirements and criteria from the point of view of the City and its companion stakeholders and then to acquire information from the development community as to the capabilities of currently offered ATN designs.

This section begins with a discussion of these two topics. The first was accomplished via a set of stakeholder interactions and independent investigation into potentially useful requirements derived from analogous conventional systems. The second was carried out by writing for the City a second RFI, much more detailed than an earlier RFI issued by the City in October 2009. The technical assessment—the initial attempt to understand and balance the three factors—follows in Section 3.4.

3.1 Requirements and Criteria Development: Their Triple Purpose for the Airport Project

A requirements and criteria development effort was conducted simultaneously with RFI preparatory work in order to establish on a preliminary basis these two components of the feasibility evaluation.

A technology cannot be judged feasible or “ready” outside of the context of requirements. It is feasible to take a Cessna 172 on a flight from San José to St. Louis, but not if you’re required to arrive for a business meeting in four hours. Feasibility can only be claimed if requirements and capabilities match up. If they don’t, one or the other must change.

There are all sorts of requirements, of course. The one illustrated here is a very high-level performance requirement, similar to the superior passenger experience requirement demanded by City of San José and Santa Clara County authorities. These, in turn, relate to other *still* higher-level requirements that can be classified as goals and objectives, as were listed earlier. Going in the opposite direction, requirements can be very specific—"ATN vehicles shall have cup holders located within reach of a seated passenger based on the 85th percentile anthropomorphic standard person."

Requirements are a standard component of all civil infrastructure contracts, of course, and all readers likely have an intuitive sense of their importance. We know that requirements are the legal expression of the desires and expectations of a customer and that every requirement carries with it a cost. They are principally a tool for effective communication; conflicting or otherwise improperly articulated requirements can lead to project delays, cost overruns, and even project failures and lawsuits. With respect to the development of systems as complex as ATNs, their importance is greater still. One need not look very far to find press accounts in which multibillion-dollar new-technology systems fail and are scrapped because of poorly stated and managed requirements. (An Aerospace colleague in his doctoral dissertation found a strong statistical inverse correlation between on-orbit satellite failures and the number of "shall" statements in underlying contract requirements!)

Requirements are important. However, they are expensive to develop and use properly. Taken to an extreme level of detail, they can impose unnecessary costs and become a burden inhibiting free-spirited innovation. Appropriately defined, however, requirements become a powerful tool for reducing risk and helping ensure success, representing the initial step along the shortest and ultimately the least expensive path from the definition of needs to the satisfaction of needs.

Requirements must be developed and used properly so as to not stifle innovation. Innovation is by definition an exploration of the unknown. Requirements become in this context more a part of a creative process than of a strict specification process.

Requirements in this sense are thus a bit of an art form, almost the inverse of those for conventional systems, which rely in greater proportion on set regulations and standards representing the codification of vast amounts of experience. For systems in development, the proper selection of requirements relies to a large extent on judgment and intuition backed by large concurrent research and analytical effort on the part of customers, developers, and third parties such as regulatory bodies, academia, and professional standards organizations.

As mentioned above, a wide range of requirements is necessary in order to fully define a system. Individual distinctions as to whether a requirement is classified as a goal or objective, or as a functional, performance, or other requirement is only important to the people whose job it is to deal with them. The important point for present purposes is that, collectively and with respect to the consideration of new systems technology, requirements have several important functions and characteristics fairly distinct from those associated with the acquisition of systems based on mature technologies:

1. In a systems development environment, requirements serve a greater role as a *starting point* for "negotiating" what the design will be. The third component of feasibility mentioned above—the *capabilities* of a device or system—are not fully known by definition. Requirements help frame or stake out the *range* of innovative possibilities that may be brought to bear in an attempt to satisfy underlying needs, goals, and objectives. Requirements that are too restrictive or too focused on a particular technology can eliminate unknown, potentially more desirable solutions, from consideration. In fact, the City is cautioned that this project itself, being focused exclusively on ATN-based solutions, represents just this sort of restriction.

2. To a greater degree than for conventional system procurements, requirements are a means for disseminating the understanding of an initially unknown capability and force the identification of conflicting desires that may be introduced by different stakeholders or even by a single stakeholder, providing opportunities for hashing out such conflicts sooner rather than later. They provide an opportunity to assign weights to previously unavailable features and benefits, articulating their relative importance. (In this case of the Airport project, this was informally but definitively established—passenger experience, passenger experience, and passenger experience, followed closely by cost.)

3. They allow a large problem to be broken up, the pieces assigned to engineers and designers who may never meet and yet have a reasonable chance of their design solutions working properly together when assembled, bit by bit.

4. They are the checklist to compare against in a process known as *verification and validation.* (Yes, the ATN vehicle can accelerate at 0.25g, and yes, passengers perceive the use of the system as a positive experience, respectively).

The value of these last two items cannot be overstated. Together, they represent the principal risk mitigation value associated with the application of proper systems engineering practices. (The City should be pleased to note that a good number of those in the development community are well-versed in these methods. See Section 3.4.1.)

Requirements therefore serve three overall purposes with respect to the City's consideration of ATN technology:

1. For the present effort, the requirements that were established formed the basis for evaluating the feasibility of currently available ATN designs, and the extent to which they do or do not satisfy the City's present and future needs.

2. For subsequent efforts, the requirements will facilitate the City's continuing interaction with its companion stakeholders, the ATN development community, and third-party organizations to communicate its vision and objectives.

3. Finally, in the event that the City elects to pursue the procurement of a transit system based on the ATN concept, the requirements will provide a starting point for generation of detailed procurement specifications.

Emphasizing this last point, it is important for the City to note that, given the level of ATN conceptual and design maturity and the state of knowledge of their characteristics in general by all affected parties, the requirements developed here should not by any means be considered procurement-specification-ready. On the other hand, this portion of the effort was not insubstantial, and the requirements developed here can serve as the basis for the set of requirements that would be necessary for an eventual acquisition.

3.1.1 Requirements vs. Standards

Standards are frequently mentioned in conjunction with requirements and in this respect are, in a sense, requirements shorthand. In nearly all fields that involve any degree of design, engineering, development, manufacturing, or construction, valuable lessons learned from long histories of success (and failure) have been captured by independent and representative organizations of many types.

While not directly carrying the force of law, standards can provide a basis for assuring the quality, safety, and usability of all manner of devices, structures, and systems.

More broadly speaking, standards represent the distillation of past experience. Specifying the use of a standard gives a buyer who understands the applicability and limitations of the standard relative to the issue at hand a degree of confidence in a positive outcome without having to bear the expense of "reinventing the wheel." Greater assurance of product and system quality is therefore one benefit of specifying standards.

Referencing standards also increases opportunities for commonality and interoperability between systems and subsystems. This in turn provides numerous derivative advantages: economies of scale, the development of specialty providers, reduced complexity of maintenance and operations, the formation of a common knowledge base, and pool of trained designers and technicians, etc. All of these lead generally to increased value for the customer.

Abandoning proprietary solutions in favor of wider industry standards also enhances the potential of providers to succeed in the marketplace; it can, in fact, create a market. The "larger pie" and market creation effects have been proven time and time again across a wide range of technologies.

These general benefits are only being mentioned because of the newness of ATNs and to alert the City to issues related to their use in any set of requirements it might specify for the ATN application. It is important for the City to note that there is an extensive body of applicable standards, practices, and guidelines from which the City can derive a certain measure of confidence. Certain of these specific standards have been incorporated into the preliminary project requirements developed here, and several are discussed in more detail throughout the body of this report.

The ATN development community is keenly aware of the benefits of adhering to standards. Most notably, the ANSI/ASCE/T&DI Automated People Mover Standards [8] provide a solid basis from which to develop ATN-specific standards. Members of the ATN development and consultant community actively participate in ASCE working group activities for this purpose. Numerous other standards established in the automotive, electrical power, civil structures, and computing/data communications fields are being leveraged in ATN designs. Through selective application of evolving standards from this point onward, a strong potential exists to further the net positive effects of standardization on ATN technologies and the industry as a whole.

3.1.1.1 The Application and Misapplication of Standards

There are important nuances relative to the issue of standards that the City must be aware of. The question immediately comes to mind of how an existing "standard" can be applied to something that does not yet exist. In fact, standards can and have been established in this very manner; they can be established either after or *before* the fact of a new development. As an example of the former, the ASCE APM Standards themselves were issued many years after the first operational system, facilitating the expansion of the industry. For the latter, Ethernet is a good example of a "standard" established *a priori* and which enabled the *creation* of an industry. The revised portion of an existing standard can also be viewed as *a priori* resident in an existing framework. Ultimately, no matter how they are packaged or where in the development lifecycle they are introduced, standards still represent the distillation of vast amounts of prior experience.

The existence of standards is not an absolute prerequisite for moving forward from a technical standpoint. From a regulatory standpoint, however, the opposite may be true depending on the degree with which regulators will rely on standards as a measure of maturity. In any event, however, should the City consider standards with regard to its ATN decisionmaking, it must do so with great caution, as there are a number of potential traps. The existence of standards, perhaps especially those based on existing systems, can provide a false sense of confidence with respect to a new system concept and *simultaneously* impose on it unwarranted limitations:

1. As mentioned, standards are not law. Standards are trumped by regulations, which carry the force of law, and so the use of standards is largely[2] at the discretion of regulatory authorities. For the ATN concept, the extent of this discretion has not yet been determined, nor would one expect it to be. As an example relative to existing APMs, however, Cal-OSHA[3] expressly refers to an older version of the APM standards with respect to its area of regulatory purview. The California Public Utilities Commission (CPUC) does not refer to the APM standards at all.

2. Certain standards are applicable across a broad range of applications and are very useful for accelerating the development of new systems. For example, a specification for the use of fire retardant materials in the construction of ATNs would almost certainly be usable as is. However, safety standards that relate more directly to the performance and/or operations (and consequent passenger experience) of an ATN system must be more carefully evaluated. Existing standards were, after all, developed for *different* systems with different characteristics. ATNs are *intended* to perform and be operated differently from existing systems.

   For example, the AASHTO standards [1] associated with the design of transitions (the beginning of off-ramps and turns) have their basis in research initially conducted in 1938 [18]. This particular standard (a recommendation, actually) is being interpreted for ATNs in terms of passenger comfort. A close inspection of the original documentation reveals, however, that the actual reference is to the level of comfort a driver has relative to *maintaining control* of a 1937 vintage automobile, not to some intrinsic discomfort associated with centrifugal force. Although supported by subsequent work and probably prudent to maintain, studies also exist that make reasonable arguments supporting its revision, based chiefly on the fact that drivers of modern automobiles feel much more comfortable and in control of their better-handling vehicles and rarely adhere to the posted recommended speeds. One would think that this will be even less of an issue for ATNs.

   Conversely, the emergency deceleration rate specified in the APM standards appears to be unsafe in the context of an ATN operating environment given current designs.

3. *A priori* standards used to *establish* a market, whether newly constructed or as part of an existing framework, can have the unwelcome effect of actually inhibiting innovation. As witnessed by a number of "standards wars" in the consumer electronics field, standards can be used as a tool to protect the R&D investment of a single manufacturer or consortium of manufacturers. For a public-use system concept as complex as ATNs, however, it would be presumptuous of *anyone* to determine at this point what an appropriate "standard" design might be. Presuming a positive outcome relative to the broader issues regarding ATNs mentioned at the outset, a principal challenge associated with a continuing investigation will be precisely how to handle this particular topic.

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[2] What is meant by the use of the word "largely" is that no prohibitions have been found in this effort (not excluding the possibility of their existence, of course) against the City writing standards into its requirements at its own discretion as long as they exceed regulatory minimums. This would obviously have to be done with great care, however, in a regulatory environment which is guaranteed to be dynamic (see Section 4).

[3] Nickname for California Division of Occupational Safety and Health (Administration).

Several of these items will be discussed in more detail throughout the remainder of this report. The important point here is that standards are shorthand requirements and can be of enormous benefit. Certain standards that would not overly specify designs and thereby dampen innovation should be striven for by standards organizations and government as early as possible with as wide a range of input as possible. The limitations and/or applicability of existing standards with respect to a new system which does not yet exist—and how regulatory authorities will view the issue—must be fully understood by the City.

The issue of standards will not be an easy task for any stakeholder if or when considering ATNs, particularly for the City. If ATNs are, in fact, found to be viable, the topic could be of national importance. The decisions made by the City, if it chooses to remain involved, would have considerable influence over the nature of further ATN development and would therefore be of matching importance.

3.1.2 Airport ATN Requirements

The requirements presented in this document represent a comprehensive, albeit preliminary, expression of the City's needs and desires for a system. This document is designed to be an integrated capture of the full range of the stakeholder objectives, desired service features, system functions and performance levels, design constraints, regulatory compliance requirements, economic factors, and environmental objectives for the Airport application, under the explicit presumption of using ATN technology.

3.1.2.1 Organization

The requirements for the Airport project have been developed using common practices used in the automotive, software, aerospace, and other industries. Consistent with these practices, the project requirements have been organized into a multilevel hierarchy representing various degrees of detail and specificity. This hierarchy for the Airport project was constructed with four levels or "tiers," as illustrated in Figure 3.1-1, the lower-level (higher-numbered) tiers addressing the more detailed requirements. Additional tiers may be included in the future as more detailed specifications are generated.

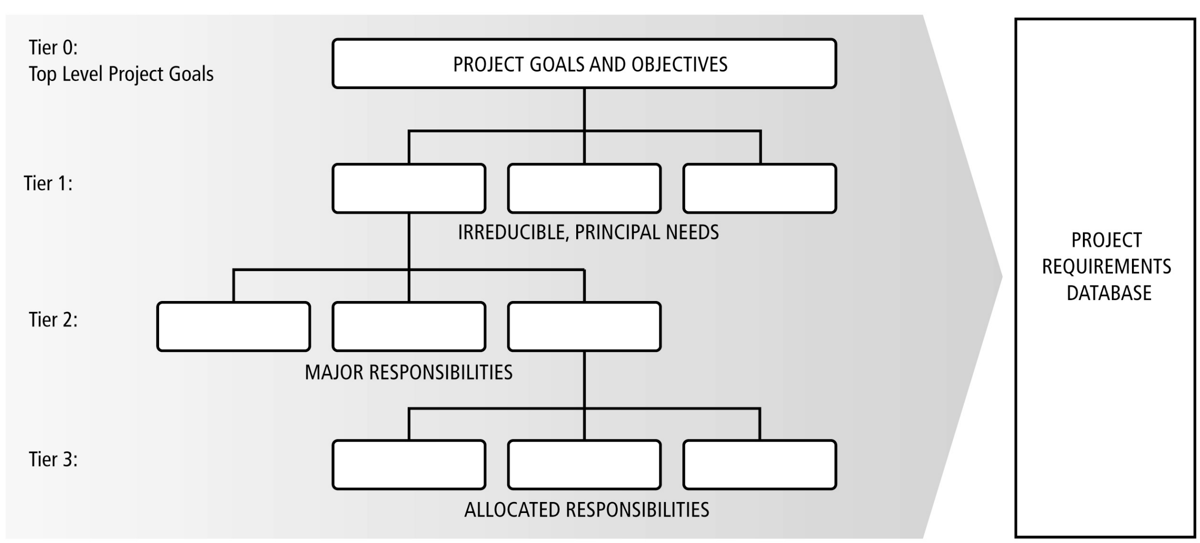


Figure 3.1-1. Requirements level of detail hierarchy.

Requirements are also commonly arranged by appropriate categories for ease of reference. For this project, they have been organized into nine such categories, derived from the top-level, Tier 0, set of requirements: Project Goals and Objectives. The selected categories are illustrated in Figure 3.1-2 and described in the following paragraphs.

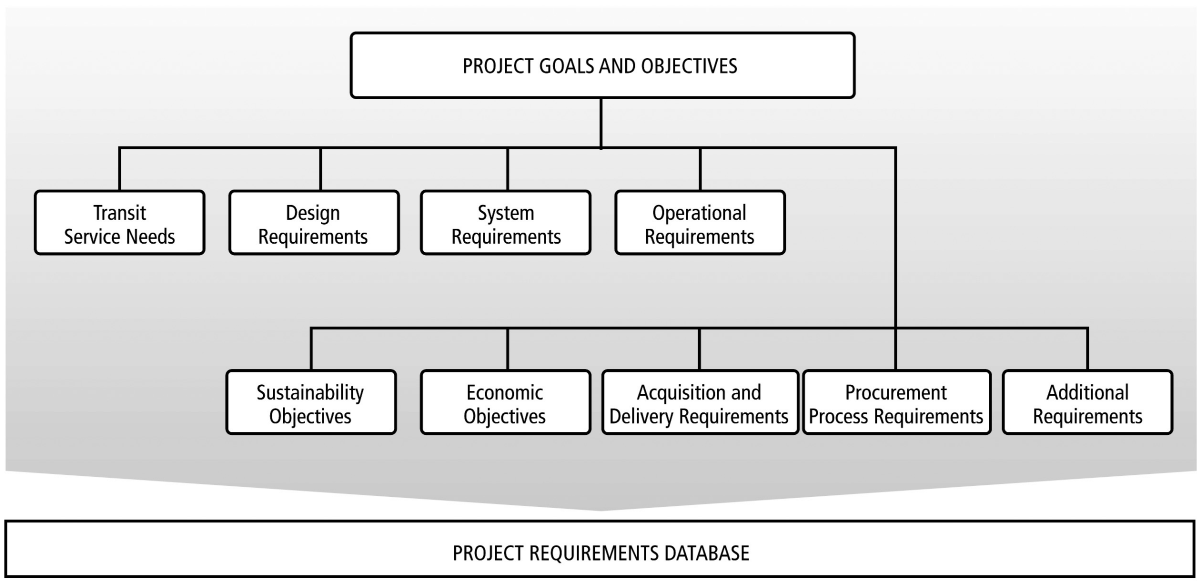


Figure 3.1-2. Requirements categories.

Category 1: Transit Service Needs

The transportation needs to be met by the system, including points to be connected, transit time objectives, the system capacity needed to satisfy projected steady-state and peak demand levels, and the basic service features as experienced by passengers.

Category 2: Design Constraints

The factors that influence or constrain the overall concept and high-level design of the system, such as existing physical conditions, technical limitations, and key stakeholder objectives/concerns.

Category 3: System Requirements

The required functionality and performance of the system, specifying "what" it should do and "how well" it needs to do it. These requirements represent the capabilities that would need to be provided by the system, where "system" is intended to mean the complete set of contributing infrastructure, hardware, software, communications, and human elements.

Category 4: Operational Requirements

Facilities, procedures, and functions required to safely and efficiently manage and conduct continuing operation of the system.

Category 5: Sustainability Objectives

The environmental and energy-efficiency goals of the system and the influences these goals impose on its design.

Category 6: Economic Objectives

The relationships between the nonrecurring implementation cost, recurring operations and maintenance costs, potential revenue or savings, and desired nonmonetary benefits of the system.

Category 7: Acquisition and Delivery Requirements

Requirements related to the organizational structures, value analysis, funding approaches, and risk sharing/risk management objectives for the project as a whole.

Category 8: Procurement Process Requirements

Key processes related to system procurement and operational management. This category of requirements covers the structures, responsibilities, and procedures involved in sponsoring a competitive award; managing the development, engineering, implementation, and verification of the ATN system; managing system operations and maintenance; and fulfilling related roles and responsibilities.

Category 9: Miscellaneous Requirements

Any miscellaneous goals, objectives, and constraints that will guide or influence the design, procurement, and/or continuing operation of the system.

3.1.2.2 Capture and Management

The Airport project requirements in each of these categories were captured and/or derived by several means:

- Interaction with key stakeholders, including the City, the Santa Clara Valley Transportation Authority (VTA), and San José International Airport (a City department)
- Analysis of San José's specific transit demand projections for the Airport and the immediate surrounding area
- Review of key design criteria, operational rules, and regulatory codes and standards for fixed-guideway public transit systems
- Review of general technical specifications and performance analyses for ATN technology
- Analysis of key economic factors and general organizational/risk-sharing approaches for capital-intensive public transit systems
- Industry experience in the processes of system engineering, design analysis, subsystem development, system integration, verification, validation, and operation of software-intensive automated systems

The resulting requirements were entered into a common database to ensure that a complete listing is maintained in a centralized location. For the purposes of this project, this was done utilizing a common flat-file spreadsheet. If the City chooses to continue its investigation of ATNs, this data can be transferred to a number of special-purpose database tools that facilitate robust enterprise-wide requirements information capture, "tagging" of requirements with additional metadata fields, flexible data views, orderly change management, and version control.

The resulting preliminary Integrated Project Requirements Document (IPRD) as defined through completion of this evaluation is listed in Appendix A. Note again, as mentioned earlier, that given the maturity of the ATN concept and current designs, these requirements are perhaps best characterized as being a bit better than notional and a bit less than preliminary. While they represent the current view of project requirements as articulated by the SJDOT and its companion stakeholders, they are intended to evolve along with the project. In particular, baseline project requirements can only be established as part of a Request for Proposal (RFP) engagement with the development community.

3.1.3 Criteria

A second component of a feasibility evaluation is the set of criteria against which various options may be judged. Criteria can be thought of as super-requirements: key features, benefits, or characteristics that are of particular importance to a customer.

The SJDOT, recognizing early that a considerable degree of uncertainty is currently associated with ATNs, elected to forgo a formal ranking process in exchange for a more detailed independent technical investigation. Nevertheless, the SJDOT and its companion stakeholders were very clear in articulating several items of particular importance that might in the future be used in a formal ranking:

- Passenger convenience, passenger convenience, and passenger convenience, specifically relative to walking distance between stations and demand locations (e.g., terminal entryways, light rail platform, Airport parking, etc.)

- Performance levels in terms of trip and wait times superior to existing service

- Operating and maintenance costs comparable to existing systems

- Realistic ability to pass safety certification and garner public acceptance; be reliable and manufactureable; possess adequate supply chain, etc.

3.1.4 Requirements and Criteria Summary

Requirements and criteria are two of the three essential components of a feasibility evaluation and take on additional importance when the issue is one of systems development. Each is changeable to a greater or lesser extent and is, in fact, used in tradeoffs as part of the technical negotiations that take place as part of the process leading to a satisfactory definition of a system.

Attention is now turned to the remaining component necessary for a feasibility evaluation: knowledge of the capabilities and costs associated with the system of interest.

3.2 The Request for Information

Turning now to the capabilities ingredient necessary for a feasibility evaluation, an interested transit system customer must have a sufficient amount of information on this topic prior to the issuance of a formal RFP in order to justify the significant effort that goes into myriad tasks such as preliminary planning, coordination with funding agencies, and even the RFP process itself. Given the uncertainties and unknowns associated with any emerging technology, the need for this information is even more critical. An interested customer must have enough information to *understand* the technology in order to envision its use, and a sense of the technology's *verification level*; that is, whether or not the technology in whole or in part has been subject to testing rigorous enough to support basic theoretical claims over a wide range of operating conditions and applications.

In order to satisfy this need, Aerospace authored the guidance and requested-items section of the RFI appearing in Appendix A, which addresses both technical and programmatic topics. The RFI was intentionally very detailed. Its goal was to separate conceptual claims from near- and long-term reality. It emphasized the guidance:

> "*Of particular importance is a discussion of the level of design maturity and verification.*"

Although it is evident from the existence of operational and research systems and discussions of the engineering methods used to design and build them that a certain level of maturity exists, limitations in the RFI process prevented definitive assessment of this extremely important issue. Moreover, future ATN systems will be so unlike current systems that this will remain an issue for some time to come. A discussion of the response to the RFI and the conclusions that were drawn from it are discussed in Section 3.4.

3.3 Early Configuration Studies

Taking a look at some of the early analyses of potential Airport ATN configurations is useful for the purpose of illustrating the development of the rationale behind the final results and provides an opportunity to introduce terminology and explain some underlying concepts in a simplified setting. It also allows one to begin observing, issue by issue, the pros, cons, and interrelatedness of various aspects of ATN design.

While the project team awaited the RFI responses, it began using the results of existing conditions surveys it had previously generated: baseline definitions of the physical surroundings at the Airport performed by the Arup team and the equivalent definition of existing ATN designs performed by Aerospace. The latter were derived primarily from responses to the more general October 2009 RFI. This collection of information, along with the results of interactions with SJDOT, VTA, and Airport officials, was used to inform these early studies.

3.3.1 Initial Notional Configurations

From the existing physical and demographic conditions, Arup developed and provided the basic notional routing shown in Figure 3.3-1 along with preliminary ridership estimates for both 2010 and 2030 in the form of the origin-destination (O/D) matrix shown in Table 3.3-1 on page 24. These inputs were used by Aerospace to develop two notional[4] system configurations and perform a subsequent traffic split analysis, described collectively on pages 25 through 35.

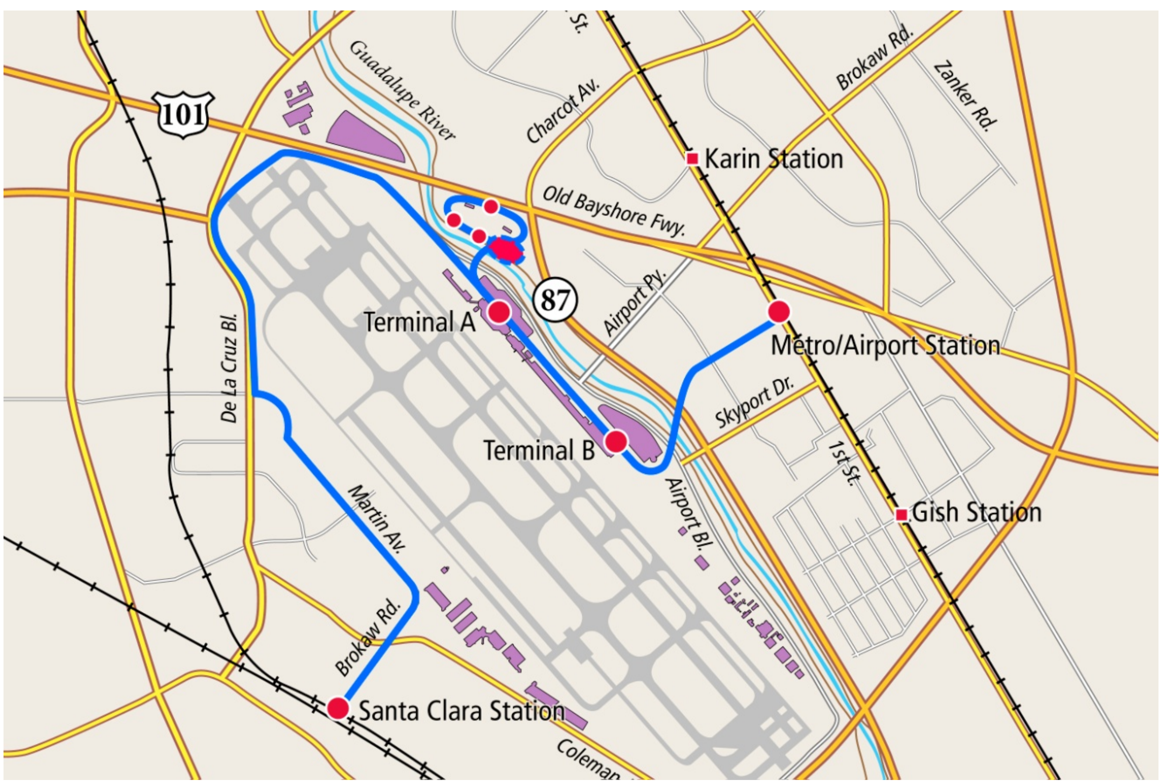


Figure 3.3-1. Initial notional routing (Arup).

[4] That is, not related to a detailed, physical routing.

Table 3.3-1. Preliminary Daily Passenger Demand Estimate (Arup)

From/To	Terminal A	Terminal B	ConRAC[5]	Terminal A LTP[6]	Terminal B LTP[7]	Metro/Airport Station	Santa Clara Station
Terminal A		400* 850*	1350 2950	250 550	N/A	85 185	85 185
Terminal B	400* 850*		N/A	N/A	375 800	125 280	125 280
ConRAC	1350 2950	N/A		N/A	N/A	N/A	N/A
Terminal A LTP	250 550	N/A	N/A		N/A	N/A	N/A
Terminal B LTP	N/A	375 800	N/A	N/A		N/A	N/A
Metro/Airport Station	85 185	125 280	N/A	N/A	N/A		N/A
Santa Clara Station	85 185	125 280	N/A	N/A	N/A	150 325	

2010 demand (total: 5890 passengers/day)
2030 demand (total: 12810 passengers/day)

*Aerospace estimate

Note: assumed symmetric

Demand Matrix Features: Note that the matrix in Table 3.3-1 is *symmetric* about the gray-shaded diagonal—that is, the same numbers of passengers are assumed to be traveling in each direction between any two O/D pairs. This is done strictly for presentation purposes as a means to introduce both the total demand between O/D pairs (easily obtained by summing corresponding values on each side of the diagonal) and the matrix form commonly used in transportation planning. It would be highly unusual for this symmetry to occur for even one O/D pair, let alone systemwide. However, for instructional purposes it is useful to keep this notion of demand symmetry in mind for the moment. It will be a topic in the following discussion and will shed a bit of light on one of the many unique characteristics and challenges of ATNs.

The following two tables, Table 3.3-2 and Table 3.3-3, which segregate 2010 and projected 2030 daily demand, respectively, and convert daily demand to peak hourly demand, retain a set of symmetric demand values. A set of nonsymmetric values has, in addition, been introduced to include a bit more realism in the form of a notional asymmetric "morning rush hour." The conversion to peak hour demand was done using a transportation planning rule of thumb by assuming it to be 15 percent of daily demand. Notional rush hour asymmetry was based on the pure assumption of an 80/20 split of total demand and a reasonably assumed dominant flow of traffic from the rail stations and parking area to the terminals.

[5] ConRAC: Consolidated Rental Car Garage.
[6] LTP: Long Term Parking.
[7] Terminal B LTP not shown in Figure 3.3-1; located south-southeast of ConRAC.

Table 3.3-2. Preliminary 2010 Peak Hourly Passenger Demand Estimate

From/To	Terminal A	Terminal B	ConRAC	Terminal A LTP	Terminal B LTP	Metro/Airport Station	Santa Clara Station
Terminal A		60* 60*	203 81	38 15	N/A	13 5	13 5
Terminal B	60* 60*		N/A	N/A	56 22	19 8	19 8
ConRAC	203 325	N/A		N/A	N/A	N/A	N/A
Terminal A LTP	38 61	N/A	N/A		N/A	N/A	N/A
Terminal B LTP	N/A	56 90	N/A	N/A		N/A	N/A
Metro/Airport Station	13 21	19 30	N/A	N/A	N/A		23 23
Santa Clara Station	13 21	19 30	N/A	N/A	N/A	23 23	

Symmetric
Asymmetric "Morning Rush"
Total = 888 passengers per hour

*Aerospace estimate

Table 3.3-3. Preliminary 2030 Peak Hourly Passenger Demand Estimate

From/To	Terminal A	Terminal B	ConRAC	Terminal A LTP	Terminal B LTP	Metro/Airport Station	Santa Clara Station
Terminal A		128* 128*	443 177	38 33	N/A	28 11	28 11
Terminal B	128* 128*		N/A	N/A	120 48	42 17	42 17
ConRAC	443 709	N/A		N/A	N/A	N/A	N/A
Terminal A LTP	83 133	N/A	N/A		N/A	N/A	N/A
Terminal B LTP	N/A	120 192	N/A	N/A		N/A	N/A
Metro/Airport Station	28 45	42 67	N/A	N/A	N/A		49 49
Santa Clara Station	28 45	42 67	N/A	N/A	N/A	49 49	

Symmetric
Asymmetric "Morning Rush"
Total = 1836 passengers per hour

*Aerospace estimate

Notional System Configurations: Multiple ways of servicing the same demand and following the same general alignment are possible. Mathematical models of a notional system configuration and an alternate notional configuration were constructed. These are depicted in stylized form in Figure 3.3-2 and Figure 3.3-3, each showing the distances in feet between key points of the network—stations and guideway merges/splits—and total guideway length. The alternate notional configuration was constructed to introduce the idea of network redundancy—alternate routes between stations necessary in the event of a failure or blockage and to balance load—thereby beginning to illustrate some fundamental aspects of network design and behavior. No consideration was given at this point to the details of an actual physical layout.

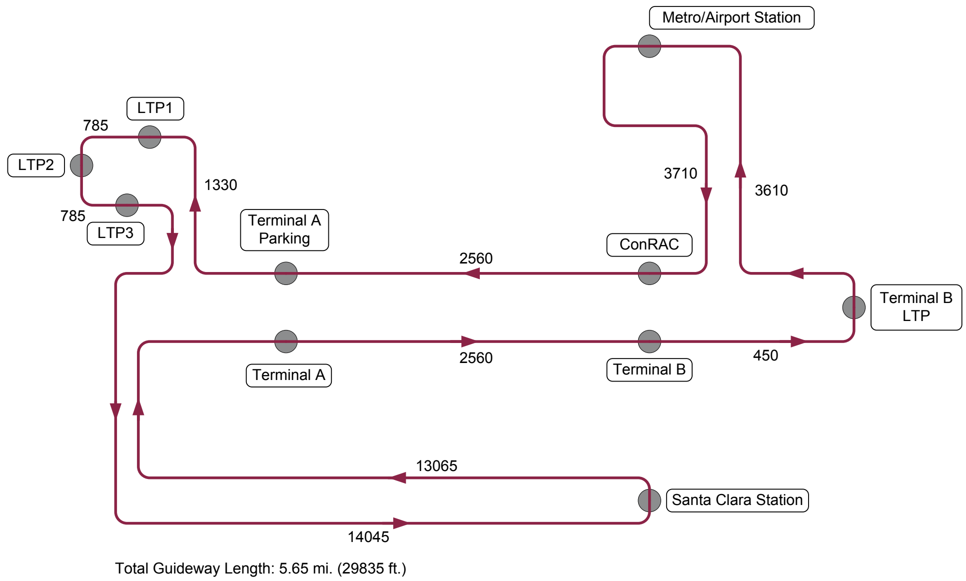


Figure 3.3-2. Notional configuration.

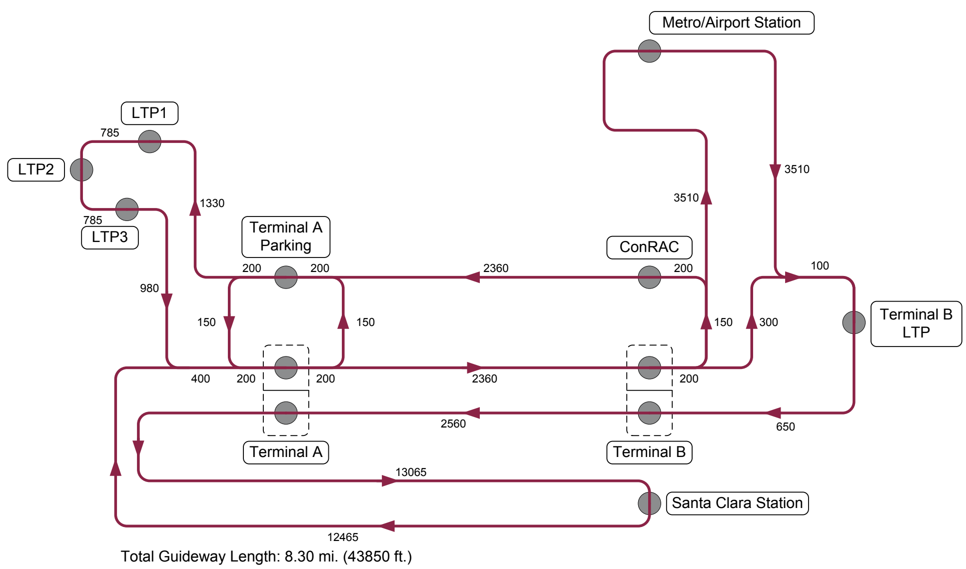


Figure 3.3-3. Alternate notional configuration.

Description of Analytical Method: The type of analysis conducted is known as a multicommodity, minimum-cost network flow model. It minimizes travel time and is *independent of control methodology*. It returns link utilizations—i.e., the number of vehicles carried by each link as a percentage of a specified maximum capacity—on a time-averaged basis, in this case over the assumed period of one hour. Thus, this method does not take into account what are known as stochastic processes: those that exhibit randomness.

The model is based on an idealized notion of station operations. It assumes a full queue of passengers at the ready; it does not account for passenger interarrival time profiles, peak-within-peak demand, or any other passenger-related activities. It therefore provides no indication of passenger in-station wait times or delays in vehicle arrivals or departures caused by variations in passenger behavior. It in fact assumes that stations have unlimited capacity to introduce and extract vehicles from the network and to do so instantaneously. The model's purpose, therefore, is as a first-order (i.e., ballpark) method of evaluating a network, providing a quick way to visualize how a system might distribute vehicles throughout a busy network on average.

The model does account for empty vehicle traffic assuming, however, that empty vehicles in unlimited supply are introduced at stations as required. The number of empty vehicles required depends on the surpluses or deficits each station experiences relative to demand and to the number of vehicles destined to a station that, once unloaded, become available to passengers waiting to depart. The amount of empty vehicle traffic can therefore be underrepresented depending on the level of demand asymmetry, meaning that the estimates of occupied traffic are to be taken as upper bounds.

Passenger demand is converted to vehicle demand through the use of a *load factor*, in this case defined as the average number of persons each vehicle is carrying and taken as 1.5 based on reported experience.

The inputs to the model include the topology of the network—the number and type of the key points mentioned earlier and which will hereafter be collectively categorized and discussed as *nodes*, portions of guideway between the nodes, hereafter referred to as *links*, and the lengths of the links. Also included as inputs are the *line speed* and *headway,* the latter defined as the minimum allowable time interval between arrivals of successive vehicles at any given point of reference. Both of these values are assumed to be constant. In these early analyses, the line speed was assumed to be 24 miles per hour and the headway to be 6 seconds.

The Utilization Rate and Utilization Allowables: An extremely important input to the model is a parameter called the *utilization* rate. The utilization rate represents how much of a network's theoretical capacity is actually used under a particular set of circumstances. In general, as the utilization rate of a network increases beyond a *design nominal*[8] *utilization allowable*, performance suffers. Beyond a *design maximum utilization allowable*, performance suffers dramatically and unpredictably.

The design nominal utilization allowable can be thought of as a kind of throttle or conservative limit placed on nominal traffic levels to provide margin so that surges can be handled without serious performance degradations. The use of a nominal utilization allowable in effect reduces the average throughput allowed on the links of a network in nonsurge conditions to some fraction of what would be calculated via a formula commonly used in transportation planning and in ATN design:

$$\text{Maximum Link Capacity} = 3600 \div \text{Headway}$$

In this case, 3600 seconds per hour divided by 6 seconds per vehicle equals 600 vehicles per hour. Six seconds is the reported operational headway (not necessarily maximum technical capability) of current ATN installations.

These parameters account for an obvious fact: that a network in which each and every link is *fully utilized* couldn't operate (except in certain very unrealistic situations). Streams of vehicles couldn't merge and passengers couldn't get on or off the network unless vehicle arrivals and departures were perfectly coordinated in time. This doesn't mean that any *particular* link couldn't *temporarily* operate

[8] Nominal: normal or usual.

at full utilization. This could, in fact, be part of a designer's intent. It just means that when a link becomes fully utilized, that link temporarily cannot participate in servicing other network traffic. Overall, however, a network must be designed having capacities beyond what might be suggested by a simple consideration of the capacities of isolated network elements in order to perform acceptably.

Determining the values at which to set the nominal and maximum utilization allowables during the design process is a nontrivial matter and depends on detailed knowledge of the numerous factors governing the performance characteristics of a particular system and the demand levels and patterns associated with a particular application. These governing factors, in turn, depend on the particular type of network (data/comm vs. air traffic, for example). No two independent networks are completely alike, not even those of the same type. The performance/utilization relationship of any new network can therefore not be completely determined in advance. Its determination is largely a matter of judgment requiring the use of sophisticated analytical techniques.

Nevertheless, patterns of performance/utilization relationships become noticeable as experience is gained with particular types of networks and the same general behavior is exhibited across network types. The behavior of existing networks can therefore be used, with well-reasoned adjustments, as guidance in *anticipation* of the real-world performance/utilization relationship that will occur in the actual operation of new types of networks.

Utilization rates relative to ATNs are discussed in considerable detail in Section 3.5. For present purposes, the utilization allowable was set here provisionally at 50 percent. What this means is that during calculations, if a particular link in the "cheapest" (shortest) route between any two O/D pairs "fills up" (is fully utilized) to a value equal to half of the maximum link capacity, the next "cheapest" (longer) route will begin to fill, thereby balancing demand across the network. If *all* possible routes between any two O/D pairs fill to a point beyond that specified by the utilization allowable, or if any single link exceeds the allowable by serving the demands from multiple O/D pairs, the model notes with a warning that a calculation is not possible, giving the analyst an opportunity to increase the utilization allowable. The final value of the allowable at which a calculation can be completed, even if it is above 100 percent, provides the designer with a rough estimate of how much additional capacity must be added in order to achieve acceptable performance levels. Thus, this is a very quick and rational, though approximate, method of conducting preliminary ATN sizing calculations.

The results of these calculations for symmetric demand are shown in Figure 3.3-4 and Figure 3.3-5 for the notional (2010 and 2030) cases and Figure 3.3-6 and Figure 3.3-7 for the alternate notional (2010 and 2030) configurations. The direction of travel is indicated by the arrows, and the values in green or red are the number of vehicles crossing the corresponding guideway segment in the one-hour analysis period. They therefore represent the superposition of all trips using a given segment. Further discussion of these results is given following the figures on page 30.

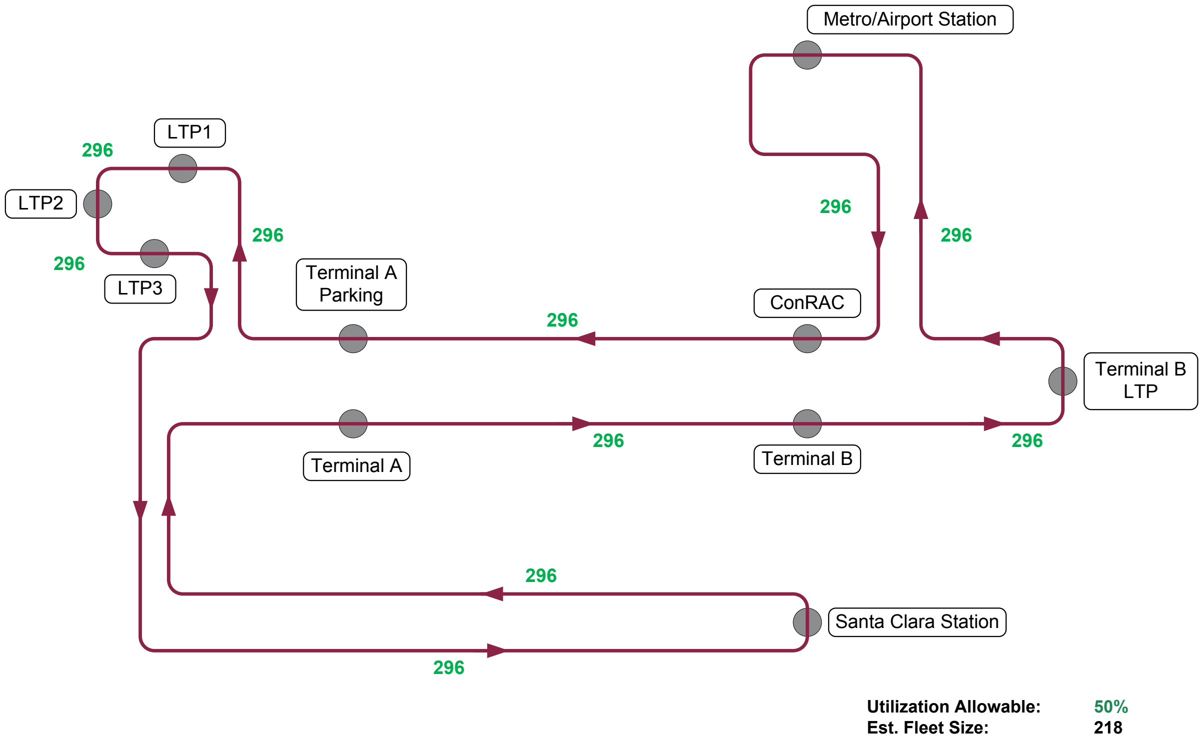


Figure 3.3-4. Notional configuration (2010 peak hour symmetric demand).

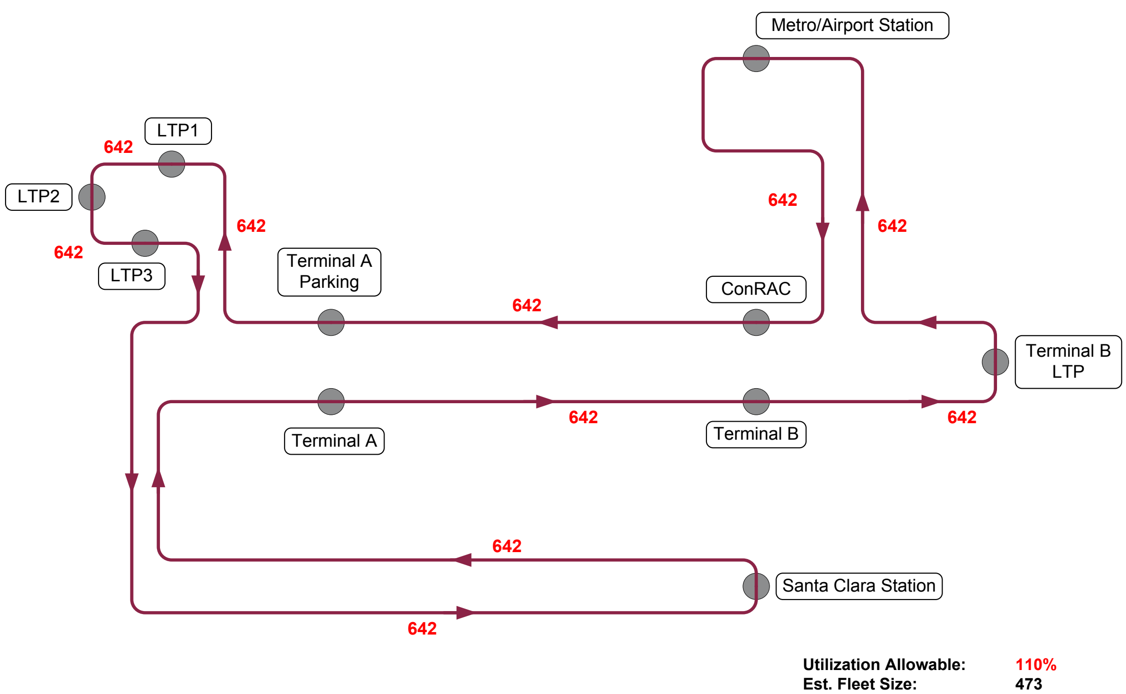


Figure 3.3-5. Notional configuration (2030 peak hour symmetric demand).

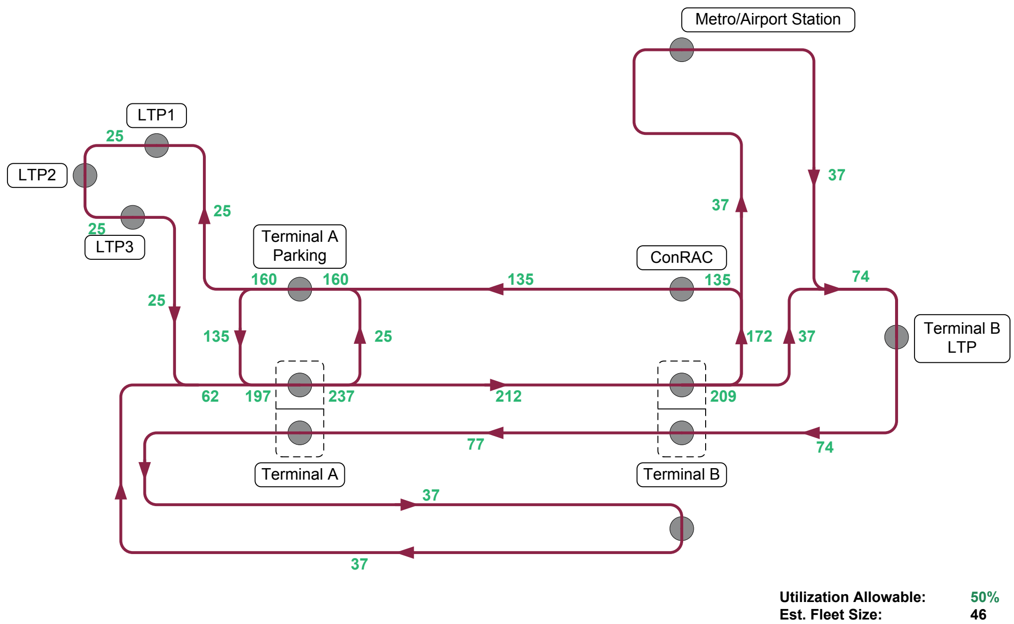


Figure 3.3-6. Alternate notional configuration (2010 peak hour symmetric demand).

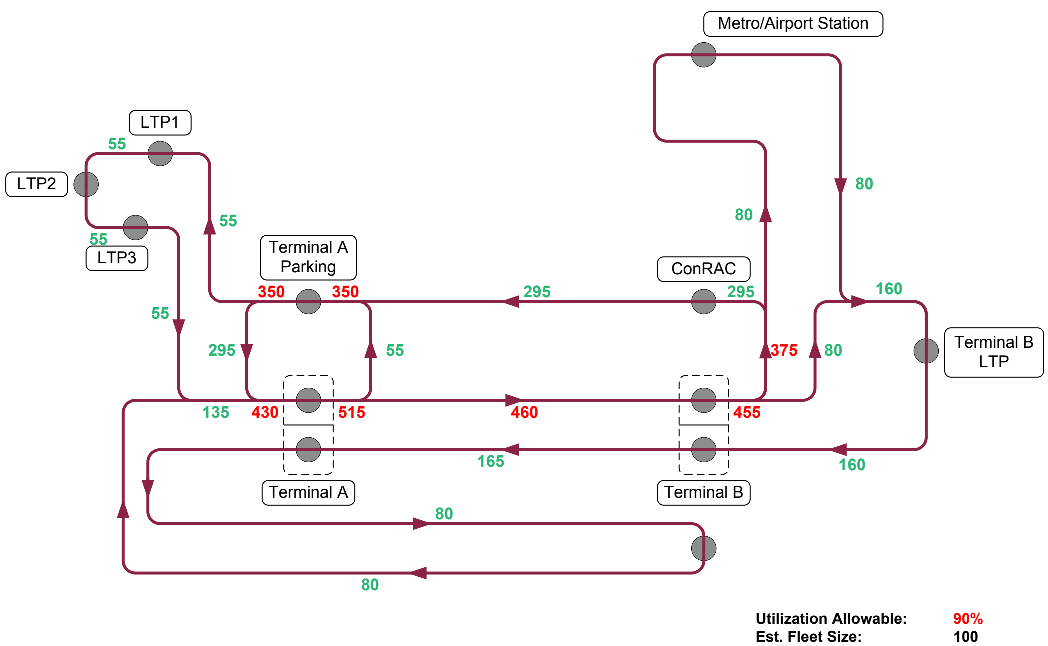


Figure 3.3-7. Alternate notional configuration (2030 peak hour symmetric demand).

3.3.1.1 Discussion of Symmetric Demand Cases

The first item of note can be seen in Figure 3.3-4 and Figure 3.3-5. These are cases of symmetric demand being serviced by vehicles traveling on a simple loop. For each O/D pair and given a constant load factor, an equal number of vehicles travel between them in each direction as first described on page 24, chasing each other around the loop, so to speak. On average, then, no empty vehicles are required to travel between the pair as newly arrived occupied vehicles unload and are then available to service waiting passengers. As this applies to all pairs in the O/D matrix, no empty vehicles appear anywhere on the loop. This configuration behaves as a simple conveyor system or moving sidewalk.

Also notice that the number of vehicles circulating in this time period (as indicated by the vehicle flow rate, 296, annotating each link) is exactly equal to one-half of the total peak hour passenger demand from Table 3.3-2 (1/2 x 888 = 444) divided by the load factor of 1.5. This is most easily understood by visualizing a single pair of stations: A certain number of vehicles arrive at a particular station on the inbound link from a particular companion station and, since the demand is symmetric, the same number depart on the outbound link to the same companion station. This situation repeats itself for every combination of station pairs between which demand exists. These individual movements add up to the value shown.

Turning attention to the value of the utilization allowable listed in the legend of Figure 3.3-4, it is seen to be at the specified 50 percent and it is noted that the number of vehicles traveling on the loop is less than one-half of the maximum theoretical link capacity of 600 vehicles per hour calculated on page 27. The value is therefore highlighted in green, indicating that traffic levels are below the allowable set for the analysis. By contrast, when the same configuration is analyzed for 2030 demand as shown in Figure 3.3-5, the utilization allowable is highlighted in red, as are the corresponding vehicle flow rates for each link. This indicates that the allowable required an adjustment in order for the calculation to proceed and that it exceeded the specified value, in this case by more than a factor of two.

This is a good place to note that throughout the various analyses of this work, SJDOT guidance called for evaluating currently reported performance against 2030 demand. *This does not imply any notion of certainty with regard to predictions of either demand or performance levels, or that comparisons between them spanning time have been used as a singular measure of feasibility.*

Fleet size is conservatively estimated by multiplying the total number of vehicle-hours in the study period by an estimation factor of 1.5.

Moving to the companion set of results for the alternate notional configuration as shown in Figure 3.3-6 and Figure 3.3-7 for 2010 and 2030 demand, respectively, one can now see the traffic splitting itself up between alternate routes. It is not possible in a single figure to easily display for each link the contributions to its traffic from all the various stations, but one *can* note that no link carries as much traffic as is carried on the links of the baseline notional "loop" configuration: i.e., multiple routes lead to less dense traffic on any given route (and therefore links constituting a route) as one would expect.

The last item to note here is that the specified utilization allowable is exceeded in the 2030 demand case, reaching 90 percent. Note, however, that this occurs only for some links. This highlights the result that the network becomes congested on the links surrounding high-demand service areas, in this case around Terminals A and B, as one would expect given the "morning rush hour" assumption.

Regardless of whether or not one believes that technical capabilities and/or regulatory measures would allow for greater maximum link capacities, or that demand will not achieve these levels by 2030, it is prudent to ask oneself how this situation might be reconciled. Therefore, without regard to how it might be physically achieved, a separate analysis was conducted for a modification to the alternate notional configuration. This was referred to as the "Magic Link" and is shown in Figure 3.3-8. This addition satisfied the specified requirement of a 50 percent utilization rate, returning the expected result that if resources are added to a network, it can service a greater demand.

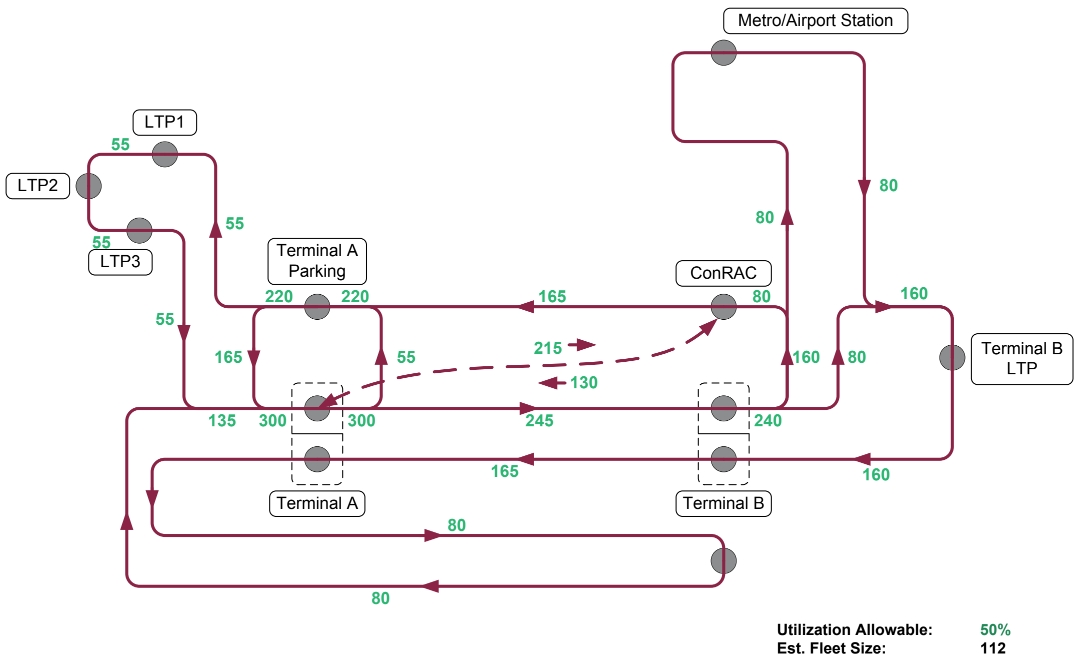


Figure 3.3-8. Alternate notional configuration + Magic Link (2030 peak hour symmetric demand).

3.3.1.2 Discussion of Asymmetric Demand Cases

The above analyses were repeated for the asymmetric demand cases; the results are shown in Figure 3.3-9 through Figure 3.3-13. If symmetric demand results in zero need for the circulation of empty vehicles, it is reasonable to expect the converse, and this is shown in the figures. In each figure, two values of the vehicle flow rate are given for each link, separated by a forward slash. The leftmost value indicates the number of occupied vehicles flowing on the link during the time period, the second indicating the number of empty vehicles.

These empty vehicles are needed to make up for the deficit of vehicles at any particular station relative to demand at that station. In other words, if the number of incoming occupied vehicles that can be unloaded to serve waiting passengers is insufficient, the difference has to be made up by circulating empty vehicles to the station and/or by having a reserve of vehicles prepositioned at the station. As mentioned earlier, these analyses assume that a supply of reserve vehicles is present at each station sufficient to make up for any deficit between demand and the number of arriving occupied vehicles "converted" to empty vehicles made available for boarding.

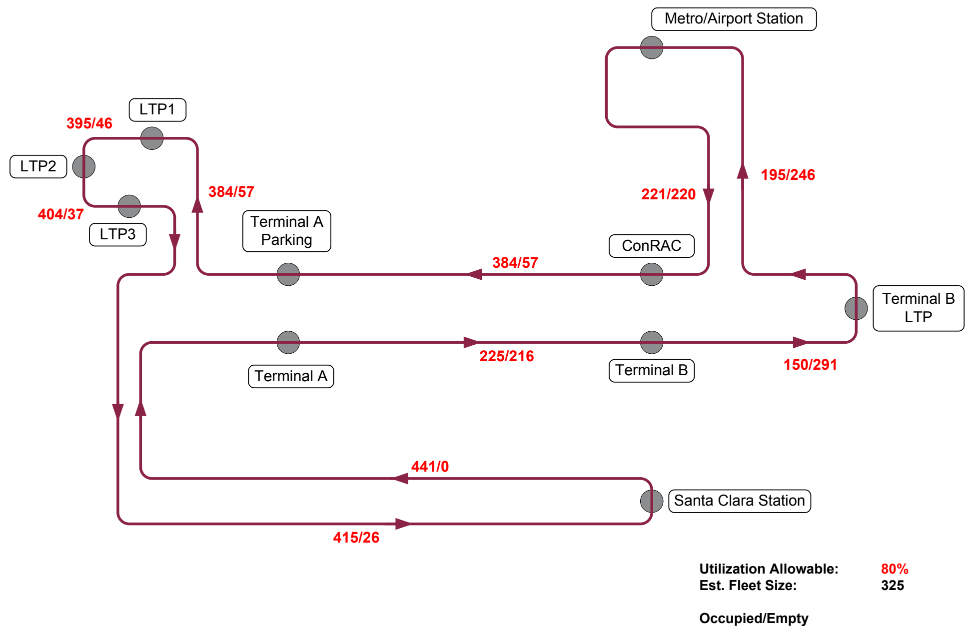


Figure 3.3-9. Notional configuration (2010 peak hour asymmetric demand).

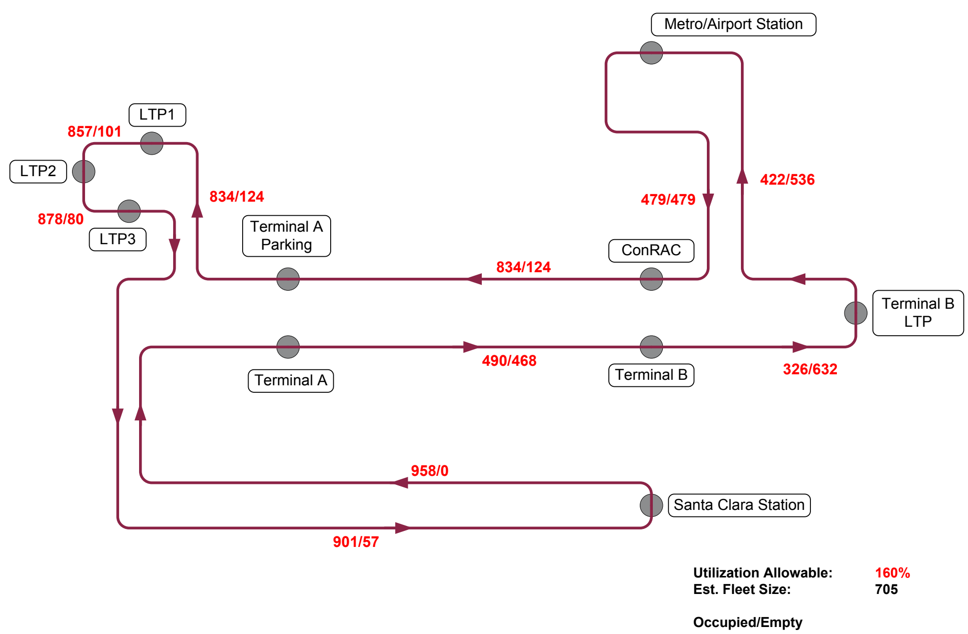


Figure 3.3-10. Notional configuration (2030 peak hour asymmetric demand).

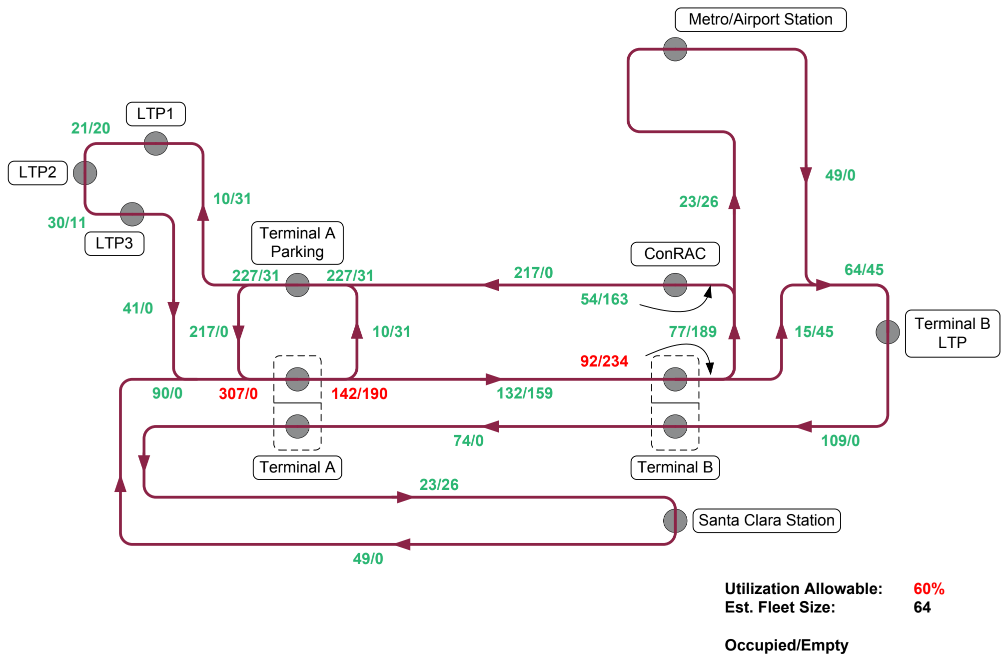


Figure 3.3-11. Alternate notional configuration (2010 peak hour asymmetric demand).

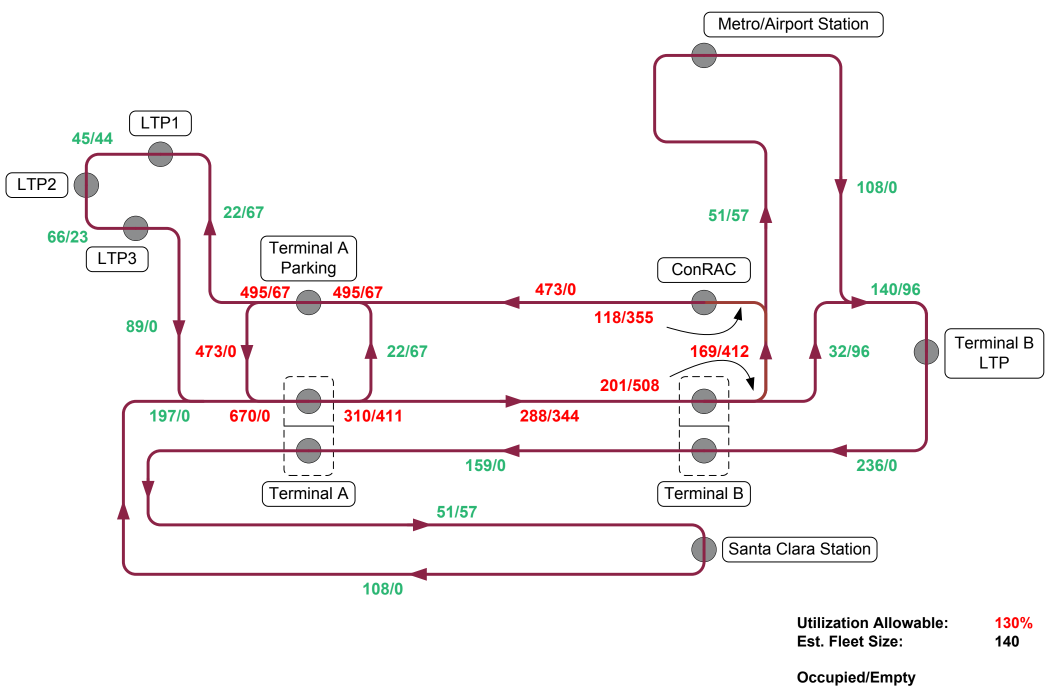


Figure 3.3-12. Alternate notional configuration (2030 peak hour asymmetric demand).

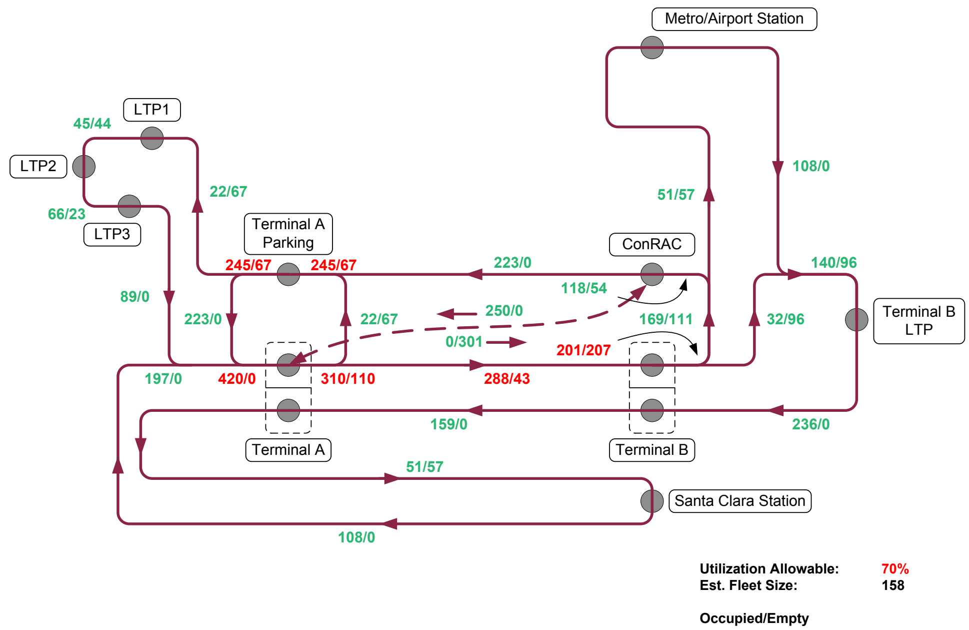


Figure 3.3-13. Alternate notional configuration + Magic Link (2030 peak hour asymmetric demand).

The effects are quite dramatic: As the vehicle stream is now composed of occupied *and* empty vehicles simultaneously, the greater number of vehicles drives the utilization rate higher, in all cases to the point where at least some of the links exceed allowable utilizations. This has a particularly dramatic effect in terms of fleet size and, although not estimated here, on energy consumption. Note once again, that as resources are added (in the form of alternative routes), yet another dramatic effect is observed relative to fleet size as the number of both occupied and empty vehicles required is reduced.

3.3.2 Summary of Notional Configuration Studies

1. Passenger demand is represented in the form of an origin/destination (O/D) matrix, listing in tabular format how many passengers or vehicles desire to travel from any one station to any other. Realistic O/D matrices will always exhibit some degree of asymmetry within short periods of time, as during a rush hour.
2. The key features of a network are *merges, splits,* and *stations*, which are categorized as *nodes*, and *guideways*, which are categorized as *links*.
3. The collection of nodes and the interconnections between them as provided by links of various lengths are referred to as the topology. Topologies can fit into various categories such as line (shuttle), loop, and network.
4. In a loop topology having symmetric demand, no empty vehicles are required and every link carries the same amount of traffic in the demand time period.
5. The number of empty vehicles required is driven in part by the asymmetry of demand.
6. There is a significant tradeoff between infrastructure and fleet size. Since these are two of the most important cost factors for an ATN installation, a thorough analysis and understanding of this interrelationship is of particular importance.

3.3.3 Routing Study Configuration

The initial configurations were purely notional. Arup thereafter undertook a series of detailed routing studies, resulting in the configuration discussed here. At the direction of the SJDOT, this configuration included a core service between Terminals A and B and the VTA light rail line at the North First Street Station; it temporarily excluded the excursion to the Santa Clara Station and to long-term parking. This routing configuration and its idealized system representation are shown in Figure 3.3-14 and Figure 3.3-15, respectively.

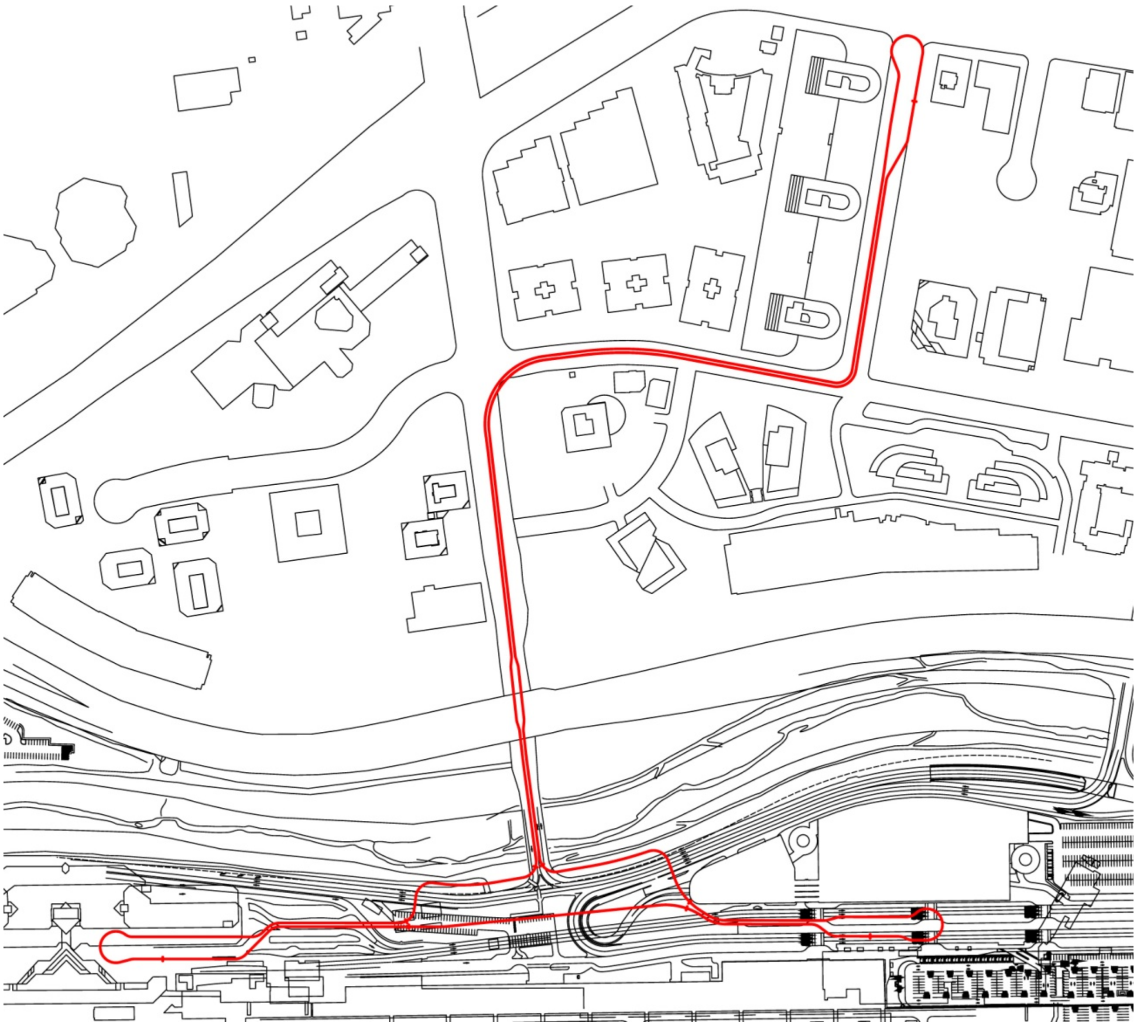


Figure 3.3-14. Routing study configuration map (Arup).

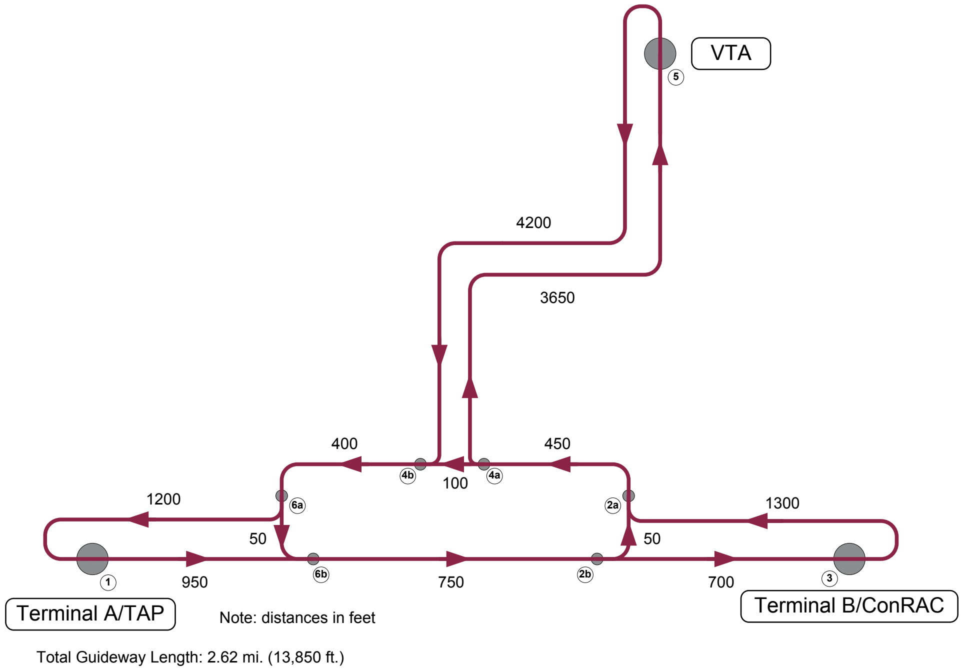


Figure 3.3-15. Routing study configuration topology.

The demand matrices for this configuration were extracted by Aerospace from the same demand matrix used earlier (Table 3.3-1 on page 24), but simplified in accordance with the pared-down set of stations and by eliminating the earlier assumption of demand directly between Terminals A and B. Hourly demand was again taken as 15 percent of total daily demand, and asymmetric "rush hours" were again defined as 80/20 splits. However, in this case, demand was formed into both morning and evening rush hours; symmetric demand was not considered any further. The resulting O/D matrices for 2010 and 2030 peak hourly demand are shown in Table 3.3-4 and Table 3.3-5, respectively.

Table 3.3-4. Routing Study 2010 Peak Hourly Passenger Demand Estimate

From/To	Terminal A / TAP	Terminal B / ConRAC	Metro/Airport Station
Terminal A / TAP		81 325	5 21
Terminal B / ConRAC	325 81		8 30
Metro/Airport Station	21 5	30 8	

Morning Rush
Evening Rush
Total = 470 passengers per hour

Table 3.3-5. Routing Study 2030 Peak Hourly Passenger Demand Estimate

From/To	Terminal A	ConRAC	VTA LRT
Terminal A		177 <u>709</u>	11 <u>45</u>
ConRAC	709 <u>177</u>		17 <u>67</u>
VTA LRT	45 <u>11</u>	67 <u>17</u>	

Morning Rush
<u>Evening Rush</u>
Total = 1026 passengers per hour

A set of analyses identical to those described in Section 3.3.1 were conducted. The same values of 6 seconds for headway, 24 mi/hr for line speed, and 50 percent as a target utilization allowable were used. The results are shown in Figure 3.3-16 through Figure 3.3-19.

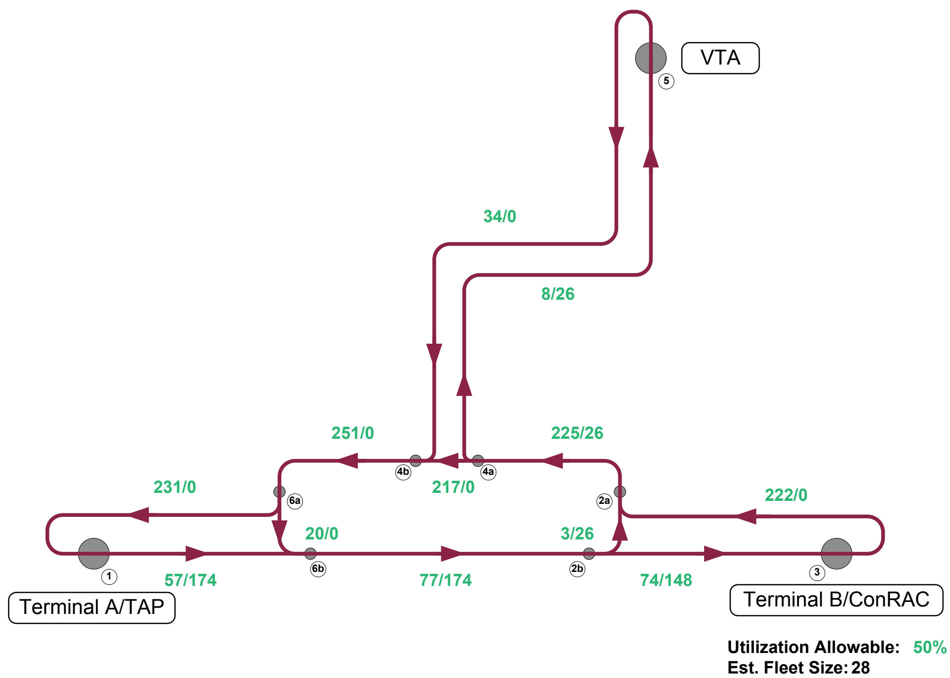


Figure 3.3-16. Routing study configuration 2010 morning rush.

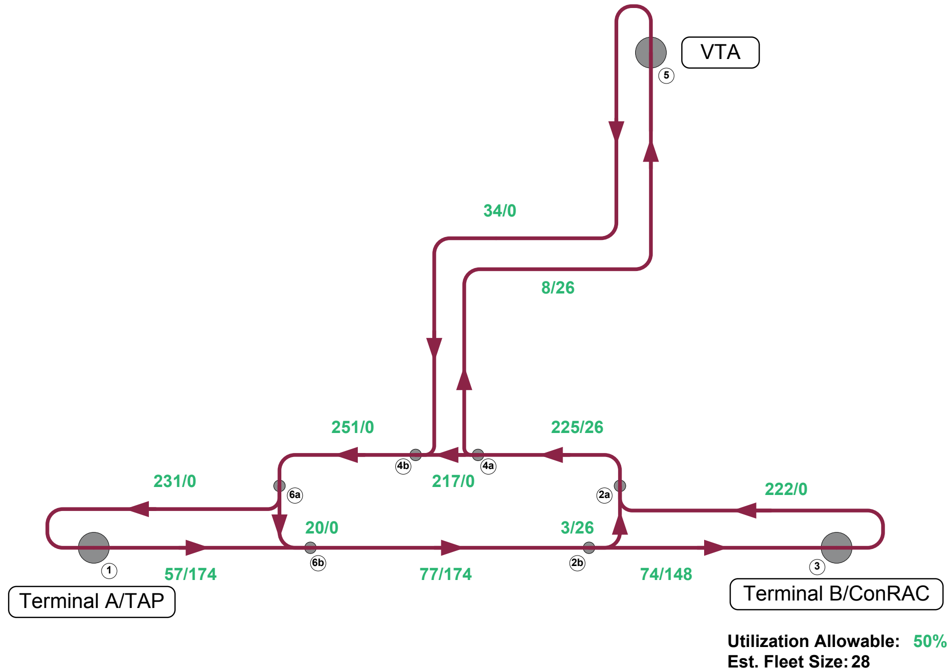


Figure 3.3-17. Routing study configuration 2010 evening rush.

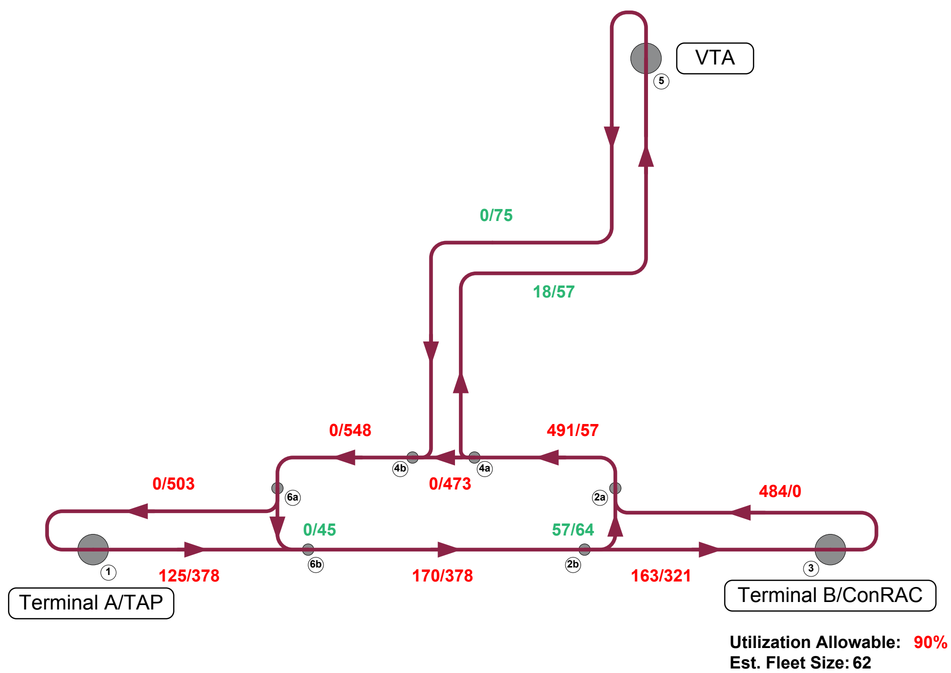


Figure 3.3-18. Routing study configuration 2030 morning rush.

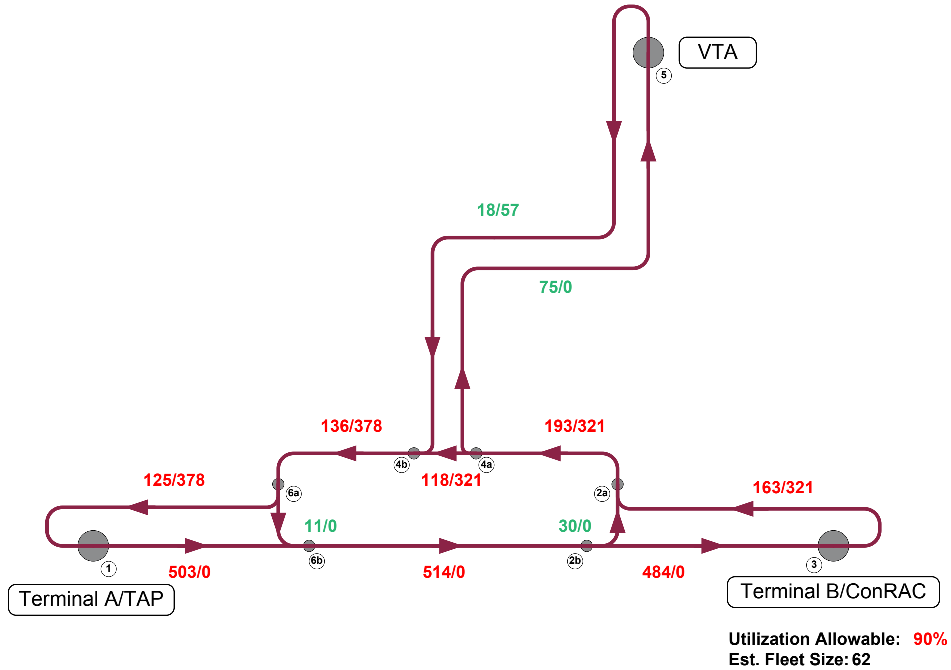


Figure 3.3-19. Routing study configuration 2030 evening rush.

These results require very little explanation as they follow from the discussions of Section 3.3.1.

3.4 RFI Response Evaluation

The RFI process and responses had a profound effect on the project's focus, shifting it further than the City had hoped away from a technology application evaluation and toward a deeper and more difficult assessment of the fundamental technical claims underlying the ATN concept. As mentioned at the outset of this report, the item most obviously lacking when considering the utilization of an emerging technology for a particular application is experience. For mature technologies, this experience manifests itself in many forms: design maturity, availability of relevant codes and standards, pools of specialist engineers, technicians and planners, a sense of public acceptance, well-understood regulatory requirements, proven operational reliability, and, for the immediate purpose of this project, generally accepted design guidelines.

In the case of an emerging technology such as ATNs at present, a lack of collective experience manifests itself in the form of a considerable knowledge gap between the development community and potential first-adopters such as the City, no less the potential user community at large. It was noted earlier that there is no equivalent of the AASHTO Green Book, for example, which provides voluminous data on highway design issues. This data, collected and verified over many decades, is readily accessible to trained professionals for the purpose of evaluating proposed designs involving roads and highways.

For the equivalent purpose relative to ATNs, the chief source of the information necessary to bridge the knowledge gap must be the development community itself—the engineering teams who have been working hard to give life to the concept.

However, the development community itself lacks experience (broadly speaking, of course), so a request of this type is a particular challenge.

The development community responded with eight ATN-specific information packages totaling some 650+ pages. This was a tremendous effort, given the detailed nature of the RFI and the short response turnaround requested. The responders are owed a thankful acknowledgment for the considerable effort that they put forth.

As a result of the development community's RFI response efforts, a number of key technical and programmatic issues were uncovered that, at present, represent a significant measure of uncertainty with respect to current ATN designs and to the overall concept. The issues ranged from relatively minor items requiring clarification to large-scale items that will require much greater efforts to understand and put into perspective. This is especially true if the City's intent is to later expand the Airport network to encompass larger service areas.

Note that the existence of significant issues should be expected. They go hand in hand with technology development and most certainly do not at this point disqualify the value of further consideration of the ATN concept. If these issues were to be resolved or otherwise accounted for, a more assured path to the understanding of ATNs and their potential for practical implementation could perhaps be opened up.

More importantly, the RFI process was itself indicative of an issue at play larger than that of the technology itself—the need for the City to undertake a role in the formation of a more assured institutional means for carefully and responsibly evaluating and allocating resources to ATN innovation efforts. Borrowing a term from author Clayton M. Christensen [9], we refer to this and related issues as the need for the development of a "value network."

The results of the RFI effort are presented in three sections encompassing the project tasking described on page 5:

1. The State of the Industry

2. The State of the Art

3. The State of the "Value Network"

In each, key issues are highlighted and briefly explained. Where further detailed explanation is necessary, this is done in later sections as indicated by cross references.

3.4.1 State of the Industry

Aerospace had an explicit contractual obligation in this evaluation to assess the "state of the industry." A discussion of this topic can involve many things: adequate organizational structure, staffing, mix of expertise, the extent of established administrative and technical practices appropriate to its product, capitalization, manufacturing capacity, and supply chain maturity, etc. A more comprehensive look at topics such as these was a casualty of the need to shift focus as a result of the RFI process from a balance of technical and programmatic inquiry toward more of the former. However, a quick read of the RFI responses revealed that there are a wide range of industry participants, from undercapitalized startups having substantial technical expertise and "paper" designs to obviously more mature startups having functioning prototypical hardware and software, the financial backing of major industrial and infrastructure firms, and foundational supply chains in place.

It is important for the City to take note of the rather obvious: that overall the entire industry can generally be considered a startup. It is arguable whether it can rightly be referred to as an industry just yet. The magnitude of the Airport project alone is likely of insufficient magnitude to justify economy-of-scale investments in manufacturing capabilities and the consequent need to account for the time and vicissitudes normally encountered in ramping up such efforts. However, the project is of sufficient magnitude that it could conceivably challenge current presumed low-production volume capabilities, thereby involving a different but still important set of obstacles that would be less of an issue in a more mature industry.

The City should also note that an RFI is important as well from the perspective of responses that are *not* received. The SJDOT, Aerospace, and other organizations that track such things are aware of a number of potential responders that chose not to participate. It is suspected that a number of useful subsystem technologies exist but were not made available for this evaluation. The implications of this are discussed in Section 4.

For present purposes, only two particular items relative to the maturity of the "ATN industry" are further discussed in this subsection—technical know-how and the ability of industry to support the City in its due diligence.

Technical Know-how: It is appropriate to mention here the first finding from the RFI process: *The City of San José and its companion stakeholders can be assured a selection of technically capable commercial providers with which to engage in pursuit of further efforts.* Crafting satisfactory integrated systems is a difficult thing to do, even if on "paper" and particularly for such a complex set of requirements as that associated with the ATN concept. The ability to do this is a fundamental aspect of the maturity of an industry and, while a wide range exists, the development community has generally proven its recognition of the myriad design tradeoffs associated with the ATN concept and with the utilization of sophisticated tools and methods to engineer capable products.

The principal caveat is that all of the RFI responses described the ATN concept similarly, listing the key discrete performance characteristics of their respective designs, but from a systems perspective admitting of little potential variation and ranging from thoughtful discussions of the complex tradeoffs and development issues involved to the making of claims both technically and conceptually suspect. Certain analogies that have been given can be very misleading. Taken at face value, the various claims could, in fact, result in the establishment of some fairly unrealistic expectations.

The hoped-for level of guidance that could be used to fully assess capabilities against requirements remained elusive. This by itself does not prove nor disprove “the” ATN concept or call into question the technical skills of the development community. It simply means that the development community has yet to fully articulate the ATN concept, including the many forms it might take, its limitations and applicability, the positive developments in related fields that would bolster efforts to bridge the gaps between the ATN concept and reality, and the details of how the community intends to work toward its fruition.

From the perspective of a nontechnical reader of the RFI responses, an impression can be gotten that all the technical and conceptual issues associated with ATNs have been solved. For the technical reader, inaccuracies or limitations in the arguments that are not fully addressed can give the impression that the development community lacks the understanding to fully realize the concept. Neither is true. A thorough airing of these issues would benefit all interested parties and has the potential to bolster the positive value that may be obtainable if the concept were to be pursued. Thus, the focus throughout the remainder of this evaluation became the development of an objective and accurate portrayal of ATNs in support of the City’s decisionmaking.

Technical Guidance: A frequent claim made by the development community is that there are so many application-dependent variables and design tradeoffs associated with ATNs that sufficient guidance can be given only on a case-by-case basis by the development community itself. Moreover, the sophisticated techniques used by individual members of the community to predict the performance of particular instances of ATNs are tightly coupled to the particular control system designs and methodologies that are considered to be the technical key to commercial success. These techniques, generally in the form of computer simulations, are therefore generally considered to be trade-secret information and closely held.

Limited-access versions of these tools and others that are generally available are of little use with respect to this evaluation—it is correct that they must reflect the underlying control methods, and it follows that these have also not been provided. This is a feature of an immature industry, one in which knowledge of performance characteristics suitable for feasibility evaluations such as for the Airport application is generally unavailable, essentially forcing the City into a much more involved and expensive preliminary design effort as the price of ascertaining feasibility.

Moreover, even if this *were* to be done, the City would require sufficient guarantees regarding the level to which these performance estimation tools have been *verified*. This basic chicken-and-egg situation regarding verified performance estimation and design guidance will require resolution if design/build risk is to be brought down to acceptable levels. A comprehensive and independent modeling and simulation effort based on control methods subject to strict trade-secret protections would be helpful as a first step in a resolution process. This will be discussed further in Section 4.

It needs to be re-emphasized that these issues are not necessarily indicative of any insufficiencies in the understanding or plans of the development community as a whole. This is simply the state of affairs uncovered as a result of an opening dialog. Even though further dialog and efforts will be needed to resolve them, these efforts can be more focused and resolution achieved sooner rather than later now that the City has succeeded in bringing them to the table. It should also be noted that, in driving toward a successful resolution of the issues, the focus should not be exclusively on the state of the *industry*, a topic that will be discussed in Section 3.4.3 on page 63.

Nevertheless, the net effect of the RFI results was that the nature of the feasibility assessment required a radical change from a *review* of the underlying logic and analytical basis of ATN performance and subsequent comparison to requirements, as would be done for conventional systems, to the necessary and more difficult task of *rigorously critiquing* by independent means the technical and conceptual claims being made for ATNs. This resulted in a complete revamping of the project, including the development of a potential design approach that might mitigate some of the uncertainties and unknowns that were uncovered via the RFI process.

3.4.2 State of the Art

The point needs to be made loud and clear: Despite its lack of emphasis in the RFI responses, the development community in general fully recognizes that ATN technology is a work in progress from both the design and conceptual standpoints. In this section, brief summaries will be given relative to the state of the ATN art, addressing the topic from both conceptual and design standpoints, highlighting key issues for each.

This is done in three subsections. The first short section is intended to assist the reader in thinking broadly about the fundamental issue—what precisely *are* the benefits and challenges associated with *automation* and *networks* relative to the City's transit needs? The second section casts the discussion in terms of the basic physical and operational features that have defined the ATN *concept* since its origination, and how they have been misinterpreted over the years. This will begin the discussion of the specifics underlying the general conclusions presented throughout earlier sections of this report and will suggest that the concept itself is due for significant reinterpretation. The third section continues along these lines, noting specific issues associated with currently proposed ATN *designs* and the challenges associated with converting concept to reality.

The reader is asked to note that many of the items discussed are interdependent and impossible to address in isolation. This is a reflection of the many underlying interdependencies that must be taken into account when architecting and designing any system but may make the discussion a bit difficult to follow. The interested reader may wish to annotate a paper copy of this section with links to common topics scattered among the listed items. The resulting web of interrelationships might serve to help the reader develop a deeper appreciation for the successes achieved by the development community thus far and the challenges it continues to face. The reader is also asked to keep in mind a corollary: These cannot be considered a checklist of independent items that can be tackled one by one in isolation as part of a risk mitigation plan.

3.4.2.1 Preface: Automation and Networks in Perspective

Many claims are made for ATNs, among them precepts such as "near-instantaneous vehicle availability," the "free flow of vehicles under automated computer control," and "scalability." Performance capabilities such as these would indeed result in a very attractive transit experience featuring little or no waiting for vehicles and congestion-free travel. Scalability implies that such service could be easily expanded across arbitrarily large geographic areas via additional network guideway and stations. Coupled with sufficiently large estimates of guideway and station capacity, very favorable estimates are claimed of a *system's overall ability* to service very large demands in this desirable manner. The net result can lead to similarly favorable business case estimates.

The literature is replete with concepts such as queuing theory, synchronous vs. quasi-synchronous vs. asynchronous control, empty vehicle management, etc.—all targeted toward these goals (and all supporting the assertion made in the opening paragraph of this report regarding the complexity of the ATN concept). However, the situation is as described earlier: There are relatively few *verified* guidelines readily available to a potential buyer in support of its due diligence or planning efforts.

These characterizations of ATNs and others are frequently made and accepted in a near axiomatic manner, as if automation were a key capable of unlocking an unlimited resource. On the contrary, while it is certainly true that automation may be used to mitigate the effects of human behavioral and performance limits, and that sophisticated algorithms can be used to help balance traffic on a network, the ability to achieve the levels of performance alluded to in these generic claims does not necessarily follow.

Moreover, although it is certainly conceivable ATNs can be designed such that they can be expanded in hardware and software beyond an initial installation, it also does not follow that performance levels associated with an initial installation can be maintained without limit.

Lastly, performance estimates of individual system elements (guideway and stations in particular) considered in near isolation, as illustrated in Figure 3.4-1, do not translate *at all* to systemwide performance of the same degree.

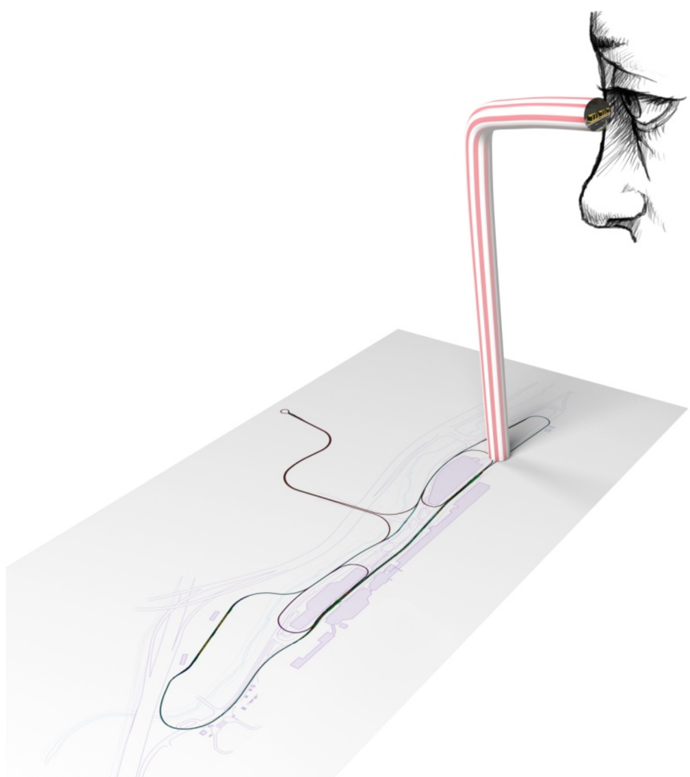


Figure 3.4-1. Too narrow of a portrayal.

In light of everyday notions regarding the benefits of automation and modern networks of all sorts, it is important that the City establish realistic expectations regarding their application in the form of ATNs. In this section, an attempt is made to put these issues into objective perspective in summary form.

3.4.2.2 What ATNs Are *Not*: Conceptual Mischaracterizations

A characterization of ATN technology is best begun by dealing with a number of *mis*characterizations of the concept's baseline operational features and benefits that have developed over the decades and are unfortunately supported by some contemporary promotional literature. The intent here is to help the City determine what it can realistically expect, and the consequent planning challenges it will face with respect to both its short- and long-term goals. The following discussion correlates to commonly accepted features that have been used over the decades to differentiate the ATN concept from those of other transportation systems:

1. A fully automated system consisting of conveniently located offline stations providing access to small, readily available vehicles, and a network of interconnecting guideways segregated from conventional traffic that *together*:

    a. provide an overall service model similar to that of the automobile, including broad area coverage and the option of *personal* transit, thereby maximizing the appeal of public transit relative to the automobile

    b. maximize throughput and minimize travel time via the ability to bypass stations

    c. minimize congestion and thereby reduce travel time by providing alternate routes between any two stations and balancing load across them in response to local demand peaks or disruptions

    d. maximize throughput by minimizing the effects of human behavioral and performance limits

    e. maximize energy efficiency and minimize emissions by enabling a closer match in time and space between capacity and demand (i.e., minimizing the inefficiencies and excess energy consumption of systems sized for peak demand when operating off-peak or, alternatively, providing a just-in-time, right-sized resource model, the resource being seats)

2. Smaller infrastructure (particularly guideways) commensurate with the smaller vehicles to:

    a. simultaneously minimize both cost and environmental impact via maximum resource utilization (i.e., less material per passenger carried)

    b. maximize ease of deployment (i.e., adding transit capacity) via the ability to more easily integrate and expand into a built urban/suburban environment

It first needs to be recognized that this feature and benefit set is aspirational, not a *fait accompli*. As many a developer over the years has discovered, achieving these goals *in toto* is challenging, to say the least.

Many of the mischaracterizations that have developed over the years and are about to be discussed derive from realistic performance estimates that apply in limited cases, but are then assumed capable of extension to more general cases sans a critical examination of their limits. Others derive from analogies that are similarly not pursued in sufficient depth or simply from an imprecise choice of words. Still others reflect, perhaps inadvertently, conceptual dissonance in terms of the simultaneous pursuit of contradictory goals. Note that these mischaracterizations have been observed in a variety of sources; the RFI responses themselves are not being singled out as especially egregious, but unfortunately they do little to clarify the issues.

So, contrary to *popular* portrayal, ATNs are *not generally*:

1. On-demand, zero-wait-time systems:

   This can be true in certain circumstances but, in general, wait times for a sensibly sized system can range from zero to very long, on the order of 10 minutes or more[9], depending on numerous factors. For the Airport, Aerospace developed a system architecture that could result in very reasonable wait times consistent with the concept's promise within the bounds of the underlying assumptions that were made for this project. In general, however, a more precise way of characterizing the "traditional" ATN concept with respect to this operational characteristic would be *"nonscheduled, demand-responsive."*

2. Uncongested, nonstop, direct-to-destination systems:

   Contrary to frequent claims, ATNs are not immune from congestion. Like all networks, they have limits to their ability to serve the amount and nature of the demands placed on them. Demand levels and patterns that can be reasonably expected may in fact result in the slowing or even stopping of vehicles on guideways. Moreover, ATNs not only allow for but *rely* on the possibility of vehicles taking *nondirect* routes. Vehicles may even be required to bypass *the destination station* and loop around for another attempt to enter (called a *station miss*). A potentially more precise way of describing these baseline behaviors might be to refer to them with the more familiar concepts of *"alternative routing"* and *"express service,"* in which the ability to bypass congested areas of the network is intended but cannot be guaranteed.

3. High-capacity systems:

   If holding true to the personal service model, this particular claim is based on a rather obvious conceptual contradiction: High capacities are based in large part on fully occupied multiseat vehicles, an operational mode that runs counter to the personal service nature of the basic concept. ATNs can operate at higher capacities or as a personal service. They can even accomplish these two goals simultaneously in different parts of a network or in the same part if operated in different modes at different times. But they *cannot* achieve these two goals *everywhere and simultaneously* on a network for a given vehicle size greater than the average rate of occupancy or *load factor*.

   From the standpoint of establishing planning, business case, and passenger expectations with regard to the transit experience associated with ATNs, this characterization must be used with care. The ill effects of its use can be particularly acute when considering currently available rather low-performance designs, which are at present unable to make up for capacity

[9] By way of comparison, it is informative to note that the train schedule for the entire *nation* of Switzerland has been arranged such that waits for transfers between lines take no longer than 15 minutes. Its daily train schedule fits on the equivalent of two 8½" x 11" sheets.

limitations by other means. A more precise characterization might be *"potentially high capacity under certain conditions at the expense of personal service"* or, conversely, *"generally personal service at the expense of energy and resource utilization efficiency."*

With further development and a favorable alignment of regulatory and other factors, it may be possible to get closer to this characterization, but in a manner other than by this line of reasoning.

4. Small, easily aligned, and quickly erectable infrastructure:

   These three claims are usually presented together and so they are here. A close conceptual cousin to this trio is the notion of "scalability" or, in more pedestrian terms, expandability. The term scalability has also been used to highlight that the *control systems* as well as the physical infrastructure will require no basic redesign in order to increase the coverage area from that of an initial installation—as well it should, since the control system is part and parcel of a general use of the term "infrastructure."

   No transit system would be very useful if it weren't generally expandable to begin with. But we all know from personal experience that there are limits to expandability. Apart from the general physical constraints and political issues associated with civil infrastructure, the practical technical limits of this trio must be explored and considered with respect to ATNs.

   Given appropriate measures of innovation and relaxation of street and highway design codes (as for bicycle lanes), the last of the three seems achievable at reasonable risk with respect to the physical infrastructure[10]. The first two items, however, deserve attention, as do other aspects of scalability seldom mentioned: the need to plan for future demand magnitudes, asymmetries arising from service area expansions, and technological development.

   a. Size and Ease of Alignment:

      It is true, of course, that in general the elevated infrastructure required to support and guide smaller vehicles can be expected to be smaller and more easily "packaged" in a built environment than that for larger vehicles. The limitations of this notion have not, however, been fully explored. Acknowledging, but putting aside for the moment, the common criticism that ATN infrastructure will be unacceptably visually intrusive in some, if not a considerable number of, situations, there are other considerations.

      As will be described in more detail elsewhere in this report, the cross-sectional size of ATN guideways will be governed by existing safety standards requiring emergency walkways and also by seismic performance considerations. Also, their general layout is inextricably linked to performance in terms of travel time, passenger safety and comfort, and capacity via the necessary minimum radii and transition, speed-change, and, most significantly, maneuvering lane lengths. The ability to integrate these layouts into any particular built environment can be a major challenge relative to performance.

   b. Demand Asymmetries:

      Although scalability of ATN hardware and software has not yet been demonstrated in terms of interrupting service in an operational environment and quickly (overnight, say)

[10] Just how large of an effort will be required to arrive at appropriate measures of innovation and relaxation of codes is, however, a significant open question.

reconfiguring or attaching a new subnetwork to an existing network, the ability to achieve this goal via innovative design and manufacturing is perhaps a reasonable expectation. However, what has not been fully discussed is scalability in terms of the ability to service new demand attracted to previously built portions of the network or vice versa by virtue of an expansion. As discussed earlier in Section 3.3.1.2, the degree of demand asymmetry is what gives rise to local imbalances between demand and capacity or, in less technical terms, congestion. In-vehicle and in-station passenger wait times are very sensitive to this imbalance.

The frequently used analogy of ATNs as horizontal elevators is rarely pursued to its full extent. Elevators are designed for essentially unchangeable service areas and demand maximums governed by fixed floor space. Unless ATNs are designed for or along with demand generators of fixed size, congestion will result. However, changing demand patterns and levels are a practical fact and cannot be gotten around; it is a feature of the very nature of transportation needs and applies to network expansion as well as to initial installation. Thus, if an expanded service area attracts additional demand to a particular destination not sized to handle it, performance at and near the destination will suffer. This similarly applies to the effects of creating new demand generators around existing ATN stations.

With regard to the Airport, the surface automobile parking lots, ConRAC, and to a lesser degree light rail are good examples of a *proper* application of the horizontal elevator analogy, as they are fixed-size demand generators. However, incorporating the necessary additional resources either before or after the fact of an anticipated service area *expansion* will not necessarily be an easy thing to accomplish. In this evaluation, a certain fixed service area and corresponding O/D matrix was assumed. What network service area should ultimately be considered when estimating the demand for service to/from Terminals A and B? If ATNs in the City of San Jose and surrounding communities turned out to be wildly successful and, due to their convenience, resulted in a dramatic increase in demand at the Airport, what could be done? Much advanced planning would be required that anticipates future demand and makes provisions for the addition of resources in initial build-outs.

It should be noted that there is nothing unique about ATNs with respect to these planning issues. The same challenge of sizing a system in the present relative to future demand exists for any system. There is, however, an issue related to scalability that *is* unique to ATNs at this point in time and is discussed briefly in the next paragraph.

c. Scalability and Technological Advances:

Which specific set of subsystem technologies should the City plan to use for its Airport project? As opposed to physical or demand scalability, this can perhaps be described as technological scalability. As opposed to conventional systems, in which expansion for the most part involves adding more of the same, ATN expansions will also involve adding more of things that are *not* the same, given that ATNs are in such an early stage of their overall development.

This is particularly true for many ATN designs that are for good reason highly integrated systems. In tech-speak, this means that functions cross physical interfaces. Practical examples of this are proposed designs in which half of the propulsion system exists in the vehicle and half on the guideway. Another potential example is a design in which the control and propulsion systems are physically one and the same. Some of these subsystem technologies may, in fact, be required in order for the ATN concept to be fully realized.

This issue of how to accommodate and plan for what could be rapid technological change is a significant challenge for the community of interested *buyers*, including the City. On the one hand, incorporating technological advances could require major surgery; unlike systems that are not highly integrated (e.g., automobiles and roads), ATNs might not be all that easy to upgrade. Conversely, a premature selection of a singular technical approach could lead the City into a technological cul-de-sac and even help stifle continued innovation.

5. Contemporary Analogies:

   Other than those of robotic taxicabs and horizontal elevators previously mentioned, more contemporary analogies have been used to communicate the characteristics of ATNs. One such is the analogy drawn between ATNs and the Internet. Like the others, this is a useful and generally harmless analogy. It provides the average nontechnical person with an image as to the general arrangement and operations of ATNs as networks, and of the "packetizing" of passengers (i.e., splitting up the passenger complement of large vehicles into smaller units). But care must be exercised insofar as *any* analogy establishes expectations with respect to ATN performance, technical maturity, or certainty of successful development.

   It is obvious that a great deal of the knowledge developed to create the communication network called the Internet can be applied to the design of transit networks. It is also obvious the two have major differences. For example, ATNs deal with "packets" that have inertia (mass), travel at extremely low comparative speeds, and for which safety is a key consideration. What is not so obvious is that the differences mean as much as the similarities. For example, the Internet not only allows but *depends* on the collision of packets to perform as it does, an obvious nonstarter when it comes to ATNs.

   The important point here is to inform the City that, in doing its due diligence, care must be taken to not rely too heavily on analogies of any sort in developing an understanding of and establishing expectations regarding ATNs.

Although it won't become clear until later, many of the above items are, generally speaking, manifestations of degradations in system performance as demand outstrips capacity. If this occurs, either the network congests or the time waiting in line for a vehicle grows. It is that simple. ATNs are not infinitely large transit pipelines.

To be more precise, networks are assemblages of interdependent resources that together exhibit highly nonlinear responses (i.e., they are very sensitive) to the smallest of perturbations. This is especially problematic for systems that serve demand that is asymmetric and random in nature, resulting in very unfavorable delays that can propagate through the network and which are largely *unpredictable* [11]. This is one of the principal differentiators between ATNs and scheduled line-haul systems like buses and trains. It is the cause of many of the "congestion mysteries" that are a common experience with automobiles. Seemingly trivial perturbations in demand or operations can result in

[11] While individual occurrences of delays can be unpredictable, mathematical modeling and simulation can be used to predict their *likelihood*.

very large degradations in performance and require very long times to recover. This is a feature of networks, *automated or not*.

The converse is also worthy of note: For a given level of unacceptable performance, the allocation of a minor amount of additional resources can improve performance dramatically. The principal question then becomes how to properly size an ATN network in accordance with specified performance minimums (including the expectation of occasional very low performance), how to plan for this across time, and how to communicate reasonable expectations to the public at large. In these respects, ATNs are no different than any other form of transportation system.

These topics will be discussed in more detail in later sections.

3.4.2.3 Current Issues and Future Challenges

Now that some of the misconceptions about ATNs have been addressed, this section presents additional perspective that is hoped will provide the City a further sense of the nature of ATNs. Coupled with an assessment of the information provided in the RFI responses and the results of independent investigations and analyses, a picture should emerge describing what the City can realistically expect of ATNs now and in the future, and of the challenges that will need to be taken up if it chooses to continue its consideration of their use. The picture is complex and difficult to articulate in summary form, and is maybe best begun via the use of an alternate set of analogies.

As perhaps a more apt description of ATNs, it is suggested that the City pursue the automated taxicab analogy described in Section 2.3. However, as opposed to the comparison used earlier between ATNs and APMs, which was chosen to initially place ATNs relative to familiar transportation systems, think in terms of a cross between automobile/road networks and factory automation systems. Given the application of automation, the ultimate aspiration of the ATN concept could be described as a convenient, desirable, demand-responsive, operationally flexible, economical, high-performance, all-weather, highly reliable, mass-produced, human-rated (i.e., safe), and very large *precision motion control system*. Thought of in this way, it is easy to see that ATNs would be a truly unprecedented achievement. Other systems possess some of these features to varying degrees, but it is hard to call to mind any that possesses them all in combination.

This analogy and comparison is perhaps truer to form, consisting of physical and operational features that are very familiar to most of us, if only through images we've seen. It combines the experience of either choosing a cab from the head of a queue, or the sometimes frustrating experience of hailing one, with common and correct notions of the high throughput and efficiency of fast, densely packed modern manufacturing production lines. Using both together highlights the fact that neither is individually a perfect analogy.

With this picture in mind, immediately below is a listing of the principal technical and subsystem performance issues uncovered through the RFI process, including a brief summary of each. They are presented in order of importance and chronological occurrence during the course of the project. Several of them are discussed in more detail later in the report. Taken together with the discussion of Section 3.4.2.2, a fuller sense of the nature of ATNs and their technical challenges should emerge. Programmatic issues uncovered through the RFI process are similarly discussed briefly in Section 3.4.3 and in more detail later on.

1. Human Factors:

   This may be an unexpected result, but the human factors topic deserves its place at the top of the list. System design begins and ends (or should) with the needs and satisfaction of the user in mind. It cannot be stressed enough just how important human factors are as the bedrock of design.

   It is obvious and well understood that passengers are more than mere objects to be moved: They can be injured, file lawsuits, limit system performance, and choose to not use or support the development of a technology. But, for a variety of reasons, due consideration of human preferences and limitations can fall by the wayside.

   Unfortunately, there is considerable evidence that this is the case at present relative to ATN technology. It appears from the RFI responses that a significant number of important human factors issues have thus far apparently gone unnoticed, been underappreciated or neglected, have not been fully investigated, or, even more significantly, may have been uncovered but unreported as major limiting factors in ATN design. It would not be too dramatic to say that complete confusion exists.

   In considering the many factors that can result in a situation like this, one can imagine the need to converge relatively quickly on a design from a business perspective and a similar sense of urgency on the part of receptive municipal transit agencies to satisfy their own goals and objectives.

   The current confusion seems to stem in considerable measure from the fact that, while the ATN concept envisions operations that are more automobilelike, ATNs are at present necessarily being designed in accordance with a variety of rail standards. Curiously, this situation appears to be simultaneously both overly conservative and too dangerous. This topic is discussed on page 55 and in more detail in Section 3.5.4.

   It isn't all about regulatory mismatch, however. Questionable suppositions and/or inadequate characterization of human-factors constraints on the part of the design community are also apparent. In only one of the RFI responses were human factors recognized as a substantial and necessary area of *a priori* research in order to inform design.

   Across the spectrum of human-factors issues, several of the most important to note are:

   a. Human Factors Affecting Passenger Choice and Load Factor:

      As discussed in Section 3.4.2.2 relative to high capacity, the service model of ATNs must be clearly defined for any particular application with respect to its personal nature. Vehicle size and average load factors will have an enormous impact on the performance, energy consumption and efficiency, and the economics of a system. Ridership—and therefore public perception and acceptance—is crucial.

      Many factors can affect how individuals would choose to use an ATN system. At the highest level, any particular ATN design application must take into account cultural factors in assessments of privacy and safety. Below this are factors such as time of day, length of trip, and perceived social compatibility relative to common trip purpose (i.e., a passenger may have different perceptions regarding acceptable traveling companions depending on the destination venue). In an effort to increase ATN capacity, a good deal of discussion in the RFI responses and in the literature is devoted to the issue of encouraging *ridesharing* on ATNs. However, these discussions are embryonic and in many cases suffer from logical inconsistencies. They are certainly not developed to a level sufficient to support design. While ridesharing is possible in certain limited situations, the obvious conceptual dissonance between ridesharing and the personal service model in the general case presents serious difficulties to the planner and designer.

Conversely, there is the issue of passengers *desiring* to travel together as a party and being unable to do so due to vehicle-size limitations. No argument has been uncovered (not that it might not exist somewhere in the literature) regarding the separability of parties consistent with the taxicab model. For example, one can easily imagine an ATN control system flexible enough to guide separated parties to individual vehicles served up in succession and coordinate the arrival of the several vehicles at the common destination, opening up a dedicated intervehicle communications channel while in transit.

This seems a reasonable approach for applications such as the Airport, in which a high percentage of users are businesspersons and other adults traveling singly or in small parties, but there is a frequently cited need for large vehicle sizes to accommodate families traveling together. Given the basic ATN tenet of relatively small vehicles, counterarguments can easily be made that, regardless of the vehicle size chosen, families exist that are larger than vehicle capacity. The family argument also presumes that families would be unable or unwilling to separate for the brief trip within the Airport system.

Similarly, the design approach to Americans with Disabilities Act (ADA) compliance deserves examination. The current approach of the development community generally appears to be one in which the entire vehicle fleet is ADA-compliant. This results in dual-purpose vehicles that are rather heavy and therefore less efficient.

The point of this discussion is that the ATN concept seems to be suffering from a sort of identity crisis resulting from an attempt to be all things to all people at all times. Contemporary ATN design seems to be following in the footsteps of their forerunners, in which vehicle sizes seemed to creep inexorably upward, perhaps for this reason as well as desire to provide capacities and throughputs perceived as necessary for economic viability. These are important issues, but the City must realize that the price for taking a conventional approach to their solution can result in ATN designs which are as inefficient and costly as the systems they purport to improve upon.

Potential approaches to satisfactorily address these issues and simultaneously preserve the principal features and benefits of the ATN concept are discussed later in this report.

b. Human Factors Affecting Station Operations:

Closely related to factors affecting passenger choice and occupancy levels are those associated with the actual accomplishment of ridesharing goals, assuming a subpopulation of willing passengers. A number of suggestions have been made to incentivize ridesharing based on comparisons to systems such as amusement park rides and ski lifts. These systems have been similarly used to suggest physical layouts and signage to guide passengers in the station concourse based on their preference relative to ridesharing. However, the concepts of operations and physical infrastructure to support ridesharing do not seem to have been developed at present to a level sufficient to support design.

Early in the project, Aerospace intended to investigate several operational concepts and construct corresponding performance models to illustrate and quantify the challenges involved. The magnitude of this task became apparent upon initial inspection, and the effort was abandoned for purposes of this project. A simple thought experiment may suffice, however, to illustrate the issue for the City:

An ATN can be thought of as a sorting machine. Passengers arrive at the various station concourses, each party[12] of passengers communicating their desired destination to the system via some interface. There will obviously be a mix of desired destinations among this collection of parties. The system performs the necessary calculations to accomplish these movements and does so, essentially sorting the parties over a period of time relative to their desired destinations.

In order for ridesharing to occur, this sorting would have to occur not only in a spatial sense, but also *temporally*. That is, the system must be based on a concept of operations within the stations that sorts parties not only by desired destination but also by *desired schedule*. Merely showing up at the same time is an expression of a commonly desired schedule; however, the system must guide parties so they arrive at a particular vehicle berth at *nearly the same time* for a trip to their common destination.

It has been postulated that this could be accomplished by simply designating certain berths (of a certain type; see Item 3.a. below) as serving certain destinations and having parties self-sort simply by following signs above each berth displaying the name of the destination. This could be done dynamically via changeable signage. The system could even anticipate the general need for the dynamic assignment of berths based on automated analyses of daily demand patterns over a period of time.

However, this becomes less practicable as the number of destinations grows relative to the number of berths. Also, if passengers were indeed willing to rideshare under the particular set of circumstances associated with the application and if there were enough of these parties, a queue would form and would be continuously processed by the designated berth(s). Passengers in the concourse desiring to travel to destinations other than the “express” destination(s) might experience this system performance success as a failure from their perspective: Their queues would process more slowly under the “typical” nonridesharing conditions. If the number of passengers willing to rideshare to a common destination was insufficient to form a queue, their non-express, nonridesharing counterparts may perceive this as a wasted resource, again not meeting their needs.

This issue is worthy of discussion and requires much further elaboration. The important point for the City to note is that it cannot base its expectations for ATNs exclusively on the performance of other systems that are only partially analogous and that this is an area in which a considerable amount of research and development must be accomplished in order to inform designs and reduce implementation risks.

[12] A party is defined here and throughout the remainder of this report as a number of passengers who desire to travel together. A party can be composed of any number of passengers, including one.

A last item of note in this category is the sparse amount of data provided relative to the response of system designs to the stochastic (i.e., irregular, random) nature of both passenger interarrival times and passenger ingress/egress capabilities, both related to the important issue of surge capacity. As is discussed in Section 3.5, network performance is extremely sensitive to surges—not just average peak demand, but peaks within peaks. At a certain point, in a straw-breaking-the-camel's-back behavior, very small increases in demand can lead to drastic reductions in performance, taking very long times to bring back to nominal. Conservative correction factors may be applied to average interarrival and ingress/egress times for design purposes, but only after they have been verified as bounding values via more detailed analysis based on stochastic processes and adequate testing.

c. Human Factors Affecting Guideway Layout and Vehicle Operations:

It is unclear precisely how current systems are being designed and operated with respect to the motion-control parameters affecting passenger comfort and safety. Some RFI responses were incomplete relative to this important information. Among those that did make note of these parameters, there existed a rather wide range of values. This highlights a very legitimate claim being made by the development community: ATNs are a technology in desperate need of certain standards.

An exhaustive inquiry into various operational standards that may or may not apply to ATNs was not possible within the scope of the project. However, one need not look too far to discover the issue as it would affect the Airport application. A set of standards oft cited by the development community is the aforementioned ANSI/ASCE/TD&I APM Standards. For the Airport, the governing set of regulations will be the CPUC General Orders, which do not currently reference the APM standards. As an example, a comparison of the two with respect to the important longitudinal braking deceleration motion-control parameter is illustrated by inspection of the table below.

	CPUC General Order 143-B	ASCE APM Standard[13]
Normal Deceleration (g)	0.10	0.25
Emergency Deceleration (g)	0.21	0.60

As can be seen, the values specified by CPUC General Order 143-B are less than one-half of those recommended by ASCE 21-05 for nominal operations and about one-third for emergency operations. Both are relatively low as compared to everyday automotive experiences, with the exception of the APM Standard emergency deceleration value. Curiously, in this case the recommendation appears to be nonconservative from a safety standpoint—physical trials have shown that almost all unrestrained passengers will be ejected from their seats at this level of deceleration. For lateral accelerations, current specifications and standards are similarly much less than that for everyday automotive experience. Section 3.5.4 is devoted to a short discussion of this topic.

These specifications and recommended standards can and will have an enormous effect on the viability of the ATN concept, affecting capacity, performance, and the ability to integrate ATN infrastructure into built urban/suburban environments.

[13] For seated passengers.

The principal point to be realized here is that standards deriving from human factors are based on the interaction of people with particular designs. Comparisons to standards developed for other types of systems, while useful and informative, have their limits. Actual utilization of such standards can both help and hurt the actualization of new system architectures.

Efforts are under way to revise the APM standards to expand their application to ATNs. Project constraints prevented a detailed inquiry as to those efforts, however. It remains uncertain as to the focus and extent of this effort and the impact it will have relative to the Airport project, especially given that the CPUC General Orders will be the governing factor.

The topic of the effect of human factors-based standards on ATN system design generally is discussed in more detail later in this report.

2. Performance Verification:

The related issues of design maturity and verification were the only portions of the RFI that were emphasized, yet very little information on these topics was provided. Several items are apparently being suggested as sufficient proxies for evidence of design maturity and verified performance:

a. The existence of small test tracks and initial deployments

b. The development of independently reviewed analytical "safety cases," otherwise known as Failure Modes, Effects, and Criticality Analyses or FMECAs

c. The use of "off-the-shelf" commercial components

While each of these is extremely useful, they are neither individually nor collectively a substitute for the necessarily extensive testing that must be carried out in order to establish the performance envelope and margins for any system.

a. From what is known about existing test installations and deployments, they exercise very limited aspects of the overall ATN system architecture being proposed by the development community. This is a completely expected situation, given that ATNs are a work in progress. It is mentioned here to make the City aware of the limitations that exist relative to the verification of higher-performance systems that are closer in design to the fully realized ATN concept.

   The development community is very clear about this, but its discussion in the RFI responses is unlikely to resonate with other than the technical reader. The important point to note is that the development community has explicitly told the City in its RFI responses that the City must account, at a minimum, for the schedule associated with a type of verification effort that is required for an acquisition of conventional systems. If more capable ATN systems are found to be necessary, additional development-level verification efforts will be required.

b. FMECAs can be thought of as roadmaps or blueprints for subsequent design and verification efforts, particularly in regard to safety. However, like actual blueprints, they are not the fully tested thing itself. They are used as a tool to help understand the many ways a complex system can fail and to focus design and verification efforts to mitigate failures.

FMECAs are solid evidence of a point mentioned earlier that the development community is conversant in well-established and effective methods that are used to help ensure development success. The community also points to the independent review of their analyses by reputable organizations and refers to the testing that has been carried out. However, neither the FMECAs, the independent reviews, nor a sufficiently thorough description of verification test or their results were provided in the RFI responses. No assessment can therefore be provided to the City relative to the applicability of verification work accomplished relative to its unique needs.

c. The use of off-the-shelf componentry, especially to establish confidence in the maturity and reliability of a new system, is what essentially amounts to another analogy that must be used with care. Off-the-shelf components are obviously designed for general and other applications and, more importantly, for operating environments that might or might not match those of the new application under consideration. The engineering world is strewn with project setbacks resulting from the use of components insufficiently screened relative to their verification heritage.

   As an aside, a similar situation exists relative to general performance requirements in which plans to use off-the-shelf components frequently evolve into custom design efforts that similarly result in project setbacks.

   Once again, the point is not to suggest this as a showstopper or to suggest a lack of awareness on the part of the development community; this situation occasionally trips up the best engineering organizations. The intent is to make the City aware of it as a potential issue affecting project risk and to note that a thorough independent review of component heritage is a matter to be accounted for in later project stages.

3. Veracity and Maturity of Performance Estimation Methods:

   a. Stations:

      As noted in Section 3.3.1, the analytical method used for preliminary network layout and sizing treats stations as a resource of essentially unlimited capabilities. Station performance will obviously have limits, so it is crucial to understand what they are.

      There are a good number of station design possibilities. Linear stations and their variants, in which vehicles queue up one behind the other in a first-in/first-out manner similar to that of a regulated taxicab stop, have been examined extensively over many years. A limitation of this arrangement that is frequently noted is that passengers slow to board a vehicle in a downstream berth will hold up vehicles in upstream berths that *are* boarded and ready for departure.

      Some in the development community have proposed an alternate class of station configurations that are intended to eliminate the “blocking” nature of linear queuing stations (e.g., taxicab stops). Looking very much like the familiar angled parking for automobiles, the theory behind them is to “decouple” (i.e., make independent) in-station vehicle maneuvers from passenger loading/unloading activities. Thus, loaded upstream vehicles are able to back out of their angled berths and then proceed, bypassing vehicles in downstream berths.

Some have drawn from this the conclusion that station throughput is a linear function of the number of berths—twice the number of berths, twice the capacity, etc. In actuality, competition between both arriving and departing vehicles for room on the station siding limits capacity. A new form of blocking has been introduced and moved to the siding. This new blocking in addition occurs not infrequently as for occasionally slow-to-board parties, but regularly, as each vehicle must always complete this maneuver.

An investigation of this topic was therefore undertaken with the expected result that station performance does in fact level off relative to the number of berths when the newly created interdependencies are taken into account. Depending on the control assumptions made, the results will vary, but beyond about five or six berths, no additional capacity can be had.

In addition, a nonintuitive side effect was illuminated by this analysis that makes perfect sense in hindsight: Average in-vehicle wait time increases as the number of berths is increased. If vehicles are blocked along the station siding by others backing out, this is of course experienced by passengers as a delay. The more vehicles blocking the siding, the more delays any particular vehicle will experience.

For the Airport project, this does and does not make a difference. For the low-demand stations, this configuration will perform in the manner promised by the ATN concept: very reasonable nonscheduled wait times. For the high-demand stations at Terminal A and B, however, performance can be marginal depending on the particulars of various other design parameters. In these cases, Aerospace proposed and investigated an alternate concept that may have the potential to eliminate this barrier and to simultaneously mitigate and even improve upon certain other important technical issues. This is discussed in Section 3.10.

b. Network:

As discussed earlier in Items 1, 2, and 3 in Section 3.4.2.2, critical operational characteristics underlying the value of the ATN concept are often inaccurately portrayed based on certain presumptions involving the behavior of networks. This extends as well to claims regarding capacity. Perhaps more than any other claim made about ATNs, common estimates of ATN capacity are fraught with factual and logical flaws. Some of these have made unfortunate appearances in the RFI responses.

This is a complex topic which is discussed later in this report. Suffice it to say that average line capacities are likely to realistically fall within the 35 percent to 45 percent range of theoretical maximums in terms of vehicles and in the range of 10 percent to 20 percent in terms of passengers, depending on the particular design and assumptions that are made.

Similar to the issue of station performance, this does and does not make a (technical) difference with respect to the Airport project. For the majority of the service area, demands are so low that traffic will actually be lower than these more realistic allowable values. In the higher-demand portion of the Airport service area (i.e., direct service between the two Terminal stations), the alternate system architecture of Section 3.10 could potentially overcome these network performance limitations.

A perhaps more important and natural question the City might have following from this result is: Does this negate the entire ATN concept? The answer is: not at all. ATNs, if properly executed, have obvious merits and can serve as part of a larger family of interoperable systems[14], potentially catalyzing significant overall improvements in transportation efficiency. ATN concepts can also be applied to a number of conventional systems, enhancing their performance even if standing alone.

The question likely to be of most importance to the City in terms of the Airport project and beyond is whether the benefits will justify the costs and risks. There is a long way to go to obtain an answer to this question, as will become apparent upon further reading.

4. Control Communications Integrity:

   There is very little that can be said about this topic at present other than to caution the City that this deserves deeper investigation. The RFI responses indicate a general approach to control communications via wireless transmission. There are means far too numerous to mention here in which wireless transmission and its various protocols can be attacked or interfered with, even inadvertently. Even the proximity of the Santa Clara leg of the network to Airport ground radar is a potential concern. Once again, the assessment is limited by the amount of detailed information that the City was able to acquire via the RFI process. To provide firm assurance, a thorough investigation is required, including items such as a ground radio frequency field strength survey, if it hasn't already been conducted for some other purpose.

5. Vehicle Design and Performance:

   a. HVAC and Auxiliary Power Requirements:

      Cabin heating, ventilation, and air conditioning (HVAC) are the perennial bane of electric vehicles. The power required to drive an on-vehicle HVAC subsystem can be of the same order of magnitude as that for propulsion, cutting range in half and increasing fleet sizes for battery-powered vehicles.

      The RFI responses touched only very lightly on this topic. Vehicle ranges, for instance, were not listed as a function of HVAC loads, nor were fleet size issues discussed. In ATN systems based on battery-powered vehicles, air conditioning cannot be considered a relatively low-cost option: The reduction of range means the purchase of additional vehicles in order to have a sufficient number of charged vehicles on hand in order to service peak demand.

      Battery-powered ATN vehicles do have the advantage over their conventional automobile brethren of being able to frequently "plug in" when at stations, thereby providing an opportunity to power HVAC at a maximum rate as well as charge batteries. Some discussion was provided in the RFI responses relative to such "pre-conditioning"

[14] A system of systems is one in which each system must function so that the overall system will function. A family of systems is one in which each system operates along with others (hence the term interoperable) to provide greater capabilities and perhaps greater efficiencies, but each system can also operate in isolation, providing independent value deriving from its own unique set of capabilities.

methods pioneered by electric vehicle researchers. Nevertheless, this remains a very uncertain topic relative to current ATN designs. No information was provided relative to recharge rates and range as a function of HVAC loads.

Lacking detailed information, Aerospace asked the National Renewable Energy Laboratory to estimate HVAC and auxiliary power loads for incorporation into a total power requirement rollup for an Airport system. The results of this effort are presented in Section 3.7.

The results confirm the general nature of the HVAC issue, quantifying it with respect to the Airport application. To the knowledge of the author, this represents the first total-system, first-principles estimate of HVAC power requirements for a specific ATN application.

b. Design and Propulsion:

These two topics are presented together because they are inseparable with respect to Newton's second law: the famous f = ma. That is, the force (and therefore power) required to move people is, of course, directly related to the mass of the people, their luggage, and the vehicle. The most important parameter is the mass of the people relative to the mass of the vehicle. This is why it is hard to beat the bicycle in terms of sheer efficiency. As another example, a longtime ATN researcher has noted that the most reliably efficient current form of practical all-weather, long-distance, and operationally flexible ground transportation is the vanpool[15].

In their current initial (re)incarnation, ATNs are both relatively underpowered and weight inefficient. The former is important as it directly affects maneuvering ability (and thereby capacity), the amount of infrastructure devoted to maneuvering, and, potentially, passenger perceptions of value related to performance. The latter is a factor in these issues as well, but is of even greater importance as its effects will cascade down into other measures of ATN value such as energy usage and infrastructure size (i.e., operating and capital costs) and revenue opportunity. A simple comparison as shown in Table 3.4-1 illustrates the "weight efficiency" of current ATN designs in relation to the current generation of compact electric automobiles[16] and the APM vehicle once considered for use at the Airport: that is, how much "stuff" is required to move a given weight of passengers and luggage (i.e., payload, assumed here to be 200 pounds). This is important because the stuff quite obviously has to be moved as well.

Table 3.4-1 Vehicle payload/empty weight comparison

	Average maximum payload/vehicle empty weight	**Average operational payload/vehicle empty weight**
"Typical" ATN Vehicle	0.35	0.10 (1)
"Typical" Compact Electric Auto	0.22	0.07 (1)
Airport APM Vehicle	0.63	0.31 (2)

(1) 1.3 passengers/vehicle average
(2) assumed 30% load

[15] No effort was made to independently verify this result for the purposes of this project, but it seems reasonable taken at face value and is useful for illustration.
[16] Note: Limited production sports versions were excluded from this comparison.

Based on reported seating capacity, current ATN vehicle designs have an edge over contemporary electric automobiles but are a little over half as weight efficient as the selected APM vehicle even at its lowest-rated maximum occupancy (i.e., as shown in the first column of values). If the average occupancy of ATN vehicles in actual operation is 1.3 passengers per vehicle—a very plausible value for the most common articulation of ATN operations—the ATN edge over the electric automobile is considerably reduced and ATN weight efficiency drops to a third in comparison with an APM vehicle, even if the latter were operated at 30 percent of minimum rated occupancy.

As will be discussed later in this report, and as confirmed by everyday experience regarding automobile gas mileage relative to the proportion of stop-and-go traffic in one's daily commute, a significant contributor to energy requirements is accelerating the vehicle/passenger mass. ATN systems will do a lot of this, especially in applications like the Airport that are small and compact. In cases like this, ATN vehicles will do a significant amount of accelerating and decelerating not only when departing from or entering station but also in transit when transitioning between sections having different nominal speeds slowing for turns, and maneuvering to avoid conflicts at merges. Numerous performance and system sizing metrics such as energy consumption and fleet size cannot be based exclusively on power and energy consumption figures taken at uniform speed. Even with regenerative braking, this will still be an issue.

Although there are obvious limitations for battery-powered vehicles, much opportunity exists for reducing vehicle weight (and cost). Various degrees of attention have been given to weight minimization across the design community. Generally speaking, however, ATN vehicles are at present limited in this regard due to production volume economics and certain design choices. They are, in general, space and weight inefficient by automotive standards, especially given the fact that ATN vehicles need not have certain automotive safety features such as those associated with side impact, for example. A second important example was mentioned earlier in Section 3.4.2.3: the choice (or perhaps necessity) to have the entire vehicle fleet be ADA-compliant.

The power side of the equation is of critical concern. Current designs seem to be operating in a narrow range of acceptability relative to performance, range, cost, and fleet size consistent with apparently smaller, slower, and lower-demand initial applications being anticipated in the near term. It is unclear without further information and analysis where the limitations of current designs will lie with respect to more extensive, higher performance applications and what plans the development community may or may not have to overcome them. Even the higher-demand portions of the Airport application will represent a challenge.

In the RFI responses, references are made to providing a selection of propulsion options and sizes to suit the application. This is fine for applications that are intended to stand alone, but for highly integrated systems that promise scalability, upgrades are problematic. The City will need to take a long view and make provisions in the near term to accommodate potential expansions. A more extensive engagement with industry will be required to understand the tradeoffs considered in arriving at current design configurations and the limitations of present approaches.

This example also touches on the need to caution the City to avoid viewing ATNs as being defined by a single "optimal" configuration. Just as there is no one automobile or aircraft suitable for all needs, there is no ATN design suitable for every application.

Fortunately, there are promising developments within the development community indicating that contributions to this misconception from this quarter are beginning to be corrected. There is no optimal single definition of ATNs; driving toward one can, in fact, stifle innovation.

6. Guideway Design:

   a. Seismic Stability and Design Codes:

      An ATN system for the Airport application must obviously contend with the seismicity of the San José environs. It is obvious that civil engineering professionals can design a guideway structure capable of acceptable performance during a seismic event. What isn't so obvious is the level of effort necessary to fully explore this issue: the response of the lightweight ATN vehicle/guideway structural system to such an event.

      Seismic design codes and design practices are the culmination of a vast amount of research and experience relative to certain types of structures. Obviously, among these structures are bridges and overpasses for transit vehicles. Conventional transit vehicles are massive in comparison to ATN vehicles, however, and not easily persuaded to leave their tracks. The question arises: Would it be possible for lightweight ATN vehicles to be ejected from the guideway or otherwise fail in a manner harmful to passengers during a seismic event at the Airport? Would an ATN guideway, designed to current "code," preclude this from happening? This question is of particular concern for free-running, rubber-tired vehicle designs but will also be a design case for so-called captive-bogie[17] systems relative to the strength of their undercarriages (or overcarriages, in the case of suspended systems).

   b. Reconfigurability and Forward Compatibility:

      As mentioned earlier in Section 3.4.2.2, although the expandability of the physical and control system elements has not yet been demonstrated in terms of quickly reconfiguring an operational system, developing the means to do so seems a reasonable design objective. Not as easy to envision is the means by which technological advances can be accommodated. This represents a considerable risk to the City, as failure to do so could result in the ownership of a system perpetually limited in its ability to keep pace with increasing demands resulting from service area expansion or from unanticipated demand generators.

      It is not possible to completely avoid this situation, but it is possible to mitigate its eventuality by anticipating its occurrence and specifying a measure of *forward compatibility* in design specifications. The guideway is likely to be the most costly and visible component of an ATN system and therefore is a good candidate for forward compatible design.

      The premise of forward compatible design is to accept some measure of design inefficiency in the present in return for much reduced future upgrade costs. The approach is to establish interfaces that define room for future system elements such that an upgraded system can make use of as much of the existing system as possible. It is identical to the practice of, say, designing an automobile chassis to accept a much larger

[17] "Captive bogie" refers to a design in which a mechanical connection exists between vehicle and guideway.

engine that is still on the drawing board. In the case of the guideway, this could be implemented by accepting a slightly larger physical envelope and defining standard interfaces that would accept future propulsion, power, and/or communication elements or modules.

The City must be cognizant of these issues and account for their resolution in its planning and specifications should it choose to move forward with a physical procurement.

3.4.2.4 Summary: The Technical Nature of ATNs

Common portrayals of a number of ATN operational characteristics are accurate only in rather limited, low-demand, low-performance cases. In general, ATNs do not offer on-demand, nonstop, direct-to-destination service, nor is automation in and of itself a guarantee of high-capacity, zero-congestion performance. Characterizing the realistic performance and scalability of ATNs is a complex topic requiring a fuller articulation by the development community.

Current ATN designs are, as would be expected, low performance and limited production. The technical requirements of the Airport application span a range that could be met in part by existing designs but would likely also require advancement in the state of the art. Especially with respect to potentially even more demanding applications the City might choose to consider, ATN designs will need to progress from their current APM-like roots to more automobilelike designs in terms of their operation and safety features.

A clear articulation of this development path is also required. Currently, it can be inferred that the development community is suggesting that safety measures long associated with conventional rail and automotive systems *both* be eliminated in order to clear a pathway to increased ATN performance. This is perhaps based on the presumption that automation and inexpensive, high-reliability systems can provide adequate measures of safety. This is of questionable likelihood and has not, in any event, been demonstrated thus far by existing designs.

The operations and designs proposed for more capable ATN systems would be unprecedented for a public conveyance. It is not clear what position regulatory authorities and the public would take on the matter nor what level of effort would be required of the development community and third parties. Although the body of knowledge existing for conventional systems can be leveraged to advantage, an effort to extend this to ATNs will be considerable.

3.4.3 State of the 'Value Network'

The term "value network" is borrowed from author Clayton M. Christensen [9]. It is used to describe the collection of participants and the communications and transactions between them that support the development of items of value in the process of innovation[18]. This is a powerful description of the environment spurring innovation because it explicitly identifies *customers* as being a key part of the process. Technology does not get developed in a vacuum. Especially when the items developed, designed, and produced are systems costing several hundred millions—if not billions—of dollars, a

[18] An equally important observation made by the author is that most of what is referred to as innovative *technology* is more accurately described as new *system architectures* based on proven technologies and having very few newly developed items. It is these few items that enable the integration of the existing technologies into the new architecture. This is the case for ATNs, in which the control algorithms are the newly developed item. This, however, is not sufficient in and of itself to guarantee success. Fundamentally, innovations succeed not because a technology (or system architecture) is possible, but because it provides value.

clear articulation of the associated goals, objectives, requirements, and constraints is absolutely essential as one of the first steps in the development process.

With respect to civil systems, local governments and agencies are in a unique position of responsibility for articulating these needs on behalf of constituents and facilitating interactions between local stakeholders. Private-sector developers, while able to suggest how proposed concepts may be of value, are in no position to fully understand *a priori* the complexities of a single significant application, no less those of the vast array of applications that can be envisioned for a new technology. In other words, developers excel at solving problems, but customers must actively engage in their formulation.

This task is vastly different than for applications involving conventional systems. In a development environment, performance capabilities, costs, and the consequent business case(s) and suitability of applications are largely unknown up front. This requires a long-term and iterative engagement. To do otherwise—to expect private developers to deliver fully developed technology and business cases—is not only unrealistic from the perspective discussed above, it is equivalent to expecting that the private sector speculate, putting at risk large amounts of capital developing systems that may or may not be generally acceptable.

This is obviously a much greater concern for large civil systems than it is for the consumer products with which we are most familiar and which drive perceptions about technology development. For these products, individuals are the final arbiters. Relatively inexpensive prototypes can be built and test marketed. ATNs, by contrast, are being proposed as an entire transit system, complete in every respect. Test marketing, unless done under carefully developed and well-managed expectations, is an extremely risky proposition for all parties. After all, under normal circumstances, individuals can only make their desires known *after* a substantial system is installed.

For these reasons and others, it is clear that local authorities need to engage not just in a procurement process but in a preceding development process. This extends as well to the numerous other stakeholders on both sides of the transaction that define the broader value network necessary for both defining and supplying innovative systems. This network is not yet mature with respect to ATNs and is moreover not supported by the existing value network based on conventional systems. That is, the existing value network is not structured to tackle the large systems development issues associated with ATNs.

Municipalities do not and will not have the technical, financial, or risk-taking capacity to lead or underwrite ATN development, but the above role is nevertheless essential. The natural next question to ask is how investment, risk, and rewards *can* be allocated such that development can proceed. This ultimately becomes an issue of development roadmapping and institutional design and is a more fundamental issue than the technology itself. This is discussed in more detail in Section 4.

3.5 Plain Talk about Networks: Operations, Control, Capacity, and Throughput

The topic of ATN passenger-carrying capacity is of undeniable importance, yet it is one of the least commonly understood. Perhaps in response to criticism over this issue, the ATN development community has engaged in a considerable effort to describe the potential capacity of ATN systems. Unfortunately, this is most commonly done by means of simplistic mathematical expressions that are generally inaccurate respresentations of the physical reality of ATNs. Given without qualification, this only adds to the confusion and controversy and can be misleading to those who don't understand the restrictions on their applicability. Throughout the entirety of the RFI responses, for example, only a single reference can be recalled addressing the limitations of these representations and hinting at realistic estimates of capacity.

More accurate representations of ATN reality do exist. They come in the form of complex mathematical algorithms used to perform simulations of ATN applications. However, as these are inextricably linked to closely held proprietary control system designs, they are not generally available and were not made available via the RFI process. Alternative general-purpose and custom-designed third-party simulation algorithms are available and have been applied in a number of recent ATN application studies, but these by definition cannot completely account for the performance characteristics of the various proprietary control system designs. And in no case has any simulation algorithm of a fully realized ATN system had an opportunity to be verified via real-world practice, including an accounting of potential regulatory constraints on operations.

The development community is correct in pointing out that accurate predictions of performance relative to a particular application can only be accomplished via simulation of proposed layouts and in accordance with particular control system designs, something which the community did not have an opportunity to do as part of this evaluation. However, it is also true that ATNs are governed as much by basic network relationships as any other type of network. Discussion of network theory coupled with the use of these simulation tools can be used to generate important general *a priori* insights into ATN performance and capacity useful to evaluations such as this and can do much to illuminate the topic more generally.

Nevertheless, a detailed examination of the simpler mathematical representations is a worthwhile exercise. It can be used to begin a discussion of the overall topic, serving almost as a tutorial to introduce certain concepts and terminology. It is also useful in helping to explain the importance of certain technical and regulatory issues, the applicability of advances in related transportation research, and the demystification of the more technical discussions associated with network theory and simulations. This section is devoted to such a step-by-step discussion. It will be found that the capacity of ATN systems in their hoped-for fully realized form will be much lower than that implied by the simple mathematical representations.

For the nontechnical reader, the following material will seem, as it is, a bit complicated but not especially onerous. The arguments can be followed ignoring the math; the physics and key operational characteristics of ATN vehicles are based on daily experience and should be no problem at all. At the conclusion of the discussion, the reader will have a deeper appreciation of the jobs ATNs must do, their promise and their limitations, and what it all means in terms of the Airport project.

3.5.1 The Basic Line Capacity Equation

$$Line\ Capacity = 3600 \div Headway \times Vehicle\ Capacity \times \%\ Vehicles\ Occupied$$

Equation 3.5.1-1. Basic ATN Line Capacity Equation

The above-named equation for line (or loop) capacity[19] is one of the principal basic equations underlying a key claim made for ATNs: that their ability to move sufficiently large numbers of passengers is such as to warrant their development, construction, and operating costs. It frequently appears in promotional and technical literature and in online discussion blogs. As this argument factors into the consideration of using ATNs at the Airport, which would require that the City arrange for the expenditure of likely several hundred million dollars in capital costs and several million dollars in annual operating costs, it is worthwhile to examine this equation in considerable detail.

The line capacity equation will be deconstructed bit by bit, each of its factors examined in detail. Figure 3.5-1 is a section-by-section roadmap of this deconstruction. The factor of 3600 is easily explained here; it is the number of seconds in an hour and is used to convert the time interval between successive vehicles, expressed in seconds for closely spaced ATN vehicles, to the more useful result of an hourly capacity. Each of the remaining terms on the right-hand side of the equation will be discussed first. A discussion of capacity and what it means in terms of ATNs is reserved to near the end of the section, where it will be seen that calculating the capacity of an ATN is not as straightforward as Equation 3.5.1-1 indicates.

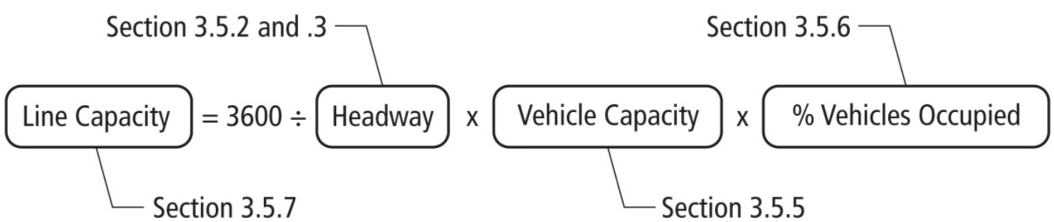


Figure 3.5-1. Line capacity discussion roadmap.

3.5.2 Headway: Time, Speed, and Distance

Headway is a commonly used term in transportation planning, most often describing the *uniform frequency of arrivals between vehicles* at some particular point—a bus stop or train station, for example. When multiplied by the passenger-carrying capacity of each vehicle and a conversion factor so that the terms of the equation can be expressed in familiar units, the passenger-carrying capacity of a *line* (i.e., a stream of vehicles) is obtained. This is precisely the situation described by Equation 3.5.1-1 with the factor of 3600 used to convert capacity per second (via the headway term, which is expressed in seconds) to hourly capacity. To clarify the units involved, Equation 3.5.1-1 is repeated below along with the units for each of its terms:

$$Line\ Capacity\left[\frac{seats}{hr}\right] =$$
$$3600\left[\frac{sec}{hr}\right] \div Headway\left[\frac{sec}{veh}\right] \times Vehicle\ Capacity\left[\frac{seats}{veh}\right] \times \text{Vehicles Occupied } [\%]$$

Equation 3.5.2-1. Basic Line Capacity Equation with Units

[19] In terms of seats available per unit time, as distinct from the similar equation for vehicles available per unit time listed on page 27.

The units abbreviations used in Equation 3.5.2-1 are self-explanatory. Note, however, that the passenger-carrying capacity of each vehicle is expressed not in terms of passengers per vehicle but rather in terms of seats per vehicle[20]. It follows that line capacity is expressed in terms of seats per hour as opposed to passengers per hour. While this may appear to be a nuance, it's in fact very important and, as indicated in Figure 3.5-1, is discussed further in Section 3.5.5.

The % vehicles occupied factor is unique to ATNs. This refers to a *limited* percentage of vehicles on the line (i.e., in the stream) that *can* be occupied, which implies that some *must* be *unoccupied*. As also indicated in Figure 3.5-1, this will be discussed more fully later on in Section 3.5.6.

Returning to a focus on headway, the reader is reminded that the term is most often used to describe the *uniform frequency of arrivals between vehicles*, typically at stops or stations. With ATNs, however, and particularly with respect to the basic line capacity equation, headway is used to describe the minimum frequency of arrivals *at any convenient reference point* on any portion of the network guideway, even though the vehicles are not stopping. This is similarly done in transportation planning when describing automobile traffic flow.

Choosing some typical values based on current ATN designs for the various terms in Equation 3.5.2-1 an initial calculation can be made to give the reader a feel for the magnitudes of passenger-carrying capacity being discussed. For example:

$$Line\ Capacity\ \left[\frac{seats}{hr}\right] = 3600\ \left[\frac{sec}{hr}\right] \div 6\ \left[\frac{sec}{veh}\right] \times 4\ \left[\frac{seats}{veh}\right] \times 80\ [\%]$$

$$Line\ Capacity = 1920\ \left[\frac{seats}{hr}\right]$$

Equation 3.5.2-2. Typical Line Capacity Estimate

As can be understood by focusing on the value of headway in Equation 3.5.2-2, ATN technology is commonly promoted as being capable of very high system capacities. Many believe that the value of headway can be made very small—on the order of about one second or less, as is approximately the case for automobile traffic streams. If this were possible, a predicted line capacity of 11,520 or more seats per hour for this example would be the result!

3.5.2.1 Where's the Speed?

For scheduled-service systems in which vehicle arrivals occur at a constant rate, using headway is a simple and convenient way of calculating line capacity. But when discussing ATNs, it tends to mask some very important concepts. For instance, it may seem strange to nontechnical readers that the *speed* of the vehicle stream doesn't appear in the formulation of Section 3.5.2. Can't capacity be increased by increasing the speed? The answer to this question in the overall sense relative to ATN operations is—yes and no; it depends on how ATNs are ultimately allowed to operate. So, speed *is* a factor, a point which is important to explain. This is done here in an incremental fashion, beginning with some basic concepts.

[20] Note that the unit of passenger-carrying capacity may also be expressed in terms of *floor space*—the actual square footage allotted to an individual passenger—or as a combination of seats *and* floor space. This is frequently done when describing the passenger-carrying capacity of a light-rail or people-mover vehicle. Here, however, *seats* will be used, as the most common conception among ATN designs is that passengers will be seated.

Returning to the example of a bus stop, it is intuitive that arrival rates and therefore line capacity can be increased *either* by increasing vehicle speed or by adding more vehicles or by doing some combination of the two. If vehicle speed is increased for a given number of vehicles, they arrive more frequently; the time period between successive arrivals (i.e., headway) is shortened. If more vehicles are added to a line while maintaining a given speed, the physical separation between them will decrease, also shortening the time period between arrivals. This is shown in Figure 3.5-2 for various cases.

Note that in the first group of cases, both speed and separation distance have been varied, resulting in identical headways and, consequently, identical estimates of line capacity. In the second group, only the line speed has been varied; the separation distance has been kept constant. In this case, the resulting headway decreases as the line speed increases with a constant increase in line capacity. The important point to note is that this increase is the result of an increase in line speed, which, like separations distance, is a more fundamental parameter than headway.

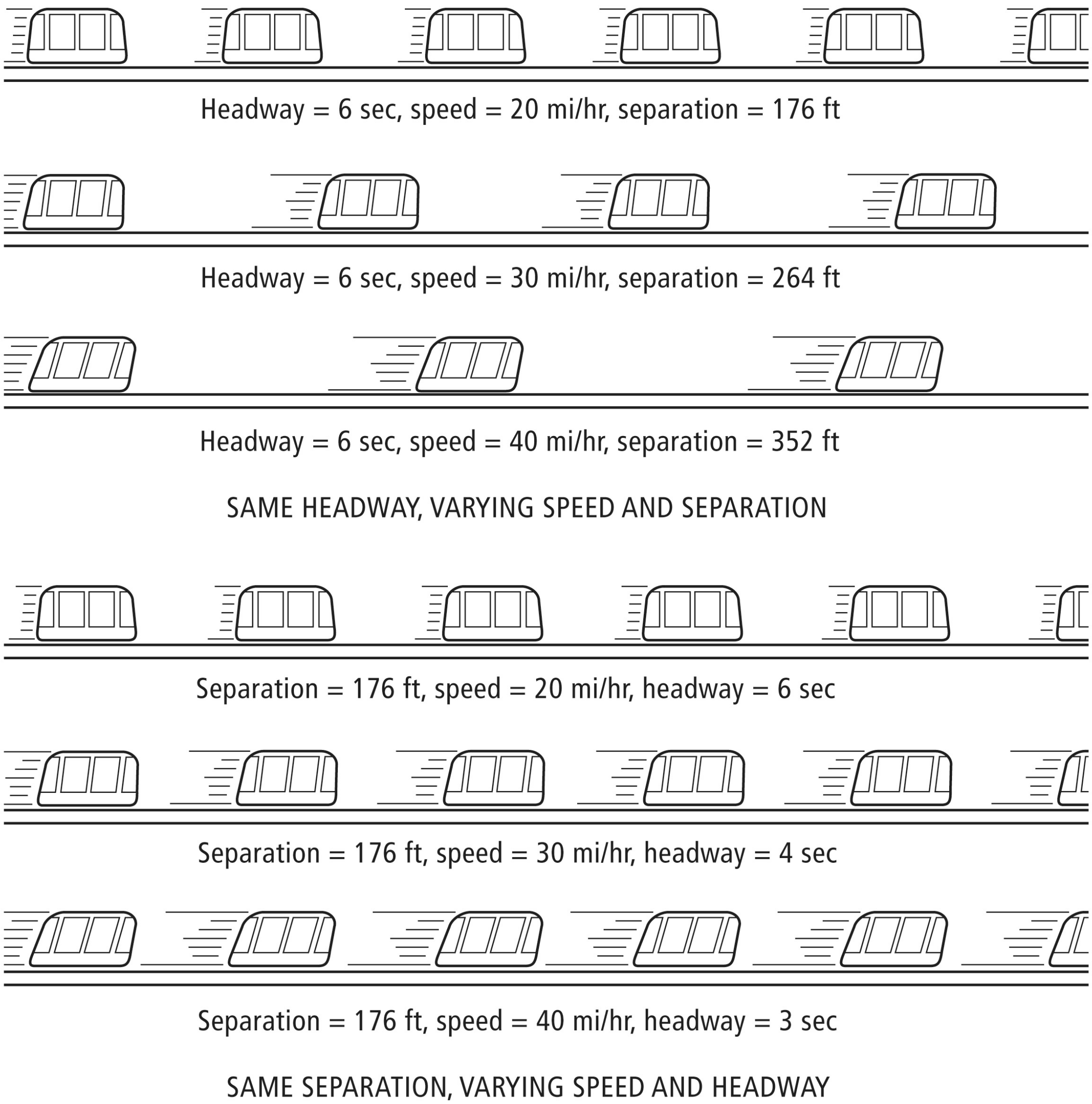


Figure 3.5-2. Relationship between headway, speed, and separation distance.

Speed is therefore hidden inside the headway term, along with the distance separating vehicles. Speed, separation distance, and headway are all related to one another; each can be expressed in terms of the other two. The basic line capacity equation implies selected pairings of speed and separation in a uniformly saturated[21] stream of vehicles, each of which results in the same specified headway. In the following brief section, both speed and distance will be extracted from within headway and used thereafter to discuss and provide a better understanding of ATN operations. It is helpful for discussion purposes to begin by keeping the focus on the relationship between headway and speed, assuming, for the moment, constant separation between vehicles.

3.5.2.2 Headway vs. Speed

Note in Figure 3.5-2, and similar to the definition of headway in Section 3.5.2 as being the frequency of successive vehicle arrivals at an arbitrary guideway reference point, a convenient point is also selected on each vehicle and used to register its arrival at the guideway reference point. The point on the vehicle is also arbitrary but is commonly taken as the nose of each vehicle. Thus, the distance of interest is measured *nose-to-nose* between vehicles and consists of two components: the separation distance between vehicles and the length of each vehicle. Defining distance as having these two components turns out to be an important nuance and will be discussed in Section 3.5.3.

Mathematically, the relationship between headway, speed, and distance is based generally on the elementary physics formula:

$$Distance\ = Rate\ (i.e., Speed) \times Time\ (i.e., Headway)$$

Or, rearranging:

$$Headway\ = \frac{Distance}{Speed}$$

Equation 3.5.2-3. General Headway, Distance, and Speed Relationship

Including both components of distance and rewriting this equation along with selected units, the definition of headway becomes:

$$Headway\,[\text{sec}] = \frac{Separation\ Distance\ [ft]\ + Vehicle\ Length\ [ft]}{\frac{5280}{3600}\left[\frac{ft/mi}{sec/hr}\right] \times\ Line\ Speed\ \left[\frac{mi}{hr}\right]}$$

Equation 3.5.2-4. Relationship between Headway, Distance, and Line Speed with Units

As in Equation 3.5.2-2, a conversion factor is used so that the terms in the relationship can be expressed in familiar units. As was also done using Equation 3.5.2-2, typical values may be chosen for a *constant* distance composed of, say, 200 feet for the *nose-to-tail* separation distance between vehicles and a vehicle length of 12 feet. Here, however, instead of selecting a particular speed and calculating a single resulting value of headway, speed is left as a variable. The relationship between headway and line speed for this *particular* case is then:

[21] Saturated meaning that the separation between all vehicles in the stream is identical; there are no empty "spaces."

$$Headway\ [sec] = \frac{200\ [ft\ ] + 12\ [ft]}{\frac{5280}{3600}\left[\frac{ft/mi}{sec/hr}\right] \times Line\ Speed\ \left[\frac{mi}{hr}\right]}$$

Equation 3.5.2-5. Typical Headway vs. Line Speed Relationship (constant separation)

This relationship is illustrated in Figure 3.5-3, reinforcing the intuitive understanding that as line speed is increased, the time interval between successive vehicles passing any given point will decrease if a constant separation distance between vehicles is maintained.

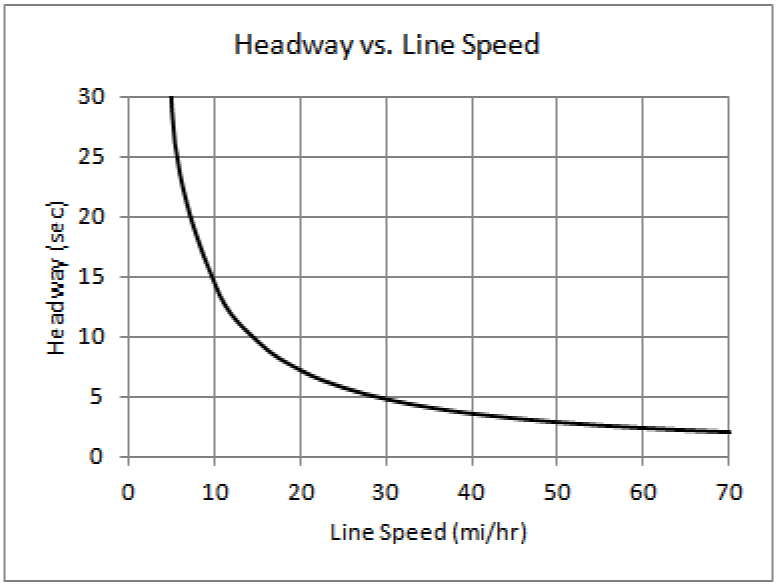


Figure 3.5-3. Time interval between vehicles vs. line speed at constant 200 ft. separation.

By referring back to the basic line capacity equation and the discussion of the previous section, it is seen that line capacity will increase as headway is decreased. Figure 3.5-3 shows such a decrease in headway. Therefore line capacity will increase as speed is increased *if,* once again, *separation distance is held constant*.

Distance cannot be held constant, however. For safety reasons, the separation between vehicles must, of course, be increased as line speed increases. When safety is accounted for, the relationship between headway, speed, and separation distance as described in Equation 3.5.2-4 becomes more complex. The shape of the curve in Figure 3.5-3 changes dramatically. As this can have an equally dramatic effect on capacity, the shape of this *safe headway* curve is of considerable interest. This is the topic of the next section.

3.5.2.3 Safe Headway

As headway is convenient for making basic line capacity estimates, knowing how it varies relative to line speed is important from an economic perspective. From a safety perspective, however, the fundamental relationship of interest is that between speed and separation distance.

Readers know from everyday experience driving an automobile that following a vehicle ahead at a constant separation distance regardless of speed is not the usual case. For safety reasons, drivers increase (or should increase) the separation distance between their automobile and others as speed increases. This extra distance is required to account for the reaction time of the driver in detecting and responding to a slowing vehicle or other obstruction up ahead and to provide enough room for safely bringing the vehicle to a complete stop, if necessary. This same performance requirement applies to ATNs.

Given the relationship between headway, speed, and distance discussed in Section 3.5.2.1, headway can be formulated in terms of this speed-varying safe separation distance. Calculated in this way, headway is known as "safe headway." This can, in fact, be easily expressed simply by revising Equation 3.5.2-4 on page 69, specifying that vehicles trail each other at a safe distance. The result is Equation 3.5.2-6 below:

$$Safe\,Headway\,[sec] = \frac{Safe\,Separation\ Distance\ [ft] + Vehicle\ Length\ \ [ft]}{\frac{5{,}280}{3{,}600}\left[\frac{ft/sec}{mi/hr}\right] \times\ Line\ Speed\ \left[\frac{mi}{hr}\right]}$$

Equation 3.5.2-6. Relationship between Safe Headway, Safe Separation, and Line Speed

It follows that, in order to determine safe headway, safe separation distance must first be understood. The first step in doing this is to understand how quickly and in how short of a distance a vehicle can safely execute an emergency stop.

Although numerous factors contribute to the time and distance required to do this, the physics describing the maneuver is elementary and governed by a few key parameters. All that is needed is knowledge of the times required for detection and response, the maximum rate of deceleration that can be achieved, and, to a lesser but important extent, how quickly the maximum deceleration can be developed, a behavior accounted for by a parameter known as jerk.

There's no need to derive or present the governing equations here. They're well known by the development community, and their results correlate to everyday experience. To begin, imagine a worst-case scenario of a driver/vehicle noticing an obstruction the *instant* the obstruction instantly appears, and responding to it by (safely) slamming on the brakes and stopping just shy of the obstruction, which remains absolutely impenetrable and motionless after its appearance. It is as if a brick wall suddenly popped up in front of you on the freeway.

The values selected for the key parameters noted above are: detection and reaction times of 0.2 second each, a deceleration rate of 19.3 ft/sec^2 (0.6 g), and a value of 64.4 ft/sec^3 (2.0 g/sec) for the jerk parameter. As revealed by the selection of values for detection and reaction times, the driver in this case is robotic. The deceleration and jerk values reveal this to be very much an emergency stop.

The instant of time at which the brick wall instantaneously appears is taken as the time reference value, and is set to zero. Similarly, the arbitrary position at which the vehicle is located at this instant is taken as a distance reference value, setting it to zero as well. The results are shown in Figure 3.5-4 and Figure 3.5-5 for two cases of initial line speed bracketing the value of 24 mi/hr used earlier.

Looking first at Figure 3.5-4, note that for the brief period it takes to detect and react to the obstruction (0.4 second), the vehicle continues moving at line speed. After this period, the vehicle begins to brake and the speed then decreases at a mostly uniform rate to zero and remains there, of course, as the vehicle is stopped. The rounded corners of the curves are due to the jerk parameter. As can be seen, it accounts for an amount of time of roughly the same magnitude as the selected values of detection and reaction times.

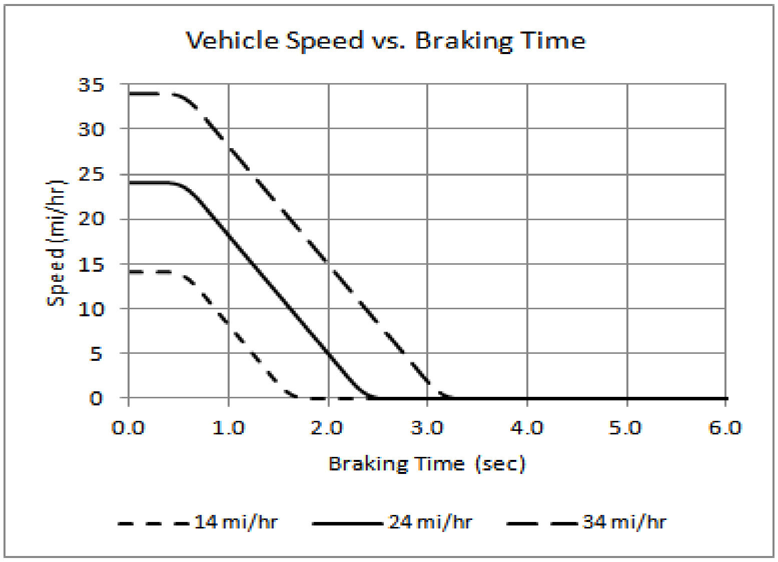


Figure 3.5-4. Vehicle speed vs. time during emergency stop.

As the speed of the vehicle decreases, it covers less and less distance per unit of time. Turning now to Figure 3.5-5, this effect shows up as a leveling off of the cumulative distance traveled until it reaches a maximum value and stays there, again because the vehicle has, of course, stopped.

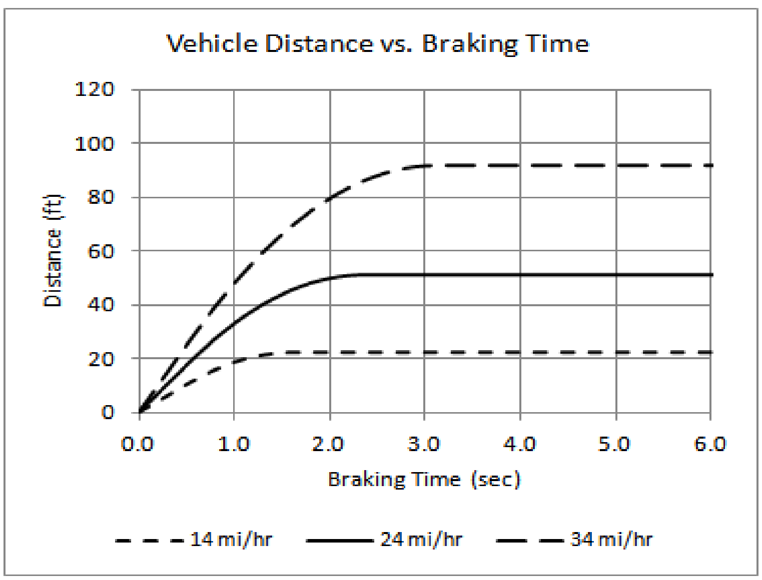


Figure 3.5-5. Vehicle braking distance vs. time during emergency stop.

These figures provide clues as to how much time would pass and how much distance would be covered during this white-knuckle incident given *any* initial line speed. Note from Figure 3.5-4 that the times at which vehicle speed reaches zero are separated by uniform increments (they are approximately 1.8, 2.5, and 3.3 seconds, corresponding to the initial line speeds of 14, 24, and 34 mi/hr, respectively). The distances required to stop are *not*, however, uniformly spaced. As shown in Figure 3.5-5, they are approximately 22, 52, and 92 feet, respectively.

These observations can be collected across a complete range of line speeds of current interest. As the reader can see in Figure 3.5-6, by plotting this collection of stopping times against line speed, it is revealed that stopping time varies linearly with speed; twice the speed, twice the stopping time. The small nonzero time at zero speed accounts for the sum of the robotic detection and reaction times, which are constant regardless of initial speed. The nonlinear behavior at low speeds (in this case, below approximately 1.5 mi/hr) is again due to the jerk parameter.

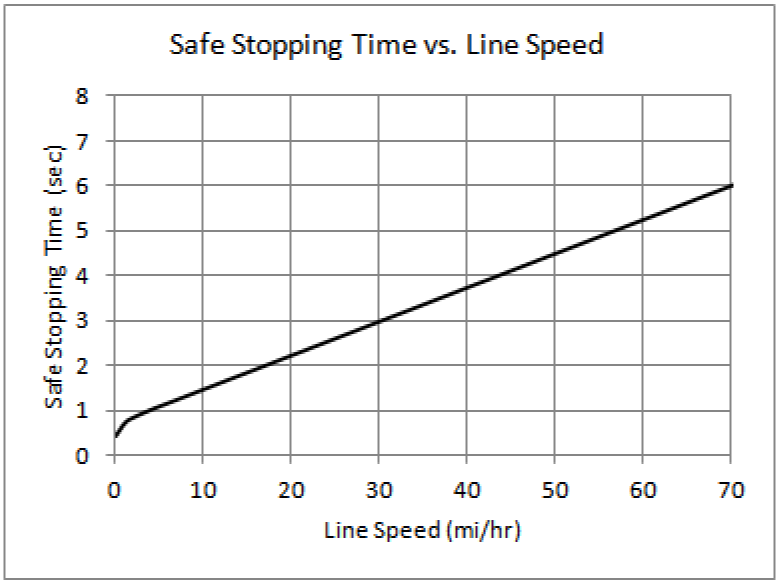


Figure 3.5-6. Safe stopping time vs. line speed.

Unlike stopping time, stopping distance increases in a nonlinear fashion with respect to line speed; ever greater increments are required for uniform increases in speed as shown in Figure 3.5-7.

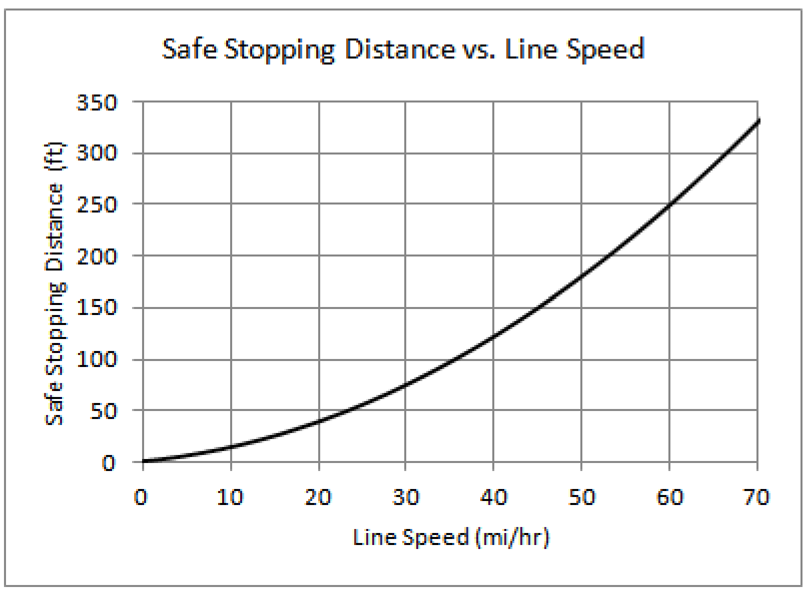
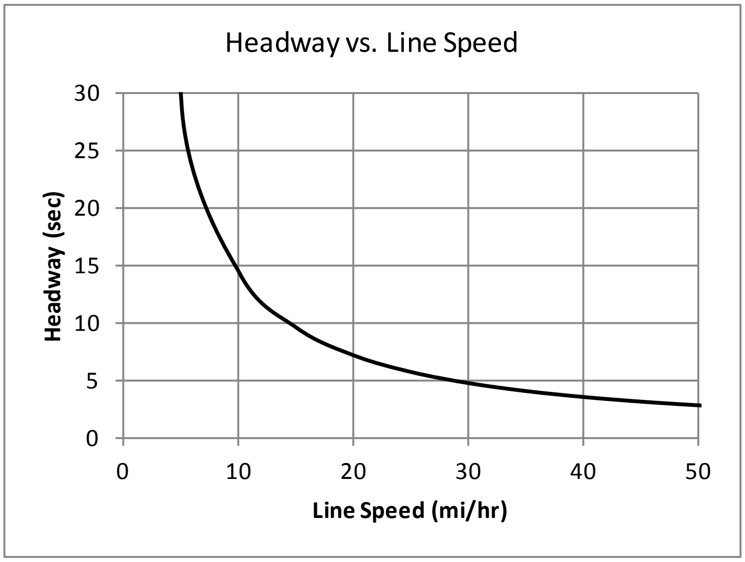


Figure 3.5-7. Safe stopping distance vs. line speed.

Figure 3.5-7 contains the complete range of safe stopping distance values to be used in the equation for safe headway (Equation 3.5.2-6 on page 71). The reader is now asked to recall from Figure 3.5-3, repeated below for convenience, how headway varies with respect to line speed at a constant separation distance.



By including the fact that *safe* separation distance is *not* constant relative to line speed, a curve for safe *headway* relative to line speed can now be generated. This is shown below in Figure 3.5-8.

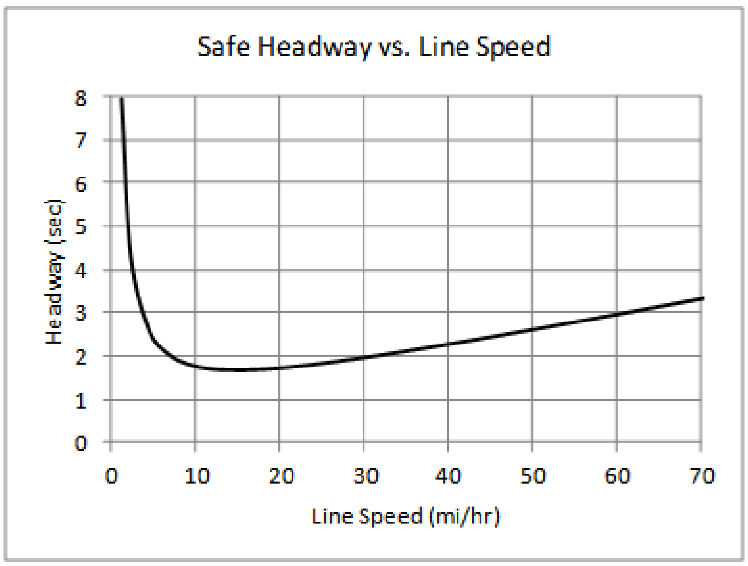


Figure 3.5-8. Safe headway vs. line speed.

This curve is well-known in ATN circles and is referred to here as the "J-curve." It shows the combined effect of taking into account the nonzero length of the vehicles, which is responsible for the curve's rise at low speeds, and the necessary increase in separation due to increased stopping distance as speed increases, which is responsible for the less dramatically increasing headway at higher speeds. Together, these effects result in a pronounced "dip" that forms the "J." The curve remains fairly linear above this point as vehicle length becomes an increasingly smaller fraction of nose-to-nose separation distance[22].

[22] As is the case for headway based on a constant separation distance between vehicles, safe headway tends toward infinity as line speed approaches zero. The shape of the curve at low speeds is a mathematical construct, however, due to the definition of headway based on nose-to-nose separations and finite vehicle lengths. The fundamental behavior of note is that safe tail-to-nose separation, as defined here, approaches zero as speed decreases. More important to note is that slow-speed operation presents a special control situation. This topic has not been fully explored in ATN literature.

This completes the discussion begun on page 66 about the basic physical relationships between time (safe headway), speed (line speed), and distance (safe separation) in the context of ATN line capacity estimates. Note that this has been a very elementary discussion for the purpose of establishing some fundamental concepts and terminology prior to an exploration of the basic line capacity equation. In actuality, the concept of headway is of limited usefulness when discussing ATNs, as the fundamental parameters underlying headway—speeds and separation distances—may be varied considerably across a network and at different times depending on the control approach. Nevertheless, headway is an important part of the ATN lexicon and is used in many arguments relative to ATN performance.

Attention is now turned toward using this understanding to explore the "performance envelope" of ATNs; i.e., what they may or may not be able to do—a matter, obviously, of considerable importance to both the Airport application and the overall business case of ATNs.

3.5.3 Safe Headway in Operation

The matter of safe headway is one of considerable import relative to ATN technology. As a matter of fact, since the conceptual equivalent of a suddenly appearing, immovable brick wall is represented in well-established regulations pertaining to railways and APMs worldwide, the issue has long been one of considerable controversy in the world of ATN development. In the context of these regulations, the assumption used above for the purpose of discussion is referred to rather infamously as the "brick-wall stop (BWS) criterion."

In this section, the limitations and practical implications of the brick wall criterion are discussed:

1. Current ATN designs operate at very safe headways. If using only the basic line capacity equation as a guide, considerable margin exists that could be used to decrease headways and thereby increase capacity. Even the assumption of a brick wall or other massive object suddenly and unexpectedly appearing does not represent an obstacle to safe operations. That is, current designs don't operate anywhere near the brick wall criterion.

2. The case is generally made that considerable *further* margin could be made available if the brick wall criterion could be replaced with one of a more "realistic" nature. There are also promising recent developments in automotive research that are demonstrating the types of technologies that would be required to take advantage of such a change.

3. There are, however, practical considerations associated with these latter observations which are likely to constrain the City's options, at least in the short term:

    a. The brick wall criterion should be considered the current baseline requirement for an ATN system in California, as it is elsewhere. The City will therefore need to either accept it as a permanent limitation, evaluating the business case accordingly for both the Airport and longer-term applications, or to assume a positive outcome of the regulatory process that will be required to change the criterion.

       The legal and sociopolitical differences between public and private conveyances require that a careful and conservative approach be taken by regulatory authorities. It is likely that a significant and lengthy effort will be required before advantage can be taken of the latest cutting-edge technological advances.

    b. Even if the brick wall criterion *were* to be relaxed, it is found that the issue may turn out to be largely moot. A replacement assumption will have to be agreed upon, and if one critically examines the effects of a range of possible replacements, the benefits of a change may be fairly marginal, despite the selection of a more physically realistic assumption. The argument will boil down to one of defining and responding to potential system failures.

3.5.3.1 Safe Headway in Operation I: Room for Improvement

Current ATN designs are being operated at limited headways quite a bit higher, and therefore line capacities quite a bit lower, than the "J-curve" suggests would be possible. Of crucial interest are the implications of this difference in terms of the simplified guideway capacity estimate. To examine this, the curve from above is redrawn in Figure 3.5-9 along with a select value of headway representative of current operations.

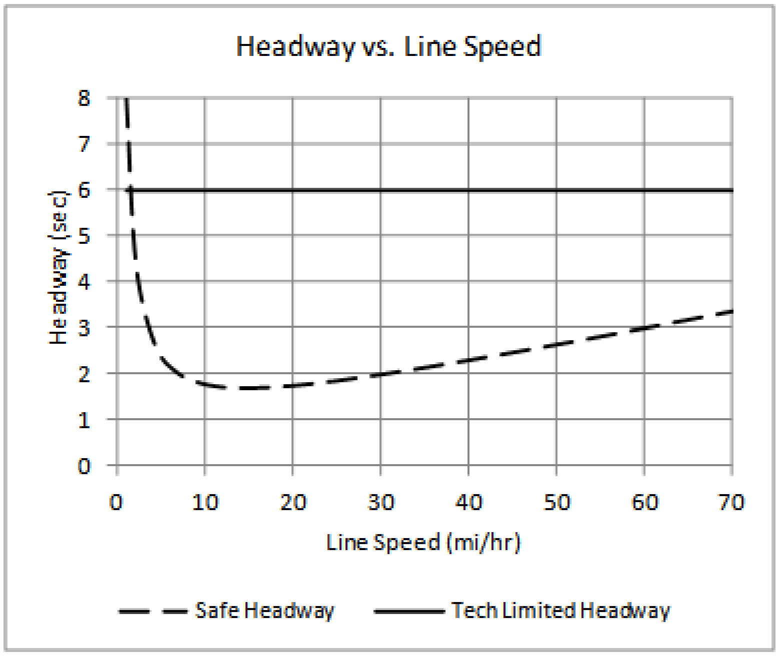


Figure 3.5-9. Comparison of safe and typical current headway.

The difference is obviously dramatic. The first item to note is that over a range of line speeds of near-term practical interest, current ATN designs operate at headways, and therefore separations, *far* above the levels at which safety would be a concern. On the other side of the coin, however, current operations represent a significant limitation with respect to maximum line capacity.

To quantify this, one need only briefly return to the simplified guideway capacity estimate of Section 3.5.2 on page 66. Substituting for the headway value of 6.0 seconds used in Equation 3.5.2-2 a value from the above plot (~1.8 sec) corresponding to the same line speed value (24 mi/hr) used earlier, the guideway capacity estimate can be recalculated:

Table 3.5-1. Capacity for Current and Safe Headway Operations

Simplified Line Capacity Estimate		
Operational Scenario	**Headway (sec)**	**Capacity (seats/hr)**
Current Typical Operations	6.0	1920
Potential Operations with BWS	1.8	6400

So, in the particular case chosen to illustrate the discussion, a line capacity *three times greater* could be had if this estimate were representative of actual operations—and this is based on what is at face value an ultra-conservative operating mode intended to account for the presumably unlikely scenario of a brick wall or similarly massive and immovable object suddenly appearing on the guideway.

3.5.3.2 Safe Headway in Operation II: More Room for Improvement

The reduction in headway and increase in capacity would be even more dramatic if the notion of the brick wall were to be eliminated. If the rather reasonable assumption is made that a failed lead vehicle would decelerate at a rate other than the infinite rate implied by the brick-wall stop criterion, it would travel some distance down the guideway before coming to a stop, allowing a trailing vehicle to travel closer to it during normal operations. The magnitude of this additional margin is indicated in Figure 3.5-10. The curve labeled 0.6 g in this figure was produced using the same set of parameters as that for the similar curve presented earlier (Figure 3.5-7 on page 73) with the exception of the delay times, which were set to zero. Figure 3.5-10 includes a second curve, produced by using a value of 0.8 g for the vehicle deceleration rate and a value of 10 g/sec for the jerk parameter. If the latter set of values were associated with a failed lead vehicle and the 0.6 g, 2 g/sec values were associated with a trailing vehicle undergoing a more controlled emergency braking maneuver, it is seen that the lead vehicle would travel a distance equal to nearly two-thirds of the safe stopping distance of the trailing vehicle. This distance can be *subtracted* from the safe stopping distance such that the nose-to-tail separation between *pairs* of vehicles can be greatly reduced.

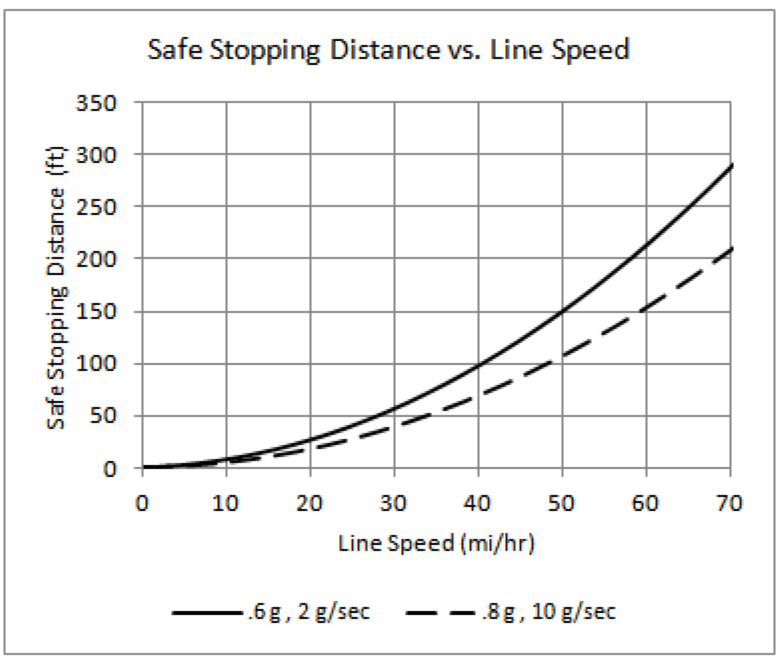


Figure 3.5-10. Stopping distance vs. line speed and deceleration rate.

The situation is easily pictured by referring to Figure 3.5-11, which depicts the two scenarios of emergency braking. The key to understanding the issue is to recognize that the trailing vehicle behaves identically in both scenarios upon detection of a failure in the lead vehicle.

In Scenario 1 on the left, the brick wall interpretation of the safe stopping distance regulation is shown. The first frame depicts the "brick wall moment" in which a lead vehicle comes to an unexpected and instantaneous stop and morphs into a brick wall. Note that the brick wall appears coincident with the rear bumper of the vehicle it has just replaced. This event is signaled to or noticed by the trailing vehicle and, after a slight delay to account for any reaction times or latency in the control system, it applies its emergency brakes (or emergency braking force, if accomplished by the same system used for normal braking operations). The vehicle therefore slows rapidly as it closes the gap between it and the brick wall. This is shown in frame 2. In frame 3, the vehicle has come to a safe stop just shy of the brick wall. Note that the diamond-shaped hash marks represent the nose-to-nose separation between vehicles.

In Scenario 2 on the right, the vehicles are initially separated by a much shorter distance, indicated by a new set of hash marks. The lead vehicle, although it has suffered the same sort of major failure as in Scenario 1, does not turn into a brick wall. Thus, in frame 1, everything appears to be normal. Immediately after frame 1, the lead vehicle slows at the much less dramatic rate of 0.8 g and continues down the guideway. In frame 2, the locations of both vehicles are shown at the same instant in time as depicted in the Scenario 1 counterpart. Note that the location of the trailing vehicle is identical in the two scenarios, but the "real" lead vehicle has not yet reached its final position. Frame 3 shows the final positions of the two vehicles. Note that the positions of both vehicles are identical to those in Scenario 1, the only difference in this case being the replacement of the brick wall with the "real" lead vehicle.

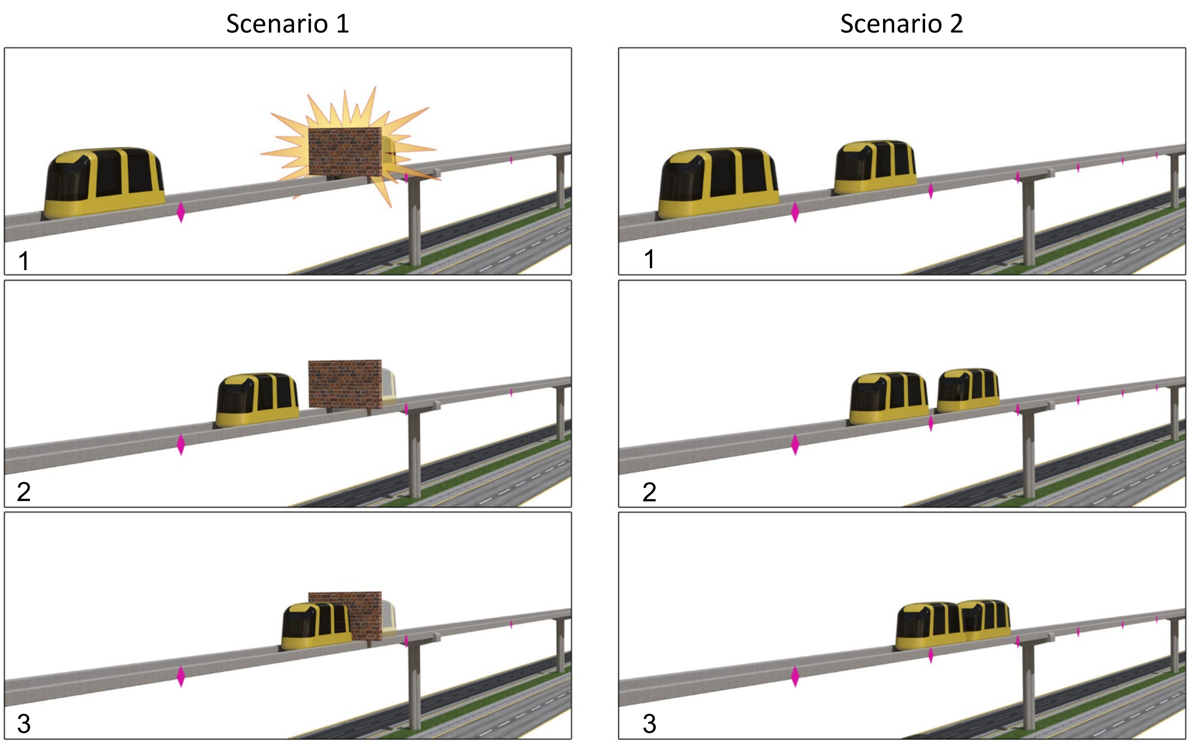


Figure 3.5-11. Emergency stop scenarios.

Recalling the plots of speed and distance versus time for a single vehicle encountering a brick wall (Figure 3.5-4 and Figure 3.5-5 on page 72), the speed and distance of both vehicles during the emergency stop in Scenario 2 are shown superimposed in Figure 3.5-12. Also plotted are the relative (i.e., closing) speed and distance between the vehicles. The figure clearly shows the failed lead vehicle stopping more suddenly and at a greater rate than the trailing vehicle. The relative speed between the vehicles is initially zero as they are both traveling at the same constant speed. The relative speed increases rapidly after the failure of the lead vehicle and before the trailing vehicle reacts. It then increases at a lesser rate as the trailing vehicle begins to slow. After the lead vehicle comes to a stop, the closing speed decreases uniformly to zero at the emergency deceleration rate.

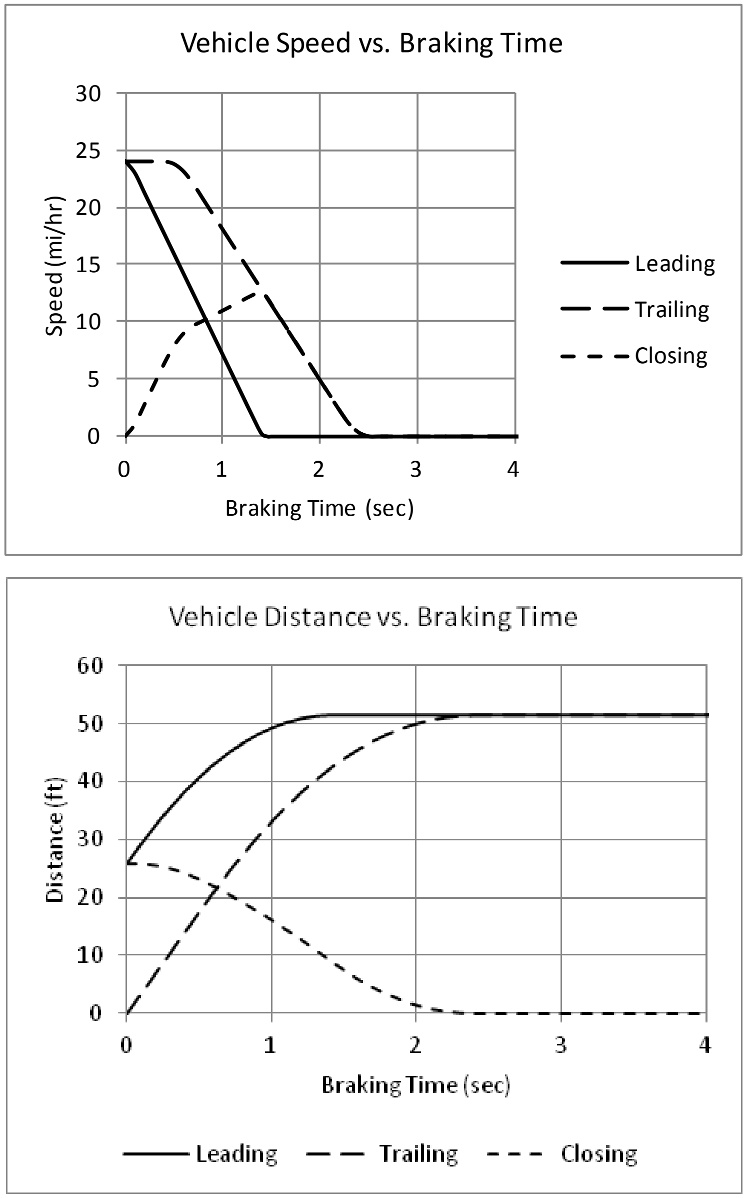


Figure 3.5-12. Vehicle pair speed and separation: emergency stop.

Similarly, the initial separation between the pair of vehicles begins at the safe separation distance (26 feet in this case) and decreases non-uniformly but to zero as the trailing vehicle comes to a stop nose-to-tail with its failed lead.

If the reduction in separation distance allowed by the non-infinite rate of failure deceleration is factored in, a new curve of safe headway can be generated. This is shown in Figure 3.5-13 along with the original curve, now identified as related to the brick-wall stop criterion and its implied infinite rate of failure deceleration.

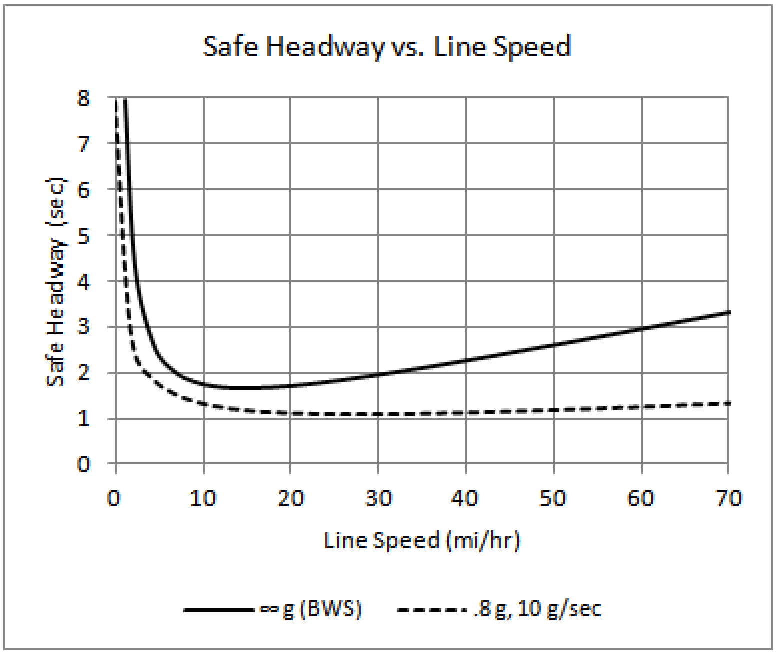


Figure 3.5-13. Safe headway vs. line speed and failure deceleration rate.

Taking now all three values of headway and holding all other parameter values in the preceding sections constant (24 mi/hr line speed, etc.), a complete table of line capacities based on the simplified guideway capacity estimate can be constructed as shown in Table 3.5-2 below.

Table 3.5-2. Simplified Line Capacity Estimate vs. Operational Scenario

Simplified Line Capacity Estimate		
Operational Scenario	**Headway (sec)**	**Capacity (seats/hr)**
Current Typical Operations	6.0	1920
Potential Operations with BWS	1.8	6400
Potential Operations without BWS	1.1	~10500

The City can easily understand why this is a matter of considerable consequence with respect to ATN development. In the particular case used here to illustrate the elimination of the brick wall scenario, the separation distance could be reduced by approximately one-half. After accounting for the length of the vehicle, the nose-to-nose separation between vehicles would be reduced by 40 percent. This would result in an *additional* increase line capacity by a factor of approximately *1.7*—an *overall* increase of *almost a factor of 6* relative to headways typical of current ATN operations!

3.5.3.3 Safe Headway in Operation III: Promising Developments in Vehicle Streaming

Before moving on to other issues associated with the headway term in the basic line capacity equation, the reader is reminded that for purposes of illustration, the above discussion has focused on the behavior of a single pair of vehicles. For practical and economically justifiable operations, of course, streams of closely spaced vehicles will have to be managed.

It is sometimes noted that perhaps an accumulation of reaction times can lead to an unsafe condition in which a vehicle at some point upstream of a failed vehicle will not have enough distance in which to safely stop. From the point of view of nominal (i.e., normal) operations, this is an unfounded concern[23]. There will be an accumulation of reaction times measured with respect to the time at which the lead vehicle fails, but only the individual reaction times are pertinent.

Even if every vehicle in a stream were aware only of its immediate downstream neighbor, each will react in an identical manner whether that vehicle fails or executes an emergency stop. The solitary difference is the deceleration rate of the pair's lead vehicle. For all pairs other than that involved in the actual failure, the emergency rate will take the place of the failure rate in the above calculations.

This leaves only the reaction times with which to contend. These will also be nominally identical for each pair. Thus, if the deceleration rate of every vehicle other than the *actual* failed vehicle is set equal to the nominal emergency deceleration rate, yet another safe headway curve can be drawn. This has been done in Figure 3.5-14.

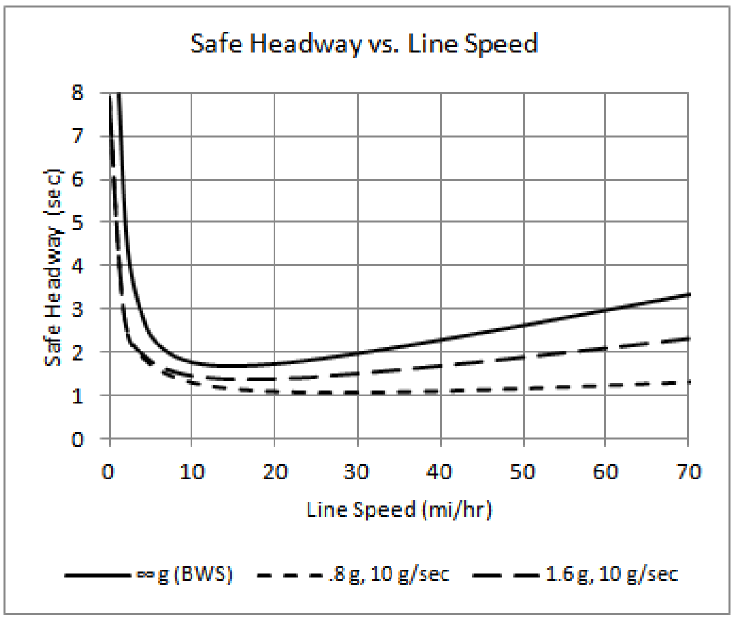


Figure 3.5-14. Headway margin within a stream of vehicles.

As can be seen, the resulting headways are lower still. This does not imply, however, that a system can be *operated* at these headways. Upon reflection, one can see that this additional separation cannot, in fact, be utilized since one cannot know *a priori* which vehicle in a stream will fail. The figure *does* imply that all vehicles in a stream behind a failed vehicle and its immediate upstream neighbor would have not only sufficient distance to stop but would stop well short of each other. In other words, if pairs of vehicles *could* travel closer together by virtue of identical deceleration rates but are *necessarily spaced further apart* to account for failures, then all vehicles other than the one immediately trailing a failed vehicle will have stopping distance *margin*.

An additional measure of conservatism will also be called for by practical limitations of the precision with which vehicles can be controlled. As will be discussed in the following section, as separations

[23] This is assuming, of course, that the system is operated at separations consistent with an absolute maximum failure deceleration rate. This topic is discussed in Section 3.5.3.4.

are made closer to the values discussed thus far only in a nominal sense, the room for error quickly becomes smaller, in some cases vanishingly small.

Sufficiently detailed information regarding failures and failure response in the context of either a single pair or a stream of vehicles was not obtained via the RFI process. Fortunately, there has been a great deal of progress relative to this issue in the automotive field, some of it very recent, in which researchers continue developing and demonstrating sensing/control systems that enable stable streams of vehicles. Research has shown that intervehicle communications between all vehicles within a stream or a platoon, as it is called, is required to maintain precise relative positioning between vehicles. Although this evaluation effort has not allowed for an in-depth examination of these developments relative to the potential need for them in the Airport application or of their performance relative to current ATN designs, this automotive work bodes well from the standpoint of ATN feasibility.

For a good portion of the Airport application (i.e., demand service other than directly between Terminals A and B), this is less of an issue and well within the capabilities of current ATN designs. That is, current designs operate at *very* large headways relative to safely avoiding collisions with a failed vehicle in a stream. A similar case can be made relative to the coordination of vehicles as they merge. Currently, the need for accurate and precise motion control is associated primarily with lateral guidance and for vehicles as they enter a station, in which they will at times be blocked by another vehicle during normal operations. However, for demand service between Terminals A and B, the capabilities that have been and continue to be the subject of considerable research in the automotive world may be necessary. They will almost certainly be necessary for more demanding applications other than that of the Airport.

3.5.3.4 Safe Headway in Operation IV: Brick Walls Now and Forever?

Although not explicitly referred to in these terms, Automatic Train Control regulations as they appear in the CPUC General Orders[24] for the Bay Area Rapid Transit (BART) system can be interpreted as an instance of the brick wall criterion. The relevant language is:

> **(CPUC General Order 127, paragraph 3.5)** *The safe distance separating operating trains shall be not less than the maximum stopping distance of the following train.* The maximum stopping distance shall be determined and make allowances for the effects of grade, propulsion and braking characteristics, equipment reaction time and the pertinent controls affecting the protection stopping distance.

In other words, if the regulated distance between trains can be no less than the maximum stopping distance of a following train given the same types of parameters discussed in Section 3.5.2.3, the lead train might as well have turned instantaneously into a brick wall and the analysis of the previous section would apply.

Beyond the physical impossibility of this, the ATN development community and proponents put forth various other arguments for the inapplicability of such a regulation to ATNs. It is argued that ATNs are so unlike trains or APMs that the criterion is wholly inappropriate. For instance, ATNs aren't intended to stop on a throughline to pick up and drop off passengers, and they shouldn't require the conservatism associated with the relatively massive vehicles of conventional systems. It is in fact argued that ATN vehicles and operations are more similar to that of automobiles and *their* operations, which are not subject to such stringent rules.

[24] CPUC regulations are issued and referred to under the title of General Orders.

Putting aside these latter arguments for the moment, the justification for the technical argument isn't hard to understand. How this will play out is one of several key factors in determining the amount of time and effort the City, the development community, and the regulatory agencies themselves would have to expend in consideration of ATNs. Even more critical, this issue affects the underlying general business case of the ATN concept, which will be a key factor in a determination of any application "sweet spots" and whether or not sufficient justification exists to pursue such continuing development efforts in the first place.

In the previous section, the importance of the brick-wall stop criterion as a limiting factor regarding ATN capacity was discussed. It was noted that its relaxation could result in significantly higher estimates of maximum line capacity, as it would enable the separation distance between vehicles to be reduced at any given line speed in a range of practical transit interest. The brick-wall stop criterion has therefore been viewed as a key barrier to long-term ATN viability.

The totality of the issue involves a complex mixture of reliability and safety engineering, extensive verification testing, and human, sociopolitical, and legal factors as expressed in regulatory form. For the present purpose of examining the basic line capacity equation, a technical focus is kept on the basic motion control parameters associated with ATN operations.

A complete discussion of the topic starts with an obvious, though not commonly asked, question: If not a brick wall, what? On the one hand are the arguments, certainly reasonable, for questioning infinite lead vehicle failure deceleration rates. The effects of doing so are discussed in great detail in ATN literature relative to their effect on capacity. Conversely, the barest of discussion is devoted to the *specification* of a value and the effects of an incorrect specification.

Most discussion centers on the identification of certain presumed worst-case failure modes such as brake lockup for wheeled vehicles, on failsafe design, and on the reliability of presumably analogous systems such as automobiles. This is all relevant from a philosophical point of view, but the arguments are generally and necessarily superficial given the correctly identified fact that the specification of a failure value other than infinite is design-dependent[25]. Many aspects of ATN design—those that can only be known given an actual design—are neglected, especially that of software reliability. The development community has developed failure analyses for their designs that would help illuminate this issue, but these were not shared in the RFI responses.

If uncertainty exists with respect to the *a priori* specification of a maximum failure deceleration rate, then one cannot know if the system is being nominally operated above or below a safe separation distance. Therefore, one must allow for the possibility of collisions.

The question then becomes: What would the safety consequences be of operating at *nominally safe* separation distances *less* than the brick-wall stop criteria but *also* less than that associated with an unexpectedly high lead vehicle failure deceleration rate? In other words, what would happen if the safe operating distances based on *an estimate* of lead vehicle failure deceleration turned out to be not enough? Furthermore, what practical effect would a relaxation of the brick-wall stop criterion in this manner have on the approach to ATN design and operations in the context of an automated public transit conveyance?

The issue of the brick-wall stop criterion was introduced in Section 3.5.3 using particular values of the deceleration rates of both a leading failed vehicle (0.8 g) and a trailing vehicle braking in an emergency maneuver attempting to avoid a collision (0.6 g). The first of these values was selected

[25] This alone makes the regulatory-level specification of an acceptable value of failure deceleration problematic.

because it is commonly used in ATN literature as a maximum value comparable to what an automobile would experience on dry pavement if in a pure skid, its wheels no longer rotating. It has therefore been used as a sort of proxy for the "worst that can happen" scenario for rubber-tired vehicles. It is also in the neighborhood of an acceptable design target to enable the low headways envisioned for economically viable high-performance ATNs. That is, if the lead vehicle failure deceleration is too high, even if very much less that the infinite rate implicit in the brick-wall stop criterion, it will still have a negative impact on maximum line capacity. The second value was chosen because it is the ASCE APM standard value for emergency braking deceleration for seated passengers.

The kinematics of relative motion between a failing lead vehicle and responding trailing vehicle for the situation described above is governed by the same handful of parameters as described earlier in Section 3.5.2.3 on page 70; they depend upon the reaction time of the trailing vehicle, line speed, and the relative magnitudes of the failure and emergency decelerations. Whether or not a collision occurs and, if it does, the magnitude of the collision speed depend on the separation distance prior to failure (assuming constant speed operation at present). For brevity, Figure 3.5-15 describing the general result is presented without derivation. It depicts an interestingly shaped piecewise-curve describing the variation of collision velocity as a function of nominal vehicle separation [24].

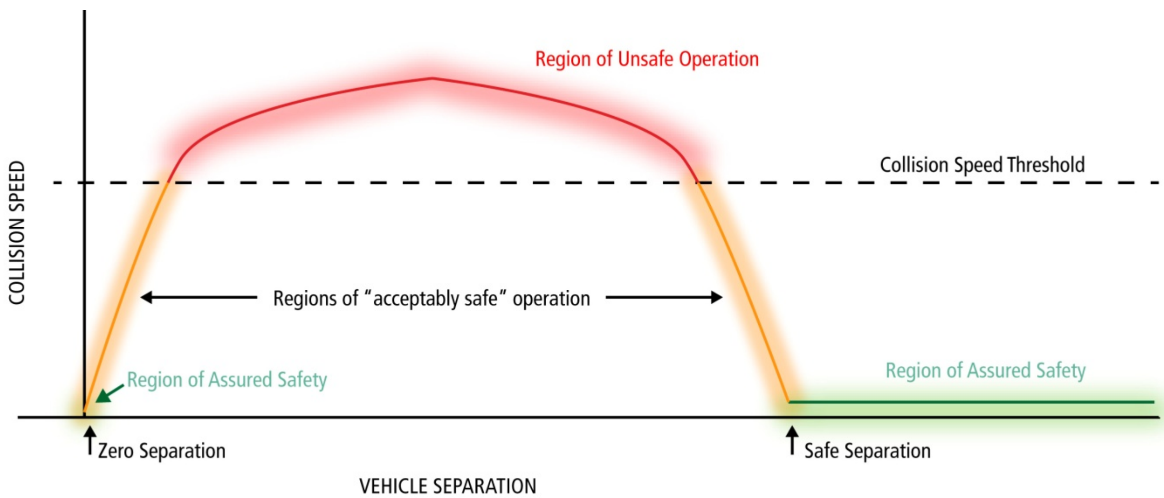


Figure 3.5-15. Typical collision speed vs. separation distance curve.

The figure is highlighted with three aptly colored zones. For a separation distance of zero and for those exceeding the presumed safe separation distance, no collision will occur. At any separation distance between the two limiting values, collisions of varying degrees of severity will occur. Below a certain threshold, a collision can be considered to be safe. Above this threshold, collisions can be quite severe. They can occur at values up to and including line speed—the same as would occur if the brick wall criterion was in effect and emergency systems failed.

This is clearly shown in Figure 3.5-16[26], which nests several curves of the type shown in Figure 3.5-15, using the same single values of emergency deceleration (0.6 g), nominal line speed (24 mi/hr) and reaction time (0.4 sec total) from earlier examples but a number of values for failure deceleration rate, ranging from the 0.8 g used previously up through 100 g. So, for instance, if a system was being operated in expectation of a maximum failure rate of 0.8 g (i.e., at a roughly 25-foot "safe" separation

[26] Introduced here is the terminology: $u_0 \equiv$ initial (line) speed, $a_f \equiv$ failure deceleration, and $a_e \equiv$ emergency deceleration.

distance) and a failure occurred at an unexpectedly high 3.2 g, vehicles would collide at roughly 16 mi/hr.

A second item to note is the steepness of the curves at both leading and trailing edges, more so at their leading edges. *This is an indication of the accuracy with which vehicle positions must be maintained.* For even benign values of the failure deceleration rate, the collision speed quickly ramps up to values that may be unacceptable.

A third and equally significant item of note is how quickly the benefits of operating at safe separations below that defined by the brick-wall stop criterion diminish with respect to modest increases in expected failure deceleration and, conversely, how marginal are the returns obtained from relaxing the criterion. From a value of 100 g, which essentially results in a safe separation distance associated with the brick-wall stop criterion, to a value of 3.2 g, a reduction in separation distance of only about 7 feet is the result.

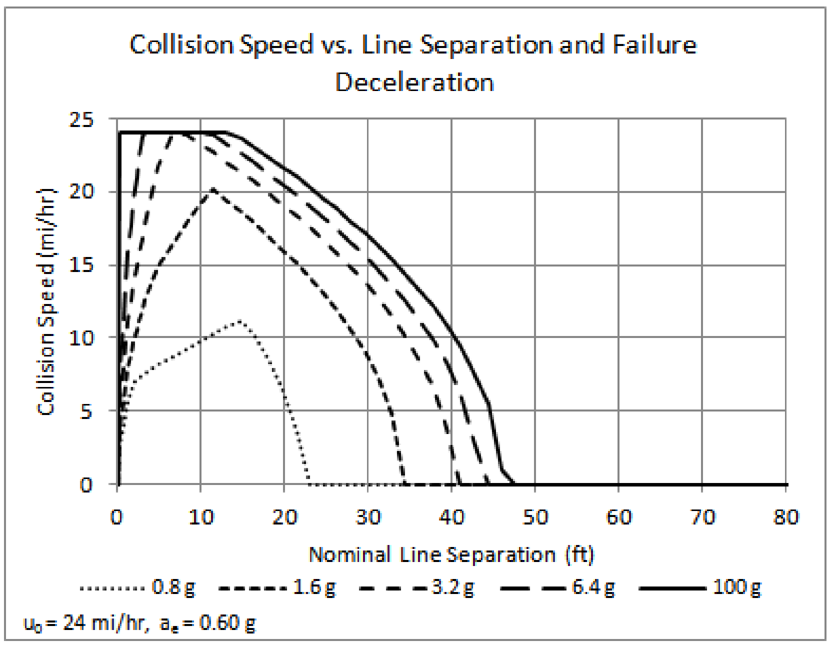


Figure 3.5-16. Collision speed vs. separation distance vs. failure deceleration rate.

This analysis can also be used to examine the sensitivity of safe separation distance and collision consequences of a specified or off-nominal *trailing* vehicle *emergency* deceleration rate. This is shown in the collection of plots in Figure 3.3-17. In each of these, the failure deceleration rate is held constant and various values of the emergency deceleration rate are considered: 0.8 g, 0.6 g, and 0.3 g. Note in particular the sensitivity of safe separation distance to this range of emergency deceleration rates. Although these three values aren't uniformly incremental, one can see the rather large increase in required safe separation distance between 0.6 g and 0.3 g relative to the increase occurring between the two higher values of 0.8 g and 0.6 g.

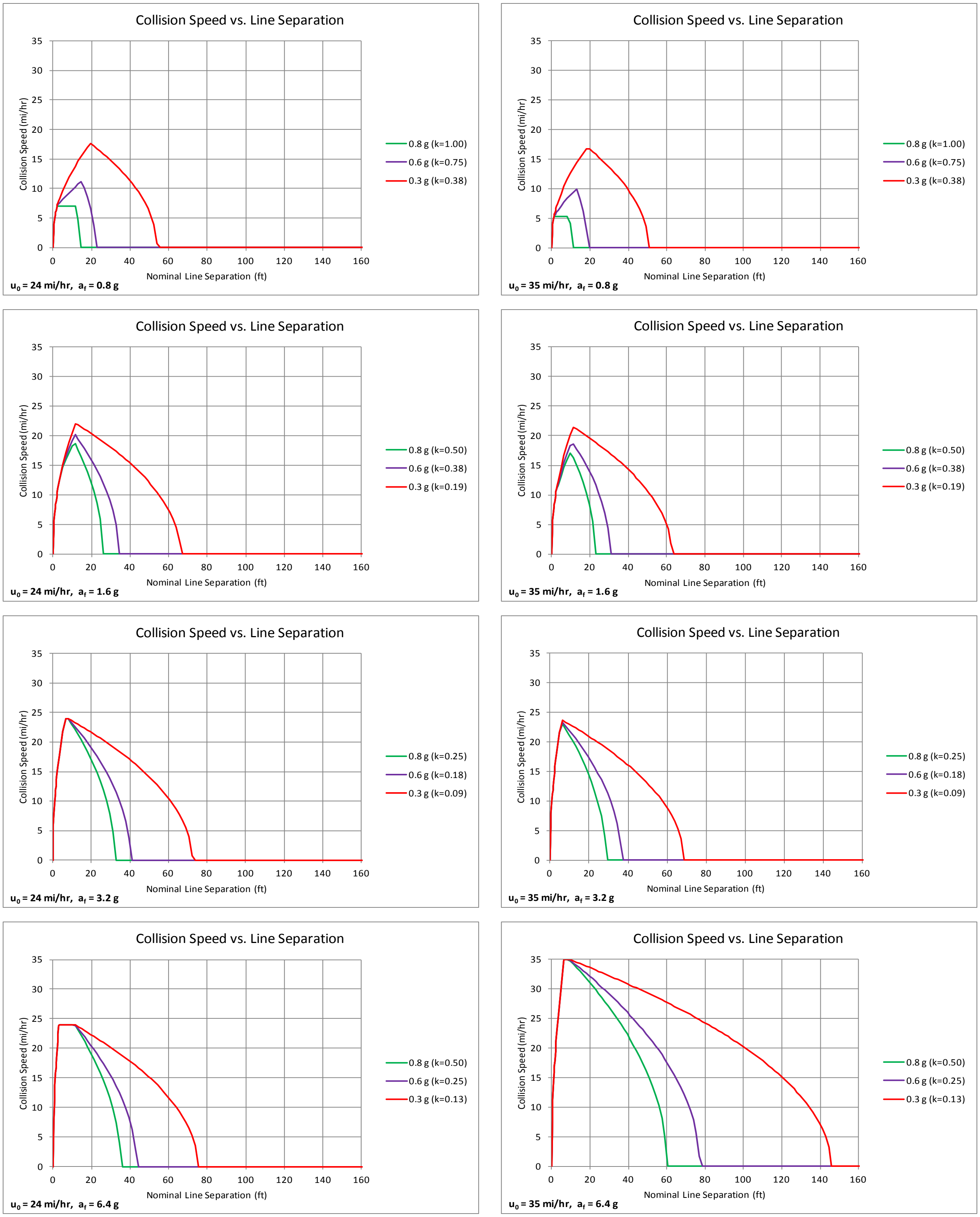


Figure 3.5-17. Collision speed vs. separation distance composite.

To sum up this section, a thorough exploration of the topic of assuring certain operational parameters of ATNs—specifically those governing the relative motion between vehicles in responding to an unexpected failure—must be undertaken as part of the design and regulatory processes. Any uncertainty with respect to these parameters can quickly change the nature of the design problem from one of collision *avoidance* to one of collision *management*. These two problems are of an entirely different nature and will have entirely different regulatory implications. However, as stated earlier, the intent of this section was to introduce the technical underpinnings of this topic. A broader discussion of the additional factors involved and their implications for ATNs are presented in Section 3.5.8.

3.5.3.5 Safe Headway in Operation V: Normal Operational Limits

Limitations requiring headways larger than a nominal safe headway can also arise from normal operations, resulting in tradeoffs between capacity, performance, and infrastructure layout that must be considered in the design process [12]. For example, some have suggested beginning to decelerate for a station stop prior to entering the station deceleration lane. This would be done if space constraints prevented the construction of a lane long enough to accommodate the entire deceleration maneuver. The deceleration rate associated with normal operations such as this would be less than those discussed earlier; a rate of 0.25 g, slightly less than that specified in the ASCE APM Standard could be considered, for example.

One can envision a number of control approaches to handle this particular situation, depending on the operational choices made. If, for example, the desire is to have vehicles travel at as constant a speed as possible for the purpose of passenger comfort, an increase in nominal separation would be required to account for the reduction in separation distance that would occur as the exiting vehicle began to brake. A more efficient approach is likely to be handled on a case-by-case basis, since bypassing stations will be a frequent occurrence.

Slowing down for curves is another common situation in which a reduction in separation would need to be taken into account. In this case, however, a uniform increase in separation distance would be required, since all vehicles would be consistently required to slow down. This situation will therefore be used to illustrate the tradeoffs mentioned above.

Unlike the previous discussions relative to a lead vehicle failure, a trailing vehicle in normal operations would not necessarily detect and react to the slowing of its lead. In fact, in order to safely minimize trip times, vehicles would likely be required to react to fixed guideway markers or other positioning signals to initiate a slowing maneuver prior to entering a curve. Each vehicle in a stream would execute the identical maneuver relative to the guideway, separated in time by a constant value equal to the headway. This is shown below in Figure 3.5-18. The two curves in the figure show speed and distance for a pair of vehicles negotiating a 90-degree, 10 mi/hr curve, assuming a line speed of 24 mi/hr along and an aggressive failure deceleration of 6.4 g. This results in a safe nominal nose-to-nose separation of approximately 52 feet. By measuring along a horizontal line between identical points on each of the curves, the corresponding and rather optimistic value of headway of 1.5 seconds can be seen.

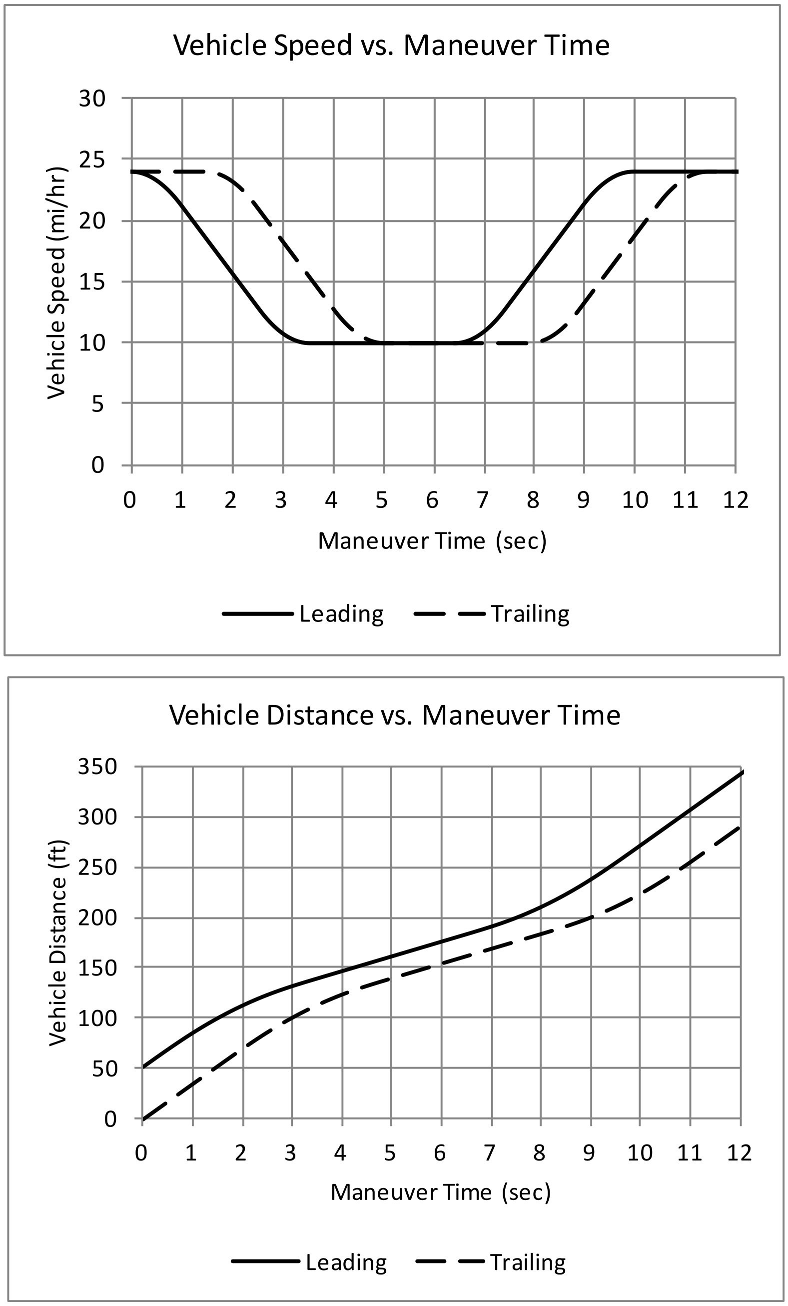


Figure 3.5-18. Two vehicles negotiating a curve.

These plots are repeated in Figure 3.5-19, here including curves for the instantaneous relative speed and separation between the two vehicles that are obtained by taking the difference between the parent curves and adjusting for vehicle length. Again, this is for the case of *normal* operations in which vehicles are traveling at safe separation and constant speed prior to slowing for a turn and the speed profile relative to a guideway reference is identical for all vehicles.

As the lead vehicle begins to slow, the relative speed increases from zero to 15 mi/hr just as the separation is decreasing to approximately 25 feet. An unsafe situation would result should the lead vehicle fail in this zone. Larger nominal separations (i.e., greater headway) would therefore need to be specified to provide the necessary additional margin.

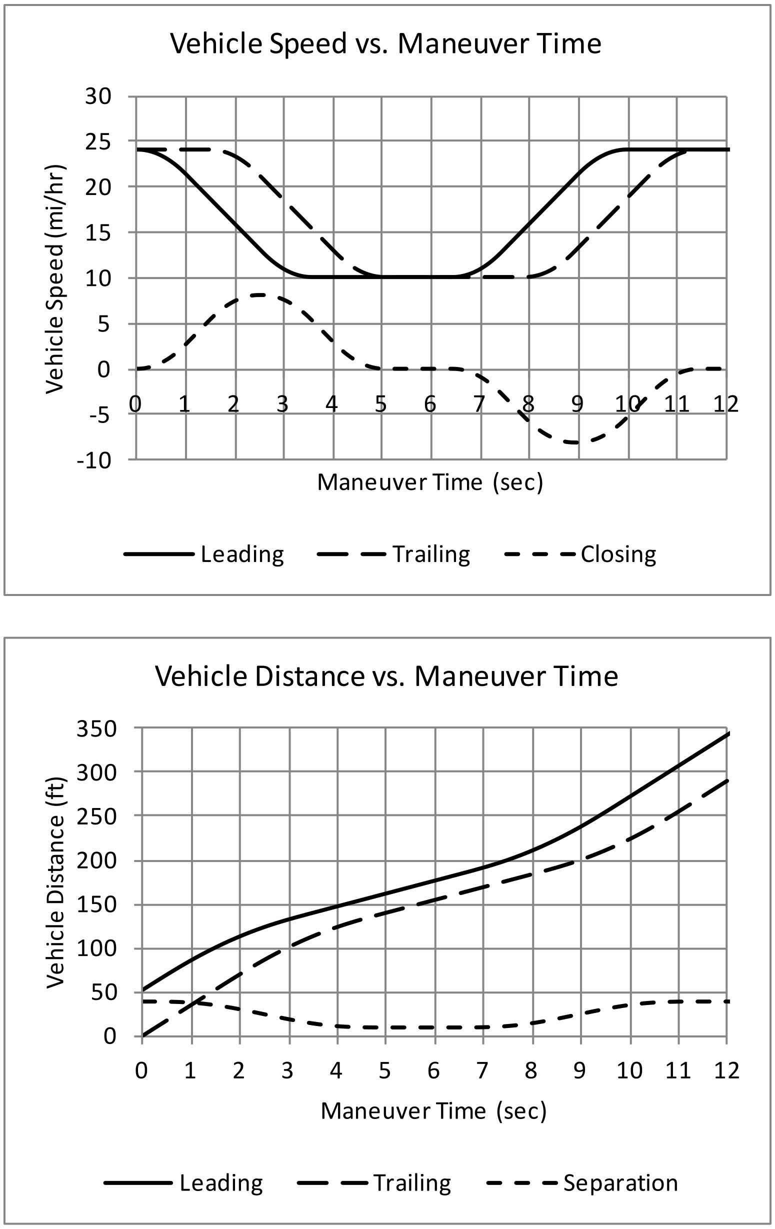


Figure 3.5-19. Instantaneous relative speed and separation.

This situation can also be explained in terms of the previous discussion of the effect of emergency deceleration rates on headway. Lower failure deceleration rates allow closer operating separations and lower headways because a failed lead vehicle travels an increased distance before coming to a stop, leaving *more* distance for an emergency stop of a trailing vehicle. Conversely, it follows that if a trailing vehicle were to regularly encroach into the minimum safe distance separating it from its lead, separation distances and headways would need to be increased because *less* distance is available for an emergency stop in the event of a lead vehicle failure at this moment. This is precisely what happens in the simple maneuver of slowing down for a curve.

As the trailing vehicle slows, the required separation becomes less, increasing again as the vehicle accelerates out of the turn. This separation is plotted in Figure 3.5-20 along with the nominal separation, assuming in this case a less aggressive failure deceleration of 0.8 g. The difference between these two curves is the safety margin between actual and required separation, as shown. Note that a negative margin indicating an unsafe condition exists throughout much of the maneuver. It becomes positive for a brief moment as the lead vehicle accelerates away from the curve. It is zero both before and after the turn, when nominal safe separations are in effect.

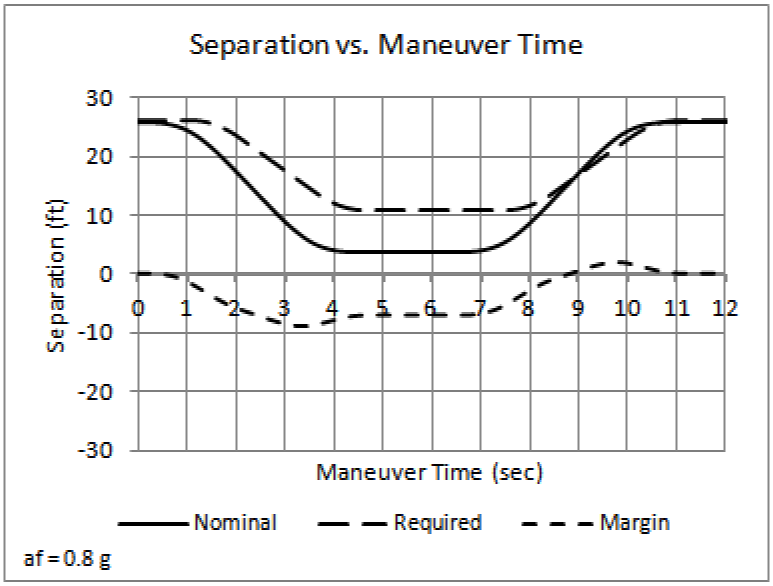


Figure 3.5-20. Separation margin (0.8 g failure deceleration).

Repeating the calculation and plotting the margin results for a range of failure decelerations, as in Figure 3.5-21, illustrates the insensitivity of separation margin to failure deceleration rate. As noted before when discussing collision speeds, there is relatively little to be gained from eliminating the brick-wall stop criterion.

These relationships carry with them significant implications with respect to guideway layout, operations, and capacity. Depending on the control methods used, either the headway of an entire constant-headway system will be governed by its smallest radius curve, or either low- or zero-speed on-guideway queues (i.e., congestion) must be allowed to form in order to safely meter traffic into the curve. Moreover, for a train of vehicles, these queues must be formed in such a way as to maintain a positive separation margin throughout the queue-forming maneuver[27]. The identical issues apply as well to transitions between portions of a network having different speeds.

Although not quantified here for the general case, these relationships impose practical limits on operations and capacity and represent another reduction in estimates given by the basic line capacity equation.

[27] Note that decelerating into a station is a limiting and safer case of queue-forming, as all maneuvers take place on a siding and the relative speed between vehicles is continuously reduced throughout the maneuver. In this case, of course, it is not the failure deceleration of a lead vehicle that must be accounted for but the failure of the trailing vehicle to decelerate.

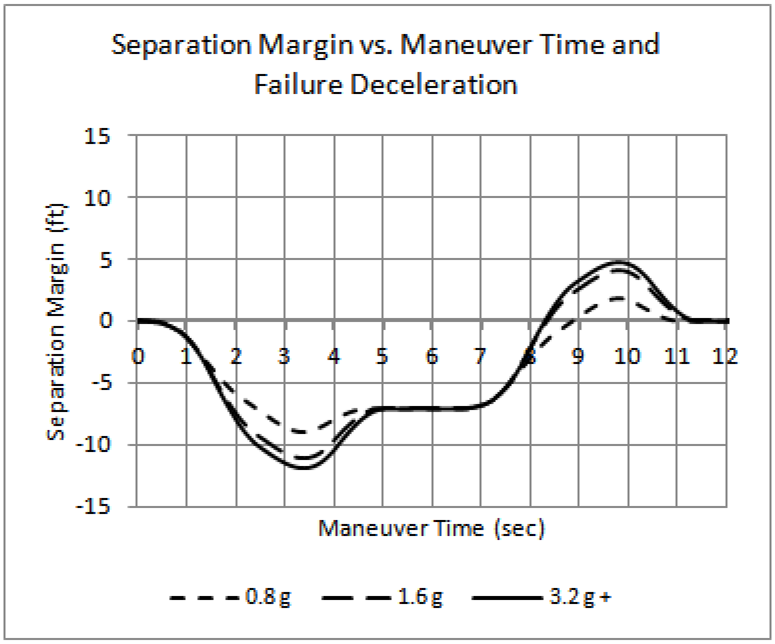


Figure 3.5-21. Separation margin vs. failure deceleration rate.

3.5.3.6 Safe Headway in Operation VI: Summary

- Current ATN designs operate at headways far in excess of that required for safe operations.
- It is better to think in terms of the more relevant factors of speed and separation distance when assessing safe operations.
- Safe separation distances are a function of speed and are an important factor in system capacity.
- Safe separation distances can be decreased by considering the elimination of the brick-wall stop criterion, but this would be problematic from a regulatory standpoint and require a considerable collective effort to achieve.
- An analysis of alternative approaches to defining safe headway (i.e., alternatives to the brick-wall-stop criterion) may not result in significant gains.
- Other factors in the design and operations of ATNs impose practical limits on minimum headway.
- Headway is a more complicated topic than that implied by the basic line capacity equation.

3.5.4 Standard Values

The selection of standard values for certain motion control parameters that govern the operation of ATNs is far from settled. Certain of these values will have what amounts to fundamental limits resulting from human factors, safety, and/or liability considerations. The selected values, the overall system design approach, and the desired business case will all have a tremendous *mutual* effect on each other.

Existing standards developed for other transportation systems can be used to inform the necessary discussion but cannot be used without question; they can simultaneously be too restrictive and not restrictive enough with respect to the operations of ATNs. The lack of clarity regarding this issue is currently an impediment toward the development of a definitive evaluation of the ATN concept and designs. As a result of this unsettled issue, ATNs are also at present suffering a sort of identity crisis; they are currently being designed and operated like trains or APMs but need to be designed and operated more like automobiles—actually, like rather advanced automobiles—in order to even approach the throughputs necessary to underwrite commonly made business-case propositions.

This section discusses the issue of relying on existing standards in some detail, although far from exhaustively. It will use familiarity with ATN operations that the reader has had an opportunity to acquire from previous sections. Two simple examples will be discussed: 1) the selection of nominal and emergency braking deceleration and 2) the selection of maximum allowable lateral acceleration. Other important parameters will be noted and discussed more generally.

The net result is that a likely significant effort on the part of civil transportation agencies, regulatory authorities, professional standards bodies, the development community, and others will be required to develop a satisfactory set—or sets—of standards for basic operational parameters of ATNs. It cannot be assumed that a practical set of standards *can* be found that will support common ATN business-case propositions; other measures of value and other design approaches might be required. And it most certainly cannot be assumed that technological advances will be capable of overcoming all obstacles in this area. Most fundamentally, ATNs are subject to certain laws of physics consistent with their job of moving people. These laws aren't relevant to other networks within common experience—the design of communications networks, for example, or the air-traffic control system. The selection of limiting, or standard, values specifically applicable to ATNs will be a critical factor in the ultimate definition of the ATN concept and its business case(s).

3.5.4.1 Example 1: Nominal Acceleration/Deceleration and Emergency Deceleration

An emergency deceleration rate must be selected that enables a safe stop while allowing the vehicle to remain in control and posing no threat to passengers from becoming dislodged within the vehicle, even if no impact occurs. For illustration purposes, values of 0.25 g (7.8 ft/sec^2) and 0.60 g (18.7 ft/sec^2) were selected in preceding sections for nominal and emergency deceleration, respectively. The latter value is commonly used in ATN literature. It is just below the maximum deceleration limit of rubber-tired vehicles and is also the value specified in the APM Standards for seated passengers. For reasons that will become clear momentarily, the value for nominal acceleration was selected as slightly lower that the 0.35 g specified in the APM Standards.

By comparison, CPUC General Order 143-B governing light rail[28] safety specifies nominal (i.e., service, in the table) and emergency braking decelerations as a function of speed as shown reproduced in Table 3.5-3[29]. Current ATN designs claim capabilities ranging from approximately 0.25 to 0.50 g for emergency braking and approximately 0.13 g for nominal acceleration. Only a single value was reported for nominal deceleration: 0.10 g.

[28] It was not ascertained at the time of this writing if these values were required by the CPUC for recent APM installations.
[29] For a complete definition of terms from this table, see CPUC General Order 143-B.

Table 3.5-3. CPUC General Order 143-B Average Deceleration Allowables for Light Rail

Average Deceleration Rate									
Brake Entry Speed(1)	Service Braking System			Dynamic Brakes Cutout(2)			Emergency Braking Emergency(3)		
mi/hr	mi/hr-sec	ft/sec^2	g	mi/hr-sec	ft/sec^2	g	mi/hr-sec	ft/sec^2	g
55	2.7	3.96	0.12	1.9	2.79	0.09	4.5	6.60	0.21
45	2.6	3.81	0.12	2	2.93	0.09	5.2	7.63	0.24
35	2.5	3.67	0.11	2	2.93	0.09	4.5	6.60	0.21
25	2.3	3.37	0.10	2.1	3.08	0.10	4.5	6.60	0.21
20	2.2	3.23	0.10	2.2	3.23	0.10	3.5	5.13	0.16

Notes:

(1) All tests shall be conducted on dry, level, tangent track for all conditions of loading up to the maximum operating loads as established by the Transit Authority.

(2) The average deceleration rates, when dynamic brakes are cut out, shall be met by the friction brakes acting alone or in combination with the track brakes.

(3) Terminology in original.

Acknowledging the fact that the CPUC values are averages and the APM standard values are maximums, it is apparent that, generally speaking, current ATN designs are most consistent with rail design standards. With the single exception of one system claiming a 0.50 g emergency braking capability, current ATN designs are capable of operating at only a significantly small fraction of APM specified maximums. There is at least one indication in the RFI responses that actual operations may be set at smaller values still. These levels are important indicators of ATN design maturity, a point which will be discussed later.

Conversely, at least one study indicates that the emergency deceleration value of 0.60 g may be too aggressive. This is illustrated in Figure 3.5-22. The data on which this illustration is based is shown in Figure 3.5-23, reproduced from a study on the effects of deceleration and jerk on passenger retention [3, 4] carried out for the Systems Safety and Passenger Security Project and the Advanced Urban Automated Systems Program of the U.S. Urban Mass Transit Administration[30]. In this study, passengers of various heights and weights were subject to various levels of emergency deceleration and jerk in unexpected maneuvers such that the passengers were not able to brace themselves. Clothing and seating materials were selected to be typical of those expected, and tests were conducted for both forward and side-facing seats and with and without a variety of simple auxiliary restraints such as tilted, contoured seats, footrests, and armrests.

[30] Forerunner of the current USDOT Federal Transit Administration.

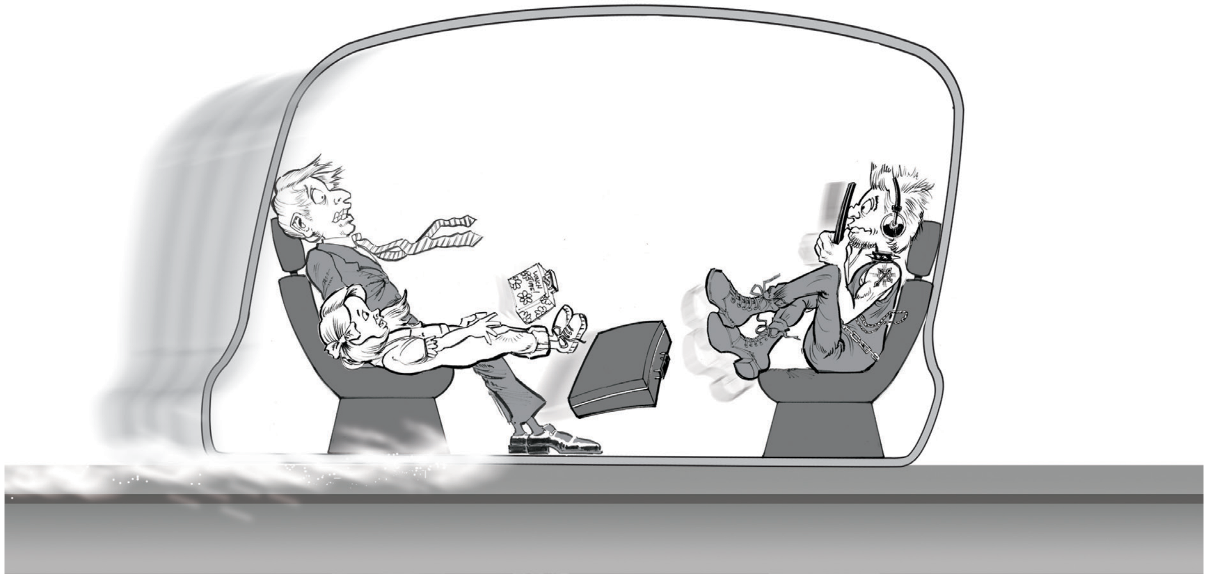


Figure 3.5-22. Safe emergency stop?

The results, taken from the initial study and confirmed by its follow-up, clearly show that a significant portion of passengers will be ejected from their seats at a deceleration rate of 0.60 g. It is only until a deceleration value of 0.25 g is met that nearly 100 percent of passengers are likely to remain in their seats. The value of jerk had no statistically relevant effect on the results up to a value of 1.25 g/sec, the limit of the experiments.

This is a clear example of the need to understand the basis of standards developed for other systems and to question their applicability to ATNs. It is possible, for example, that the value of 0.60 g was derived from calculations of an acceptable probability of injuries occurring over long periods of time based on, what would be for ATNs, a very conservative fixed-block safety system[31] and operations. Or perhaps later research supersedes the results discussed here. It is interesting to note, however, that a value of 0.25 g is roughly consistent with commercial aircraft auto-braking systems, the maximum setting of which is 0.30 g. A full airing of the selection of this particular value is suggested as a near-term effort, but, as will be seen in the continuing discussion below, a comprehensive determination of the full set of values pertaining to ATNs will require a larger and longer-term effort.

[31] A fixed-block safety system is a feature of Automatic Train Control specifications as embodied in CPUC General Orders and elsewhere. It partitions tracks into sections long enough to accommodate the length of a train and a safe stopping distance for a following train under "brick wall" conditions. A train is not allowed to enter a fixed block unless sensors indicate that a leading train has traveled clear of it.

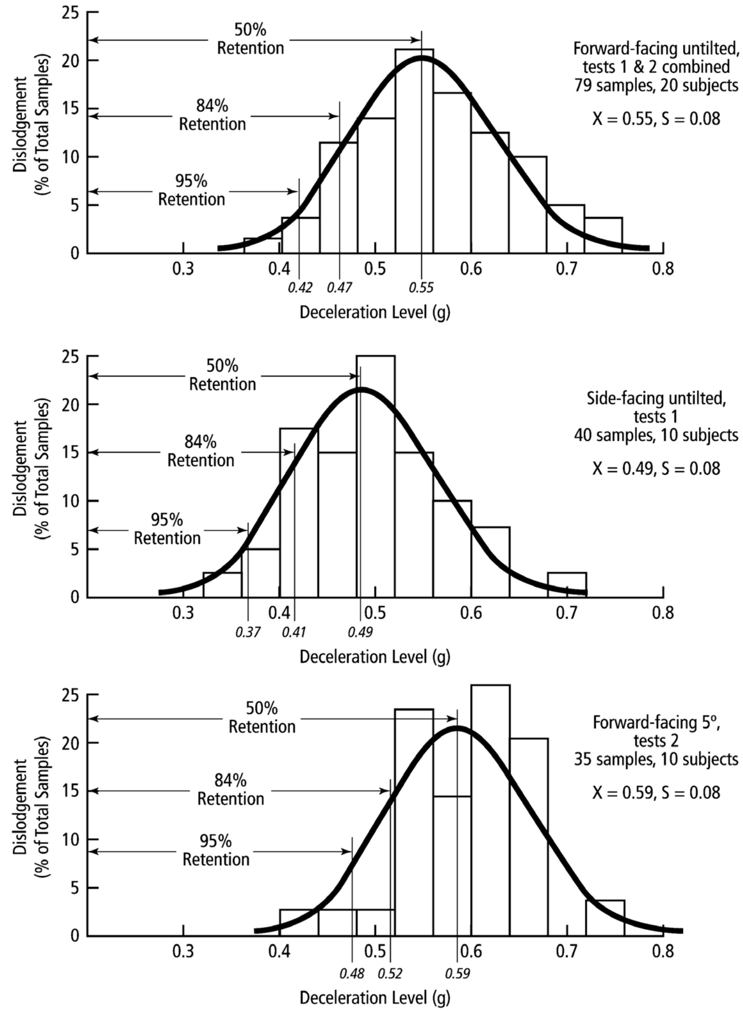


Figure 3.5-23. UMTA study passenger retention curves.

3.5.4.2 Example 2: Lateral Acceleration

A second simple but enormously important example of the proper selection of certain parameter values is that of allowable lateral acceleration. The allowable level of lateral acceleration will have a direct and substantial effect on the compactness and service level of ATNs. Its value will be an important factor for the Airport application.

In this case, standards for APMs and highway design are roughly comparable. The ASCE APM Standards specify a value of 0.25 g for vehicles in which passengers are seated. For highway design, data compiled by AASHTO results in recommendations of lateral acceleration limits that are speed-dependent, ranging from approximately 0.25 g at 20 mi/hr to approximately 0.15 g at 50 mi/hr for "flat" highway curves (i.e., no superelevation or banking) [1].

It has been suggested that the highway design levels are low in relation to the capabilities of modern automobiles. The original investigation into this matter was conducted in 1938 [18]! While the values have been generally reaffirmed by multiple studies over many decades and are prudent to keep in place given the wide range of conditions and driver capabilities associated with the operation of automobiles, it is instructive to put them in perspective and note their applicability to ATNs.

Although expressed in terms of lateral acceleration, the “discomfort” noted by drivers in these investigations does not refer to some sort of intrinsic discomfort with the experience of lateral forces. Readers can (safely!) verify for themselves with the aid of any of several inexpensive smartphone apps that 0.30 g of lateral acceleration is frequently, easily, and comfortably exceeded while pulling onto a main thoroughfare from a stop sign. The same value of longitudinal acceleration can be reached coming to a stop in one’s driveway. Brisk (and legal!) driving on mountain roads can result in double these values, although in the equivalent ATN case, superelevation would be involved.

A close read of the source material indicates that the discomfort mentioned is associated primarily with the perception of the driver’s ability to maintain control of the vehicle. It is based on the complete set of sensations one experiences as a driver, including such factors as body roll, under- and oversteering tendencies of the vehicle, and tactile feedback through the steering wheel—even the number of turns of the steering wheel and the need to reposition one’s hands in order to negotiate tight corners. It also depends a great deal on line of sight and a driver’s estimation of the vehicle’s limit of adhesion under a wide range of weather and road surface conditions. Needless to say, it is precisely these types of variations that are among those ATNs hope to eliminate in order to achieve efficient traffic flows.

Once again, a standard value developed for another transportation system must be used with care if applying it as a design constraint to ATNs. In this case, the value would perhaps impose an unnecessarily conservative restriction.

3.5.4.3 Summary: ATN-Specific Standard Values and Design Paths

These few simple examples illustrate the care with which existing standards must be used in relation to ATNs. It is easily argued that ATNs are unique unto themselves, requiring their own specific set of newly developed standards. Standards based on human factors are especially important. The same motions and accelerations experienced while riding in a 100,000-pound light rail vehicle may be experienced in an entirely different way if riding in a 1,000-pound ATN vehicle traveling at moderate speed on an elevated guideway and perhaps having no visible means of support. The values selected as standards can directly affect public perceptions of value and safety in much the same way that consumers are willing to pay more for automobile performance packages and feel safer in larger automobiles. Thus, standard values specifying minimum as well as maximum acceptable values may need to be considered.

In other words, care must be taken to avoid potential “tunnel vision” arising from too strong a reliance on existing standards as a template for ATNs; all factors specifically relevant to ATNs must be considered. For example, designs that lack low-frequency rocking motions and which impart a feeling of stability or “connectedness” in response to lateral maneuvers and perturbations (as from a wind gust) may be crucial. Brisk acceleration, ride smoothness, and lack of cabin vibration and noise are all likely to contribute to public perceptions of value. Many of these items are covered in existing standards and are being taken into account by the development community but, as is by now clear, need to be evaluated and agreed upon by all stakeholders within the context of the ATN passenger experience.

Along these lines, a principal concern resulting from a study of the RFI responses are certain hints that suggest some sort of human-factors-based limitation that is unique to ATNs. This comes in the form of low reported values of operational longitudinal and lateral accelerations—as low as one-quarter of ASCE APM standards. It is not known, for example, what proportion of the current low-performance capabilities and operations are due to packaging constraints, energy storage, and range limitations or energy efficiency considerations, and what proportion may be related to adverse passenger experiences. It doesn't seem likely but, if true, the latter would impose severe limitations on the overall design and operation of ATNs or require significant redesigns.

One observation that is clear was noted in the opening paragraphs of this section: ATNs are currently being designed like trains and/or APMs, but will likely need to be designed more like automobiles to support the broadest range of applications possible. This confusion in design philosophy is exemplified in the range and apparent uncertainty in the selection of standard values and in contradictory design arguments. On the one hand, it is being argued that the brick-wall stop criterion be eliminated and automobilelike operations be pursued to enable higher-throughput systems. On the other hand, trainlike passenger cabin designs, without passenger restraints, are being relied on as a factor in quick boarding operations. It is apparently being argued by some that critical safety features of both trains *and* automobiles be simultaneously eliminated to make way for ATNs.

ATNs therefore currently stand at what could be a design bifurcation point: A choice will have to be made as to whether ATNs will be most like trains/APMs or automobiles. It may be more desirable, perhaps necessary, to define multiple sets of standards pertaining to variations in ATN design approaches appropriate to different types of applications, even within a single installation. The range of standards and standards organizations relied upon for guidance and definition most likely needs to be broadened. The Society of Automotive Engineers (SAE) will likely be as important to have as a contributor as the ASCE.

Lastly, it is appropriate to pursue the definition of the standards and their values discussed here in the near term; they are not technology-specific and therefore would not inhibit innovation. Based primarily on first-principle human factors and safety/liability considerations, they would apply nearly equally to any of the system architectures currently being proposed for ATNs. The City must recognize, however, that an *a priori* definition of standards risks a forced design philosophy, as discussed above. The alternative is to expect that all standard factors and their values cannot and should not be established in advance.

An appropriate set or sets of operational standards is best developed via an appropriate program of recursive testing—educated trial and error—outside the context of a public procurement. This would not be a trivial undertaking and would involve a variety of stakeholders in order to be most effective. The City and regulatory bodies may not see themselves as being in the standards definition business, but the development of a new breed of transit system, the public acceptance of which will likely be critically based on a proper definition of standards, puts traditional roles in a new light. The City and other authorities hold critical positions within the value network connecting designers with users. A possible means to accomplish some of the necessary testing and to accelerate the sorting out of standards and design approaches is discussed in Section 4.

3.5.5 Vehicle Capacity and Load Factor

As discussed in Section 3.4.2.3 (Item 1.a.), average vehicle occupancy, otherwise known as load factor, is a crucial determinant of ATN system capacity. This factor is not often highlighted in ATN literature. The basic line capacity equation does not include it. Perhaps this is because of the argument that, just as for other modes of transportation, capacity is legitimately described as the ability to hold and transport something. In these conventional systems, demand can either exceed capacity or underutilize it, resulting in the respective ill effects of service delays and inefficient use (i.e., using resources to move empty seats). Shouldn't ATNs be judged by the same standards?

The answer to this seems to be—no. One of the principal value measures of the ATN concept is transit that is personal. The standard measure of capacity should therefore not be how many passengers can ATN vehicles carry but how many they will carry based on the promised service model and other operational characteristics; i.e., on how they will actually be used.

Actual vehicle occupancy is also an extremely important issue from the standpoint of operating and capital costs, as discussed in 3.4.2.3 (Item 5.b.). This topic is pursued further in Section 3.10. For present purposes, the key issue is what value to expect for average vehicle occupancy and its meaning relative to the basic capacity equation. From the ATN literature and observations of how automobiles are used on average, this figure is plausibly taken by many to be approximately 30 percent.

3.5.6 Empty Vehicle Traffic and Its Management

The "percent occupied" factor in the basic line capacity equation accounts for the fact that in the vast majority of cases a portion of an ATN vehicle stream must *necessarily* be unoccupied. This characteristic of ATNs occurs in part as a result of the usual situation in which inbound demand to a station does not precisely match outbound demand at each station. If they did match, each occupied inbound vehicle could be immediately converted to an occupied outbound vehicle. Unoccupied vehicles can remain at stations until needed, but must depart in order to free up berths needed for incoming occupied vehicles. Unoccupied vehicles therefore generally circulate throughout the network, traveling to service demand when and where it arises or simply avoiding conflicts with occupied vehicle traffic.

Empty vehicles in transit must for the most part be accommodated as if they were occupied. Maintaining safe separations from surrounding occupied vehicles, coordinating merges, and managing in-station maneuvers involving mixes of occupied and empty vehicles are each operationally similar to their counterparts involving occupied vehicles. Their presence therefore requires resources and tends to diminish overall passenger-carrying capacity, a fact known since the inception of the ATN concept. A related issue and topic of frequent criticism of the ATN concept is based on the suspicion that, because of small vehicle sizes and the perceived inability to provide enough empty vehicles at the proper times and locations, ATN systems are not likely able to handle surges in demand. ATNs have also received criticism for the large fleet sizes relative to large-vehicle systems that will be necessary, a situation aggravated by the presence of empty vehicles.

Responding to all of these issues simultaneously translates to a need for operational methods that minimize the frequency and distance of empty vehicle movements while simultaneously providing demand-responsive service with as little passenger wait time as possible. Certain measures, collectively known as Empty Vehicle Management or EVM, if effective, could help reduce some of the perceived deleterious operational characteristics of ATNs while maximizing quality of service. A number of commonsensical methods have been proposed for use singly or in combination to help address these issues:

1. Continuously circulate some number of empty vehicles so that they are available nearby when demand arises.

2. Use sophisticated algorithms to concentrate empty vehicle density on portions of the network serving anticipated high boarding demand.

3. As above, retain empty vehicles at stations until required to vacate.

4. Store empty vehicles off the network at strategically placed sidings or in larger-capacity structures. The portion of unoccupied vehicles in transit that are both unneeded and in excess of storage capacity can be considered to be stored in motion on the guideways.

5. Take advantage of potential waivers in operational requirements that would allow closer separation between empty vehicles in transit, thereby freeing up guideway for use by occupied vehicles.

A significant number of factors are involved in optimizing empty vehicle management for a given system, including, of course, the size and connectivity of the system guideways and stations, the levels and time profiles of passenger demand at each station, and the distribution of demand across the network, particularly the degree of asymmetry. Especially for large networks with numerous widely spaced stations and significant levels of demand, providing an adequate and timely supply of empty vehicles that utilize the minimum amount of resources will require a highly sophisticated decisionmaking process at both the design and operational levels. The more sophisticated the techniques, the more complex the hardware and software that will be required for implementation. The cost and practicality of each must be traded off against simpler, albeit less operationally efficient, approaches.

Although much discussed in the ATN community of interest, very little in the way of quantitative analysis and trade studies describing actual EVM approaches and their effects were uncovered as part of this study. The more sophisticated EVM techniques appear to be for the most part cutting-edge doctoral research topics that have not yet had the opportunity to be implemented, an important consideration for the City in its decisionmaking process.

For the purposes of the present discussion, the salient factor is the extent to which the presence of empty vehicles reduces actual passenger-carrying capacity as described by the basic line capacity equation. Due to the high degree of dependency on the factors described above, conclusions both general and specific relative to the effectiveness of EVM techniques in minimizing empty vehicle traffic are difficult to draw without benefit of extensive analysis of actual EVM implementations across a wide range of applications.

Simple demand-based estimates of the proportion of empty vehicles in a traffic stream are common in the decades of ATN literature relative to specific applications and calculated by a variety of methods. Generic estimates can be found in the range of 10 percent–30 percent; a common rule-of-thumb figure is approximately 20 percent. The corroboration between multiple investigations bolsters the credibility of this figure, although a caution is in order relative to its use, particularly with respect to the basic line capacity equation.

The figure is useful as a rule of thumb, perhaps also providing a hint as to fleet size, but it is a *system-wide average* whereas the remainder of the equation applies to the capacity of a *single line*. On any given line at a particular time and for a particular situation, the portion of empty vehicle traffic can range from 0 percent to 100 percent. This is neither good nor bad; it is just the way ATNs operate. This is a function of the asymmetry of demand as discussed in Section 3.3.1.2.

As a refresher example, imagine a spur line such as the line to the North First Street station, which won't see any bypass traffic. Also, imagine that of the total demand for trips from/to the line's only station during the morning rush hour, 75 percent is departing traffic and 25 percent is arriving. Assuming no empty vehicles are held at the station, all vehicles must be supplied via the station's upstream link. Assuming a constant departure/arrival ratio and a total number of departures and arrivals of 100 over a particular time period, the upstream link would carry a mix of occupied and empty vehicles in a 33 percent/66 percent proportion (25 occupied and 50 empty vehicles, respectively). The line downstream of the station would have a 100 percent/0 percent traffic composition (75 occupied, 0 empty).

This fact is important from a transportation planning perspective because to neglect it would lead to erroneous conclusions about the efficacy of ATNs in particular circumstances and possible over- or underestimation of local capacity. For example, presumptions about the inability of an ATN system to supply a sufficient number of empty vehicles to a station may be inaccurate if based solely on the rule-of-thumb figure for empty vehicle traffic. Conversely, the remainder of the basic line capacity equation is not meaningful as a measure of overall system capacity.

Before leaving this topic, a few general comments are appropriate regarding the necessary presence of empty vehicles as a characteristic of ATNs. ATNs tend to draw criticism for this because a certain number of vehicles must be empty *in transit by intent* in order for an ATN system to function. It is argued, conversely, that other forms of transit use vehicles more efficiently because they aren't dispatched until the need for them arises and then have sufficient capacity to handle surges.

However, excess average capacity is characteristic of *any* realistically sized and operated system. If one thinks in terms of seats instead of vehicles, this is obviously true for any conventional mode of mass transportation even under normal conditions. Scheduled buses can be empty between stops but nevertheless must maintain their schedules. Every stream of cars, planes, or trains *can be* but only under very limited circumstances actually *are* completely filled to capacity. With ATNs, this excess capacity manifests itself as empty vehicles—excess seats that just happen to have their own structural shell, propulsion system, and so forth. In all cases, the movement of empty seats uses resources. Rather than a detriment, ATNs explicitly recognize and have the potential to deal more effectively with overcapacity issues by continuously putting vehicles into and out of service.

3.5.7 System Average Utilization Rate: The Missing Variable

Preceding sections discussed limitations to the basic line capacity equation as it applies to ATNs. When lines are assembled into a network along with stations, the limitations become even more significant. The maximum vehicle flow on the guideways of an actual system will on average *always be less* and will *most often be much less* than the value derived from the simple line capacity formula even after accounting for all of the limiting factors discussed thus far.

3.5.7.1 Basic Principles: Traffic Density and Merge

The basic effect is simple to understand. If a line is understood to be a portion of a loop and Equation 3.5.1-1 represents the maximum capacity of the line, what is the capacity of any adjoining loop that feeds into or *shares* the line? Taking the simplest case in which lines from two adjacent loops merge into a single line, the situation is illustrated in Figure 3.5-24. Clearly, two lines operating at maximum capacity cannot merge into a third having the same maximum capacity; each stream of vehicles is contending for the same resource.

Figure 3.5-24. Contention for resources.

The situation is, in fact, a zero-sum game. The flow rate of vehicles on the shared line must always equal the sum of the flow rates on each of its “feeder” lines. So if, for example, the traffic on each feeder line was equal, each of these lines would be able to pass a maximum of only one-half the maximum number of vehicles that a single line in isolation could technically support. In other words, each of the feeder lines would only be able to *utilize* 50 percent of maximum line capacity. Traffic on the feeder lines in any other proportion would also never be able to exceed a sum of 100 percent of maximum line capacity.

An ATN network is nothing more than an assemblage of loops in which lines are shared. It is this sharing of lines that allows trips to occur between stations distributed throughout the network. Trips between any station pair will in general utilize at least some of the same lines utilized for trips between other station pairs. This sharing of resources is what defines a network.

Efficient and effective sharing of resources requires that some sort of management system be put in place as depicted in Figure 3.5-25. This, of course, is the function of the control system. The figure depicts the best, balanced case mentioned above. The traffic-cop control system is managing two feeder lines, each operating at 50 percent of maximum capacity, as they vie to use the resource of the downstream guideway. He directs vehicles to proceed alternately between the feeder lines; left, right, left, right, and so on. The two streams of vehicles join together on the downstream guideway like a zipper being closed; the downstream guideway ends up operating at 100 percent of theoretical capacity.

Figure 3.5-25. Managing resources.

Like the alternating teeth of a zipper, what makes this possible is the separation between vehicles on the feeder lines. The reader is reminded that line capacity is defined in part by the required safe separation distance between the vehicles. Therefore, in order for this merge to occur, the total separation between vehicles in each feeder line must have an *additional* component. The two components are: 1) the separation required for the vehicles to operate safely and 2) an additional separation so that vehicles in the *merged* stream end up separated by a safe distance. In other words, looking at the converse, if vehicles in feeder streams were spaced as closely together as safety allows (i.e., the feeder lines operating at 100 percent capacity), and the streams were allowed to merge into the safety gaps between vehicles in their counterpart merging streams, the vehicles in the combined stream would not be operating at the required safe distance downstream of the merge point[32].

Of course, this is all for a very simple and unlikely case chosen to illustrate the basic concept. It is a *best* case in the sense that the downstream guideway operates at 100 percent of theoretical line capacity. These two feeder lines and the downstream guideway are said to be operating at full *saturation*. Like water in a sponge, only so much traffic can be accepted by a guideway. Although neither of the feeder lines is operating at 100 percent of maximum line capacity, they too can be considered as operating at saturation because neither could accept any more traffic. It is thus seen that the term "saturation" need not and does not refer to a single particular density of vehicles on any given portion of the guideway network.

This remains valid for other than a 50/50 split between traffic on the feeder lines. If their combined traffic saturates the downstream guideway, each of them can be considered to be saturated. In these cases, however, the average total separation between vehicles in each of the feeder streams would differ; the stream having the highest traffic density would obviously have lowest average total separation between vehicles. In the bounding case of a 0/100 split, for instance, the line having no traffic would obviously have "infinite" separation between vehicles; on the line with all the traffic, vehicles would be nose-to-tail at the safe separation distance.

[32] This is unlike the situation depicted in Figure 3.5-25, in which no separation is shown between vehicles in the merged stream. The figure was exaggerated for effect for purposes of this section's discussion. Situations similar to that depicted in the figure are, however, discussed in Section 3.5.8.2 and thereafter.

Readers may have already asked themselves about the possible presence of still other feeder lines coming into the saturated merged line downstream of the merge point; the single merge discussed here is, after all, only a small portion of a larger network. Wouldn't the merged line then become a feeder line itself and be forced to operate at less than 100 percent maximum theoretical capacity? The answer is yes—provided no *split* exists upstream of the second feeder line that can siphon off a sufficient amount of traffic from the saturated merged line. If a split were present to which vehicles could be diverted, it could perhaps open up space on the merged line into which vehicles on the second feeder line (which is downstream of the split) can merge.

Nevertheless, it is clear that looking at the operations of a single merge or merge/split pair is insufficient for drawing general conclusions about average line capacity across a network. If every line is simultaneously a feeder line, a split line, and a merged line, and can't be counted upon to carry 100 percent of theoretical maximum capacity, what amount of traffic *can* it be counted on to carry? When does it all stop? It stops when the *density of traffic is low enough such that a sufficient number of gaps are available to allow vehicle streams to easily merge*. The topic of maneuvering vehicles within merging streams in order to accomplish this is discussed in the next section.

3.5.7.2 Managing Merges: Tennis Anyone?

To the number of analogies used to describe ATNs, another is added here. It is sometimes said that in a game of tennis, there exist only two important moves once in play, the forehand and the backhand—everything else amounts to positioning oneself in order to effectively execute one of these two moves. In ATN operations, the important moves are vehicle routing to minimize trip costs, managing empty vehicles, and, most of all, managing merges. With respect to this last item, everything else amounts to the positioning of vehicles in order to effectively manage merges.

Effective merge management means avoiding contentions in order to maximize throughput and minimize the need to redirect vehicles onto longer routes. This subsection takes a brief look at this aspect of ATN design, which is perhaps its most challenging, particularly with respect to the very complex control algorithms that will be required. Two rather simplistic maneuvering techniques will be used to illustrate the issues involved. Many techniques have been studied over many decades. Nevertheless, these simple cases will lay the groundwork for providing the reader with perhaps the best taste thus far of the daunting complexity of ATN systems and the challenges faced by their designers. This simple discussion will also provide additional important and more direct clues illuminating the performance of current ATN designs and the long-term viability of the concept.

In the discussion so far, the traffic cop had an easy job. The vehicles in any of the split cases were assumed to be arranged on each of the feeder lines with respect to vehicles on the opposing feeder lines so that when they arrive at the merge point they enter the merged stream at precisely the correct separation distance front and rear. All the traffic cop had to do was give "all clear" signals to merging vehicles at the merge point. Unfortunately for the traffic cop, however, his job also includes arranging the vehicles on the feeder lines as they approach the merge point.

In other words, vehicles will not, in general, approach the merge point in the nice, orderly fashion discussed thus far. The randomness of vehicle arrivals is, in fact, one of the most important features distinguishing ATNs from scheduled-service transit; it is the flip-side interpretation of "demand responsive." The traffic cop needs to look ahead at both randomly distributed incoming streams and direct vehicles within each stream to advance ahead or slip backward relative to the stream in order to eliminate any contentions at the merge point. This requires a *third* component of vehicle separation—sufficient room to maneuver fore and aft—also without violating safe separation requirements.

Vehicles can maneuver relative to the stream that they're in or the entire stream can maneuver simultaneously, depending on the composition—the number and spacing between vehicles—of each stream relative to its counterpart. In either case, it is instructive to look at two approaches to handling a worst-case scenario. Imagine either two individual vehicles, one on each feeder line, or two streams of vehicles of acceptable (i.e., "mergeable") composition. For convenience, imagine that each stream is composed of a regular distribution of vehicles and interposed gaps equal in length to the safe separation distance; the 50/50 proportion discussed earlier will be used to illustrate. Imagine further that their trips have been so timed that, if the traffic cop does not intervene, the pair(s) of vehicles would be destined to arrive at the merge point simultaneously.

If conditions are such that it would be inadvisable to direct individual vehicles or vehicle streams on one of the feeder lines to either speed up or slow down in order to avoid contention at the merge point, the vehicle(s) on the opposing feeder line must either advance or slip a distance equal to a single nose-to-nose separation distance so that the vehicles when merged are positioned at the safe separation distance relative to one another. Since the maneuvers for this simple, worst case are identical whether applied to a single pair of individual vehicles or for multiple pairings between two mergeable streams of vehicles, two individual vehicles will hereafter be used to illustrate the argument for ease of discussion.

It is obvious that the vehicle designated to maneuver must begin to do so well in advance of the merge point and that a certain length of guideway upstream of the merge point must be allocated to accommodate the maneuver. The maneuvering vehicle must complete its maneuver no later than the instant the nonmaneuvering vehicle enters the merged stream in order to maintain safe separation. In order to account for the possibility of the failure of an advancing vehicle, its maneuvers must also be completed prior to its physical arrival at the merge point since, if allowed to pass the merge point, it would not by definition be positioned a safe distance ahead of the nonmaneuvering vehicle until its maneuver is complete. Again by definition, a slipping vehicle always completes its maneuver prior to the merge.

These two observations point to additional allocations of guideway length that must be made upstream of the merge point. Slip maneuvers require an allocation equal to the safe separation distance at line speed; this in the event the nonmaneuvering vehicle fails at the merge. Advance maneuvers require a similar, but greater, allocation to accommodate an emergency stop from the higher speed associated with the maneuver. In the following paragraph, however, it will suffice for the purpose of this subsection to focus strictly on the allocation of maneuvering length.

For control schemes in which maneuvering for a merge is conducted in the vicinity of the merge as described above, realistic physical environments will place practical limits on the maneuvering lengths that can be allocated. There may be nearby curves on which it would be imprudent to maneuver or upstream merges in near proximity that would interfere with the maneuvering. The length of line that can be allocated affects the severity of the maneuvers required in order to avoid the contention. For the simple worst case being discussed here and for which vehicle advance is employed, Figure 3.5-26 and Figure 3.5-27 show the minimum possible maneuvering accelerations and speed changes, respectively, as a function of line speed and allocated maneuvering distance[33]. The acceleration values, in particular, must be compared to the maximum accelerations allowed by human factors and safety considerations.

[33] Assumed values for vehicle and emergency decelerations are shown in the legend located in the bottom left corner of the figures. It will be recalled that it is these two values in conjunction with line speed that determine safe, no-collision separation distances. See further discussion on page 119.

This value is located on the vertical axes in the figures. By reading across from a selected value of acceleration and up from a selected value of line speed, the required maneuvering length can be estimated. If, for example, 0.25 g were allowed, Figure 3.5-26 indicates that the minimum practical length for maneuvering would be approximately 180 feet (via extrapolation) for a nominal line speed of 20 mi/hr. Every additional 10 mi/hr increase in line speed requires roughly another 120 to 150 feet of length. If, however, a value of 0.13 g was selected as the acceleration limit, the maneuver would require approximately 230 feet with roughly 175 feet of additional length for each 10 mi/hr increment in line speed. Conversely, if longer maneuvering lengths can be incorporated into a particular setting, much milder maneuvers are possible. Factors influencing this selection are discussed in the next subsection.

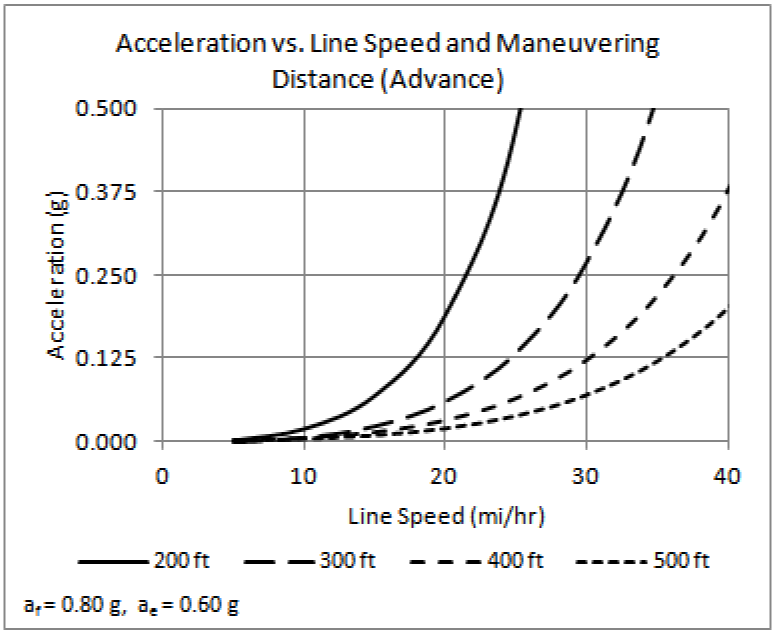


Figure 3.5-26. Minimum maneuvering acceleration (single advance).

Another important consideration is depicted in Figure 3.5-27. As the case considered here is for advancing vehicles, the required minimum maneuvering speed change shown in the figure represents an increase in speed *that must be subtracted* from the maximum speed capabilities of ATN vehicles/systems in order to establish the nominal operating line speed. For wide-area, yet dense, compact layouts in which only the minimum maneuvering lengths can be allocated, this suggests ATN systems would be required to operate at substantially lower nominal speeds—and at significantly lower fractions of maximum speed—with consequent effect on overall trip times.

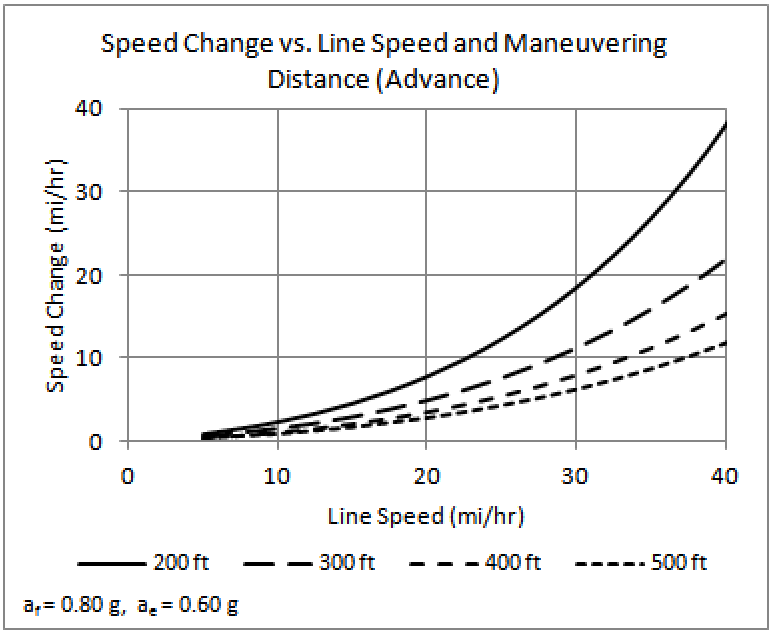


Figure 3.5-27. Minimum maneuvering speed change (single advance).

For the opposite approach in which vehicles are slipped rather than advanced in order to avoid a merge contention, the required decelerations and speed changes are more benign for a given maneuvering length allocation, as shown in Figure 3.5-28 and Figure 3.5-29. In this case, there is by definition no limit to the amount of speed reduction; a vehicle can be directed to come to a complete stop if necessary. Some current ATN designs, in fact, operate in this way—an important point to remember when unqualified claims of "nonstop" service are made. More on the matter will be discussed in Figure 3.5-29.

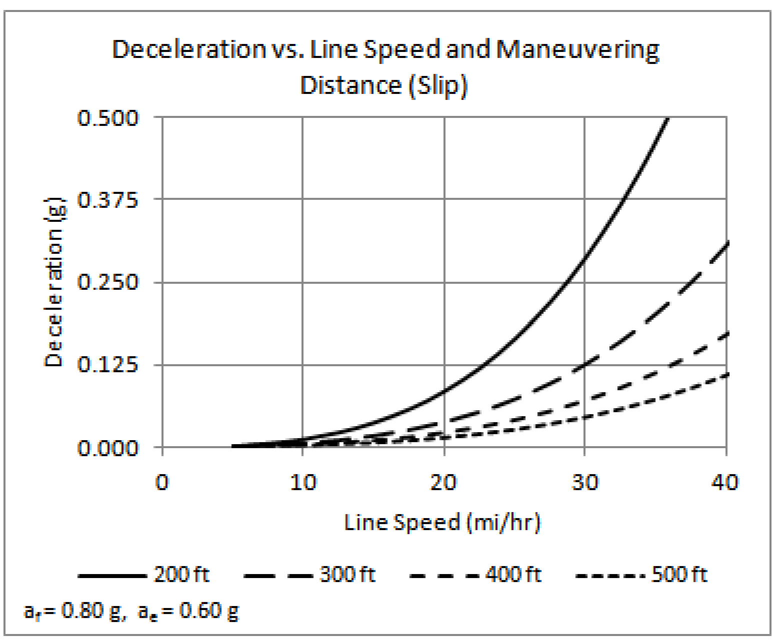


Figure 3.5-28. Minimum maneuvering deceleration (single slip).

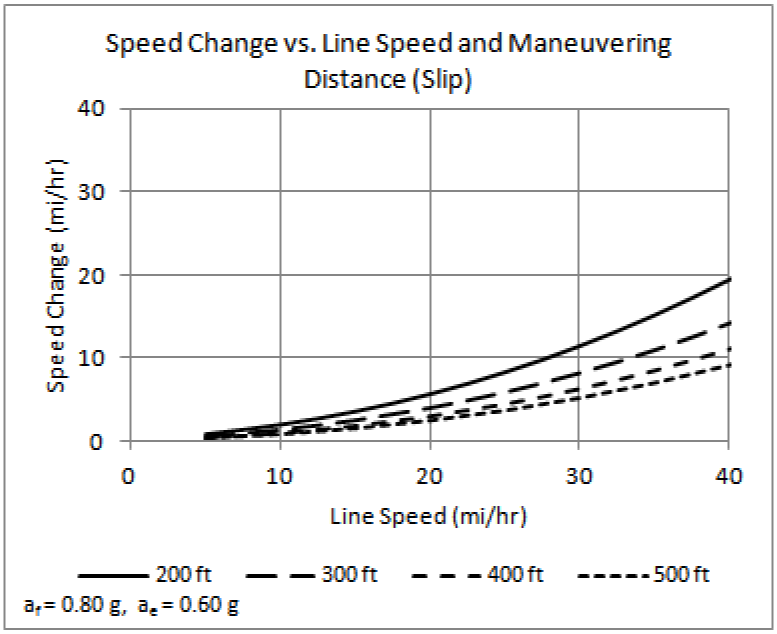


Figure 3.5-29. Minimum maneuvering speed change (single slip).

This collection of results suggests that the vehicle slip technique be given preference in any merge contention management scheme. Note, however, that system control approaches restricting themselves singularly to either of these two techniques would eliminate at least some operational flexibility. They may also perhaps result in other deleterious effects, such as increased sensitivity to upstream diversions as traffic density is increased with consequent increases in trip lengths, times, and energy usage. However, the selection of a particular technique is all subject to a rather complex set of considerations and tradeoffs. The existence of more sophisticated merge contention management will be discussed in the following section. The important point to note at present is the complex interplay between vehicle stream composition, speed, existing infrastructure and consequent guideway geometry, and human factors/regulatory considerations—and the focus thus far has merely been a single merge!

With regard to regulatory considerations and as previously noted, the above curves were generated from safe separation distances consistent with failure and emergency deceleration rates of 0.80 g and 0.60 g, respectively, used previously to introduce the topic of vehicle motion control. These rates govern the safe separation distance and, hence, the amount of vehicle advance and/or slip required. As discussed in Section 3.5.4, if a value of emergency deceleration consistent with unrestrained passengers was required (0.25 g), the results are quite different. As the use of this value requires an increase in safe separation distances, higher values of the maneuvering parameters are required. These can be allocated in various combinations of minimum maneuvering accelerations, maneuvering length, and higher minimum maneuvering length thresholds. It would not be possible in this case, as an example of the latter, to execute a vehicle advance for maneuvering length allocations very much lower than 300 feet at a line speed of 20 mi/hr, and such a maneuver couldn't be executed at all for speeds of 25 mi/hr and greater; there is simply not enough room. This is shown in Figure 3.5-30.

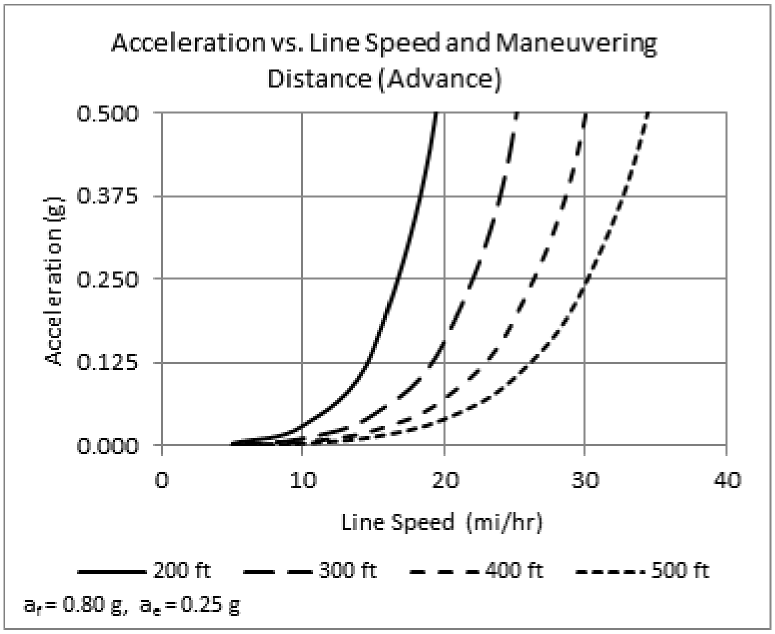


Figure 3.5-30. Minimum maneuvering acceleration (single advance, a_e = 0.25 g).

Still greater minimum accelerations, speed changes, and maneuvering length thresholds are required if higher failure decelerations must also be accounted for in establishing safe separation distances; a failure deceleration of 3.20 g, for instance, at which safe separation is roughly equivalent to those consistent with the brick-wall stop criterion. The influence of these various parameter values is shown collectively in Figure 3.5-31 for vehicle advance maneuvers and in Figure 3.5-32 for vehicle slip maneuvers. These figures are based on a select maneuver length of 400 feet, within which all maneuvers are able to be performed across the indicated range of line speeds, even if at some very unrealistic values of acceleration, deceleration, and speed change.

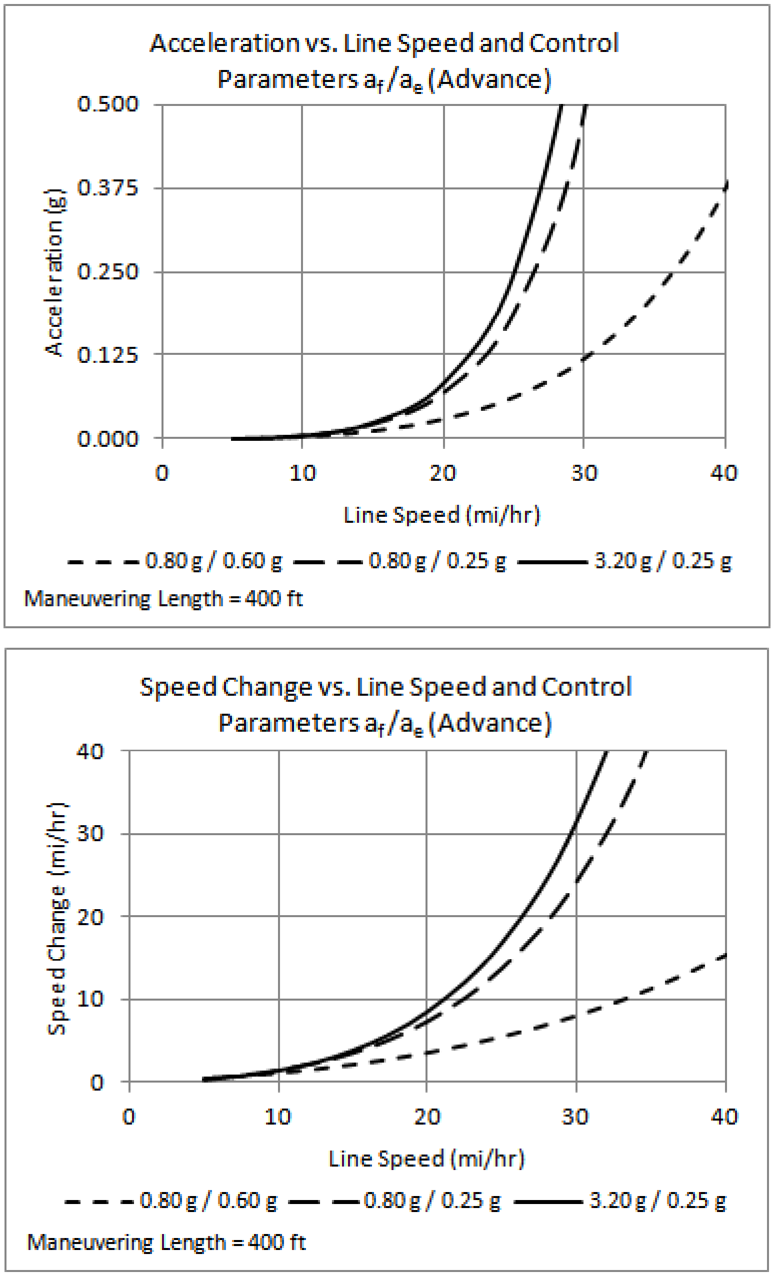


Figure 3.5-31. Minimum vehicle advance values (400-foot maneuvering length).

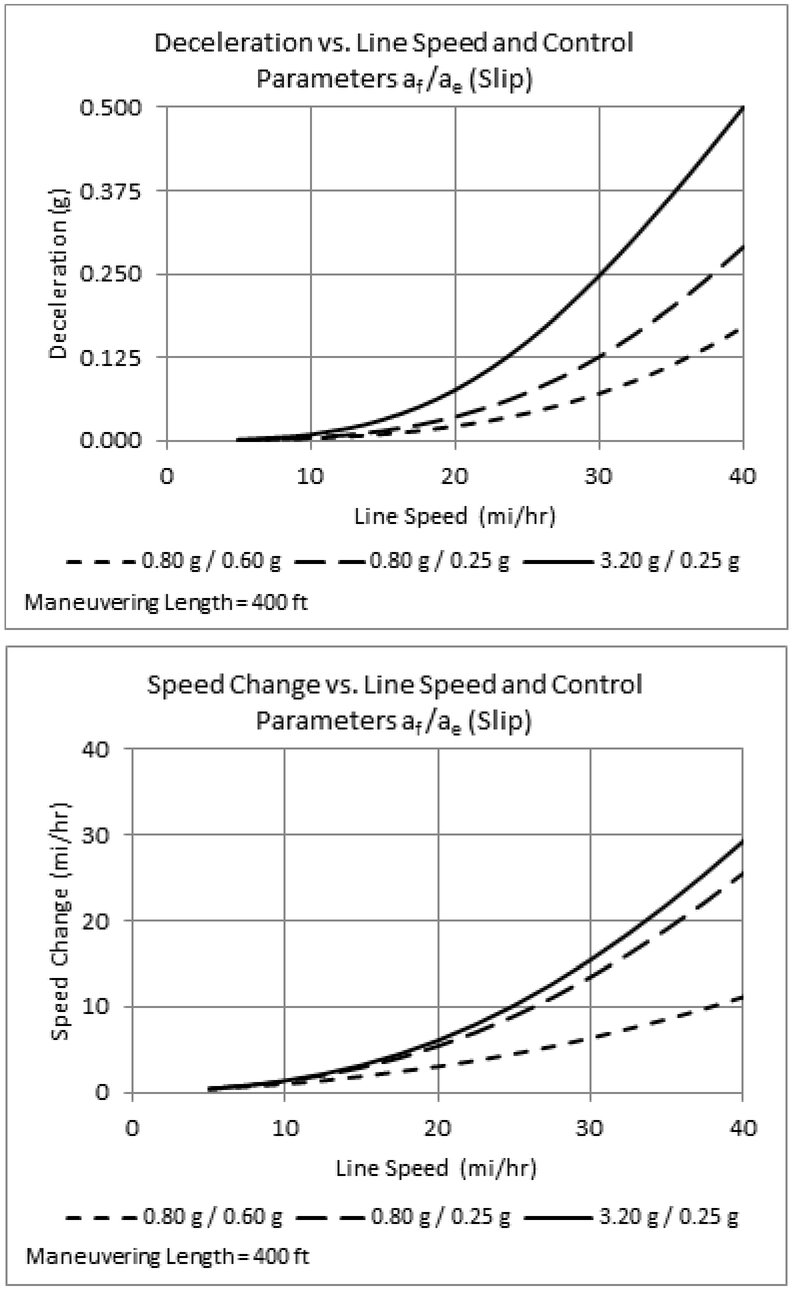


Figure 3.5-32. Minimum vehicle slip values (400-foot maneuvering length).

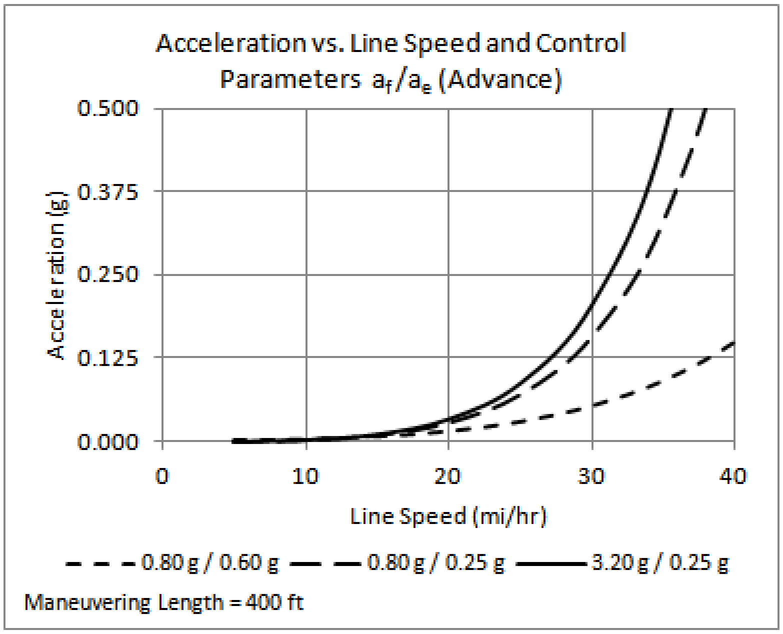
The reader can easily see from these figures the dramatic effects of taking into account values of emergency and failure decelerations, which will almost certainly fall within the range considered by regulatory authorities. These simple cases starkly illustrate the constraints that govern current and future ATN designs. Regardless of which of these two maneuvering approaches is considered or the values eventually specified for the governing factors of failure and emergency deceleration, the sharp rise in minimum required accelerations, speed changes, and/or maneuver lengths represents a barrier of sorts to high-speed operations. Of all the considerable number of challenges faced by ATN designers, this barrier is perhaps the most formidable. At present, ATNs appear to be operating in a narrow range of acceptability, relegated by virtue of both immutable physics and current regulations to low-speed operations and/or low-demand applications for which merge contentions are manageable. In order to extend the performance capabilities of ATNs, and thus the range of applications and business cases that can be envisioned, significant efforts have and are being made to overcome this barrier. These are discussed in the next section.

Before leaving this introduction to merge-contention management, however, it is important to take a look at other than the worst cases. The best case[34] for managing a contention in the vicinity of the merge is if vehicle maneuvers were split between the two feeder lines, one advancing and the other slipping. If the amount of single safe separation were allocated equally between advancing and slipping, the results are as shown in Figure 3.5-33 and Figure 3.5-34 for the advance and slip portions, respectively. The net effect of this technique is to push the advance acceleration “barrier” out approximately 7 mi/hr and the slip deceleration “barrier” out by approximately 3 mi/hr, both at a maneuvering acceleration of 0.25 g.

This does very little to alleviate this principal ATN design challenge and reinforces the need for merge management approaches far more sophisticated than those considered in these simple scenarios. For example, even if regulatory relief were obtained in the form of a relaxation of the brick-wall stop criterion, designers would still be confronted with a significant challenge. Emergency deceleration rates would need to be set at a substantial fraction of the anticipated failure deceleration, requiring passenger restraints. Conversely, the steep rise of the curve associated with a relaxed brick-wall stop criterion and unrestrained passengers (0.80/0.25) prohibits operations at line speeds much above 30 mi/hr in any event, should that be the eventual specification as determined by regulatory, performance, and public acceptance considerations. And the reader is asked to recall that these illustrative scenarios accounted for advancing or slipping only a *single* unit of safe separation. Something more is needed beyond the elimination of the brick-wall stop criterion in order to boost capacity and overall performance. That something is discussed in Section 3.5.8.2.

In preparation for tackling this topic, the next section returns to discussing merge contention and its effect on line capacity.

[34] That is, from the standpoint of this introductory analysis. The “best case” in *general* is, of course, the object of design efforts.



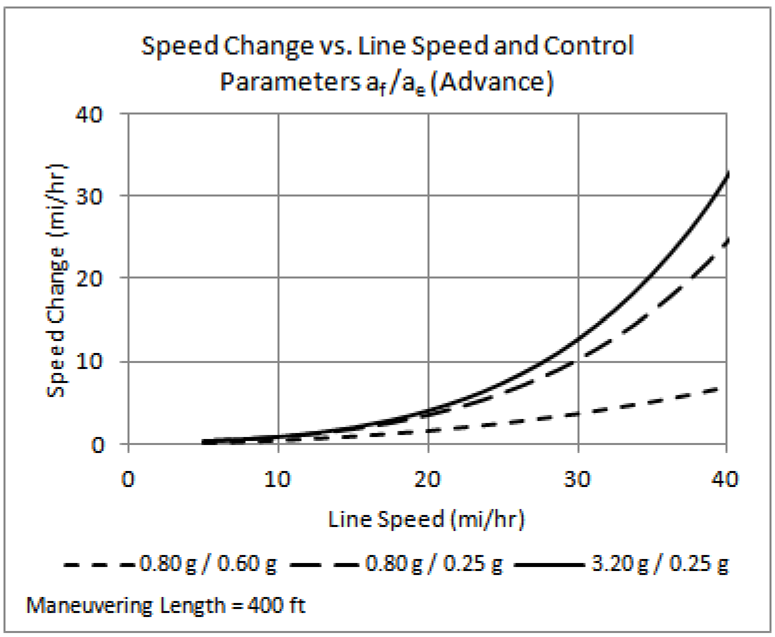


Figure 3.5-33. Minimum vehicle 50/50 advance values (400-foot maneuvering length).

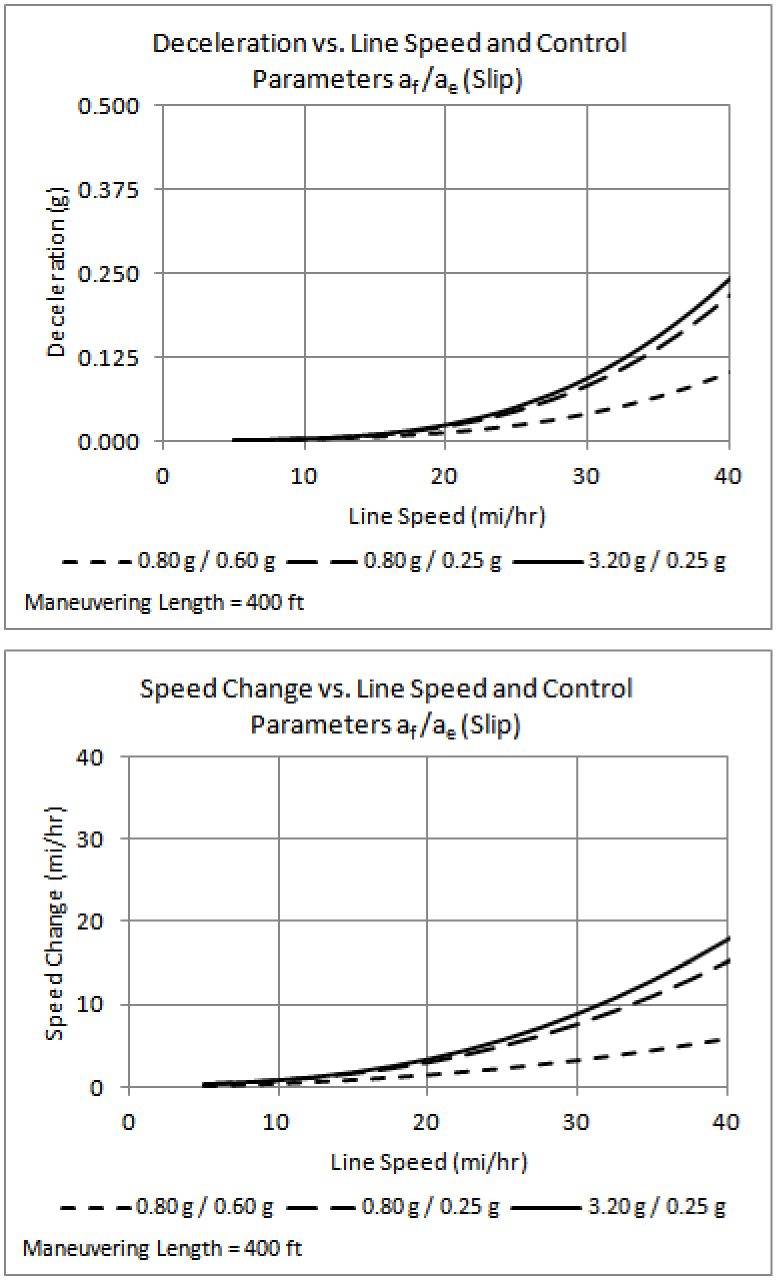


Figure 3.5-34. Minimum vehicle 50/50 slip values (400-foot maneuvering length).

3.5.7.3 Complex Merge Contention Management and Line Capacity

For current ATN applications, merge contention management is not much of a technical challenge. Vehicle separations are governed not by regulatory limits but rather by technical capabilities commensurate with low demand for service spread over a small number of stations. This is reflected in current control system designs which, as reported in the RFI responses, are capable of maintaining rather large six-second headways. Resulting separations are quite large. At a line speed of 20 mi/hr, this equates to 176 feet of nose-to-nose separation, far in excess of the severest of safety minimums. Such large separations in turn equate to very low traffic density, providing ample opportunity for vehicles "streams" to "merge" with little chance of contention or unsafe operations. Merge contentions can also be easily managed simply by controlling the timing of departures from the stations, an approach otherwise known as synchronous control.

Perhaps because of this or perhaps because of trade-secret considerations or simply that merge contention management techniques have yet to be fully developed, no discussion was provided in the RFI responses regarding the impact of merge contentions on line capacity. For this, a look at past analytical research efforts offers some clues as to what to expect from future ATN designs. A good number of such studies were conducted in the late 1960s and early 1970s as well as a few more recently.

As an example of the former, The Aerospace Corporation simulated the operations of an ATN intersection consisting of two merges and two immediately upstream bypasses [13]. Two versions of this intersection are shown in Figure 3.5-35 and Figure 3.5-36. The performance of these two versions is shown in Figure 3.5-37 for two assumed rates of "merge demand," i.e., the percentage of each stream entering the intersection and desiring to exit its line and proceed toward a merge onto the crossing line.

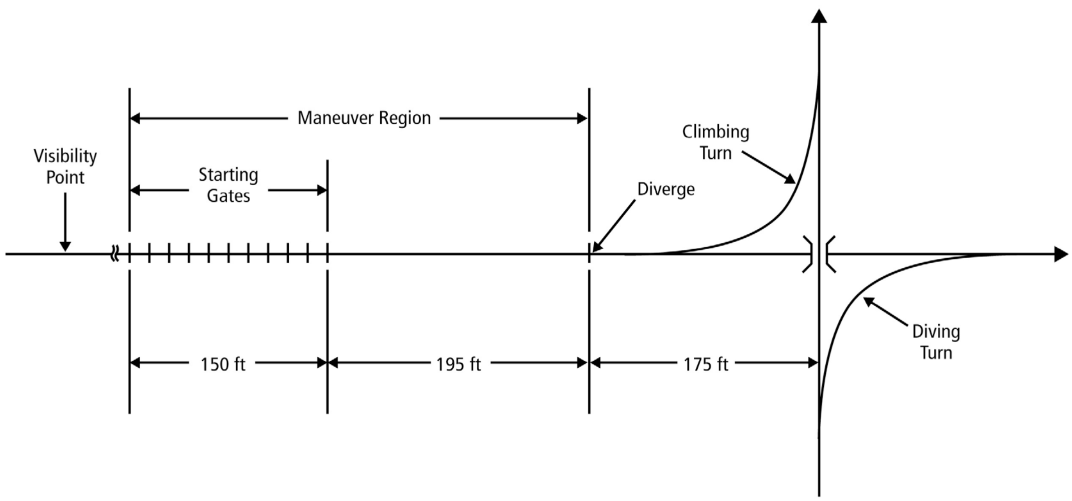


Figure 3.5-35. Single-stream intersection.

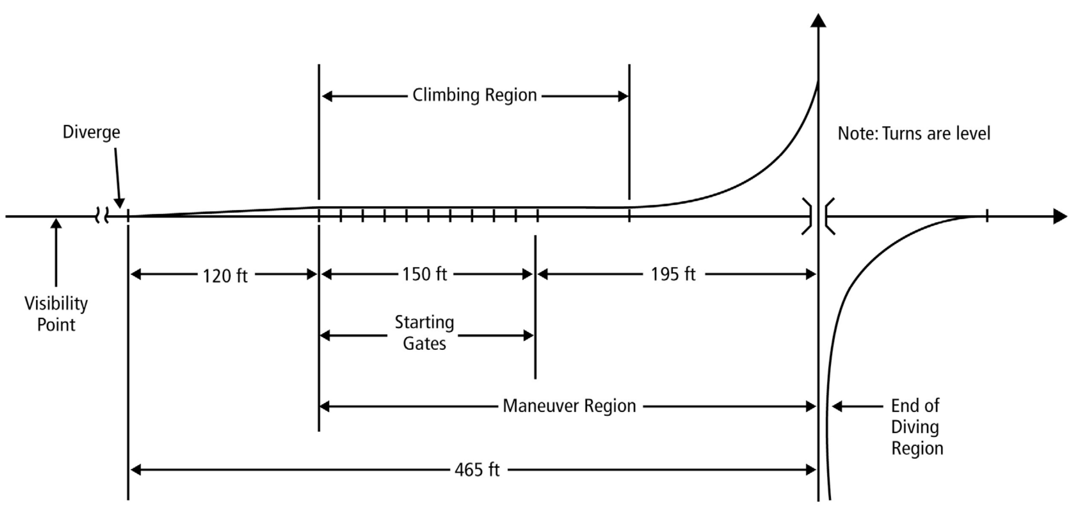


Figure 3.5-36. Split-stream intersection.

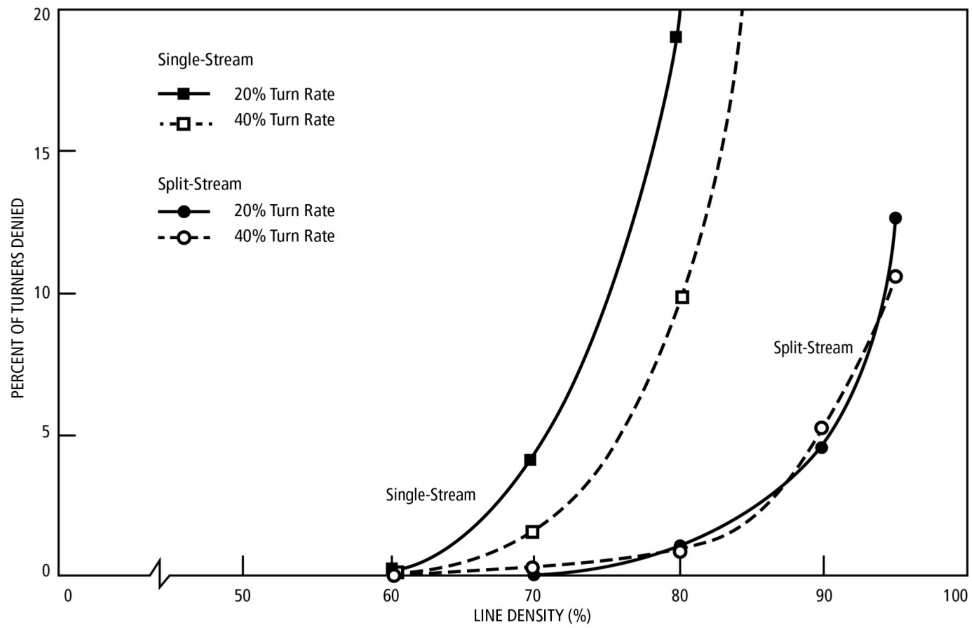


Figure 3.5-37. Intersection performance comparison.

This simulation assumed an advance-priority maneuver approach, although slip maneuvers were also allowed up to and including maneuvering to a complete stop to allow a saturated vehicle stream at 100 percent of theoretical line capacity to clear the merge point. It also assumed both restrained passengers and operations that violate the brick-wall stop criterion. A mere five feet of vehicle separation was specified. Thus, a maneuver length of 195 feet was sufficient to allow for advancing not one but two positions relative to an opposing vehicle or vehicle stream.

The latter figure shows that for the assumed conditions (discussed immediately below), merges can only be guaranteed up to a line density of approximately 60 percent. Beyond this density, vehicles are denied the opportunity to merge and are waived off; that is, they are forced to continue through the intersection. This maximum line density for zero denied turns applies to each line entering and exiting the intersection. Acknowledging the fact that this applies to two sets of merges and bypasses interacting, it is nevertheless instructive to note the line densities immediately upstream of each merge. Applying the turn rate percentages to this figure, one can see that individual line densities on the feeder lines entering the merges are 12 percent/48 percent and 24 percent/36 percent for the 20 percent and 40 percent turn rates, respectively. These are percentages of maximum theoretical line capacity for the assumed conditions and merge management techniques. In each case, they sum to the 60 percent figure after each merge.

This is the first bit of evidence presented here associated with the level of service (here in terms of turn denials and the consequently longer trips) that can be expected of ATNs as a function of various design parameters. The above analysis also pertains to a system operating at a speed (20 mi/hr) below the “barrier” discussed in the preceding section. In the next section, more complex approaches to merge management will be discussed that are intended to push the limits of the merge management barrier.

3.5.8 The Future: Complex Merge Contention Management

The resulting line density limits resulting from the simulation described above are by no means to be taken as an absolute measure of merge management performance for ATNs in general. As mentioned, numerous approaches have been studied over the past few decades, each study reinforcing two principal characteristics of ATNs: Performance is not calculable via simple mathematical expressions, and it is inseparably linked to the intricacies of the chosen control techniques.

It was certainly not possible within project constraints to comprehensively catalog and assess the collection of techniques described in these studies, nor would it have been particularly relevant to do so for present purposes. The challenge of merge management is an immutable fact having limitations governed by basic physics and is well-recognized within the development community. In order to provide the City with a sense of what the future might hold, this section will briefly describe and highlight the characteristics of the generally well-known categories of control approaches and describe several techniques that are seen as opportunities to maximize performance.

3.5.8.1 General Control Type Fundamentals

It is a bit strange to discuss the future of ATN control techniques when the basic approaches were developed and implemented in research and demonstration systems several decades ago, but that is the nature of ATNs. The discussion should serve to once again reinforce the magnitude of the challenge and the complexity of ATNs. Most of all, it establishes that the only accurate assessments for purposes of design/build considerations—and the only relevant simulations—are ones which are based on realizable control systems that are the result of rigorous technical and economic tradeoffs and are fully verified in hardware and software under a wide range of conditions.

Although an ATN control system must manage overall operations, the topic is introduced here because merge contention management is, as mentioned, perhaps a control system's principal and most challenging task. The following will focus on the merge contention management function of ATN control systems and is not intended as a detailed expository on the general topic of control system design, although some general comments are made. The three generally accepted major categories of ATN control approaches are: synchronous, quasi-synchronous, and asynchronous.

Roughly speaking, a synchronous approach can be envisioned as an interlocking set of conveyor belts operating at a constant speed. Vehicles are placed in nonvisible but by no means imaginary slots on the "conveyor" at stations after a systemwide scheduler calculates a clear path to their destinations relative to all other vehicles that will be sharing network resources and crossing their paths. The length of the slots is composed of the vehicle length and the allowed separation distance. By definition, there is no need to manage merge contentions locally and there is no need to maneuver vehicle streams into mergeable configurations since this is all calculated prior to departure.

In a quasi-synchronous approach, a portion of the control calculations is distributed to local controllers that manage merge contentions via the maneuvering of vehicles in the vicinity of the merge. This maneuvering is imagined as vehicles advancing or slipping "slots" in integer multiples of the established separation distance; the analytical results presented in Section 3.5.7.3 were for just such a system and operations. Vehicles depart stations when ready. A systemwide controller may direct a vehicle to a less-congested portion of the network in order to balance the traffic and reduce combined in-station, in-vehicle, and in-transit trip times for passengers, but the precise route a vehicle takes is determined in transit by each local controller in succession as it manages merge contentions. That is, some vehicles will be diverted from their desired routes as traffic density increases.

Both the synchronous and the quasi-synchronous approaches are referred to as "point follower" because vehicles are directed to follow the invisible points defining the slot boundaries and which are in continuous, constant-speed motion. Thus, vehicle positions within streams are discretized, i.e., vehicles must remain positioned within a slot, except when advancing or slipping slots during a maneuver. When in constant-speed transit, vehicles may not encroach into the separation distance of their own assigned slots, even if no vehicles were immediately ahead or behind.

In the asynchronous approach, vehicles operate more autonomously. Again, they may be initially directed by a systemwide controller toward a less-congested area of the network, but, as in the quasi-synchronous approach, they leave stations when ready and have their merges managed locally. The principal distinguishing factors in this approach are that vehicles may travel at variable speed not just when maneuvering, but in transit, and allowed separations are maintained not by following points but via detection of leading vehicles. For this reason, asynchronous systems are often referred to as car-follower systems.

It is useful here to recall earlier analogies of ATNs to communication networks in order to reinforce the concept of quality of service, which is intimately associated with merge management. The performance characteristics of the various ATN control approaches spanning the spectrum from synchronous to asynchronous can be seen as being roughly equivalent to those for a similar range of communication network types from circuit-switched to packet-switched networks. Other interesting analogies are also possible, such as to Time Driven Switching (TDS), a variant of basic circuit switching in which resources are allocated locally and dynamically. For the purpose of the present discussion, the two bounding network management analogies will be considered. It will be seen that there are two measures of performance that must be traded off—capacity and quality of service.

Both synchronous ATN control and circuit-switched communication networks dedicate channels of "communication" over which vehicles and communication signals respectively flow. Resources are allocated and exclusively reserved for the duration of the particular trip or conversation. The key performance advantage resulting from this is that the trip or conversation is guaranteed to take place without interruption; i.e., a high quality of service is provided to the particular customers having access to the dedicated circuit. In practical terms, this means for ATNs an uninterrupted trip over the shortest unused route available at near-constant speeds. A further principal advantage is the relative simplicity and therefore the generally lower capital cost and higher reliability of the control system. The disadvantage is that the dedication of resources temporarily precludes them from being used by other customers, resulting in denial of access to the system[35] and lower overall utilization of those resources, i.e., "capacity." This, in turn, results in greater operational costs per unit of throughput and, in practical terms for ATN passengers, longer waits in stations.

With packet switched networks, the reverse is generally true. Resource sharing results in greater utilization of resources, resulting in higher throughputs, lower per-unit operating costs, and, for ATN passengers, shorter in-station wait times. But this comes at the expense of a lesser quality of service in transit: Passengers would experience this as longer, more circuitous trips and an increased amount of maneuvering and congestion—even stopping on the network. The increased level of maneuvering in particular may be perceived as uncomfortable if occurring too frequently or at levels of acceleration and deceleration that are too high. Automobile traffic is, in fact, asynchronous. An asynchronous ATN system is likely to exhibit many of the same behaviors: smooth, uninterrupted flow at low levels of demand, "stop and go" traffic at higher levels, and sometimes inexplicable stoppages beyond a certain level.

[35] For a telephone network, an "All circuits are currently busy" message.

Synchronous control methods are suitable for low-demand applications such as those currently in operation, but they have been for the most part abandoned as a solution for more demanding applications. Contemporary proposals focus on some sort of hybrid approach incorporating features of both quasi-synchronous and asynchronous methods. With respect to merge management, both require maneuvering in the vicinity of merges in order to avoid contentions. Note that for fully saturated vehicles streams in the vicinity of a merge, the two methods are indistinguishable.

Given this basic concept of how network design of all types involves trading capacity against quality of service, the next section will discuss particular techniques that may be and likely are being contemplated for ATNs in order to find a satisfactory balance.

3.5.8.2 Complex Merge Management Control

For insight into the opportunities and limits of future ATN merge management techniques, one can look for clues in some of the underlying assumptions and results of the analyses discussed thus far: a) The zone of merge decisions and maneuvers was restricted to the immediate vicinity of the merge, b) no preference was established for either advance or slip maneuvers, and c) safe separation distance was defined as that consistent with the avoidance of collisions in the event of vehicle failure [24].

To review: Under these assumptions, considerable lengths of guideway must be allocated to maneuvering. This, in turn, can complicate upstream merge operations and/or place limits on the compactness of ATN layouts. It is also clear from the previous discussion that maneuvering room within a vehicle stream must also be available: i.e., a vehicle cannot advance or slip unless it is separated from vehicles either immediately ahead of or behind by at least a single multiple of safe separation in addition to "normal" safe separation. The need for maneuvering space results in a further reduction of capacity as compared to that estimated by the basic line capacity equation.

Potential clues to approaches that might be used to alleviate these issues are evident as counter-assumptions to those made above: a) Extend the zone of merge management out to greater distances, managing multiple merges simultaneously; b) allow for maneuvers in which vehicles may travel at maneuvering speeds for extended periods of time; c) give priority to slip maneuvers, perhaps relying on them exclusively; and d) redefine "safe" separation distances as being consistent with the *management* of collisions, not their avoidance, thereby enabling the formation and operation of vehicle platoons—a number of vehicles traveling together as a unit with very small tail-to-nose separation distances.

Extending the zone of merge management requires that no dedicated maneuvering zones be specified and possibly that multiple merge points be managed simultaneously. This would help alleviate constraints on the compactness of a network layout but at the cost of considerably higher control complexity. Similarly, allowing for advancing or slipping at maneuver speeds for extended periods of time will require the control system to look further ahead in time. Extended advance maneuvers and extended merge management zones go hand in hand, as the former requires the latter. Extended slipping is much easier to envision as a merge management technique, the extreme form of slipping being a matter of bringing a vehicle to a complete stop at which point it can slip any distance required.

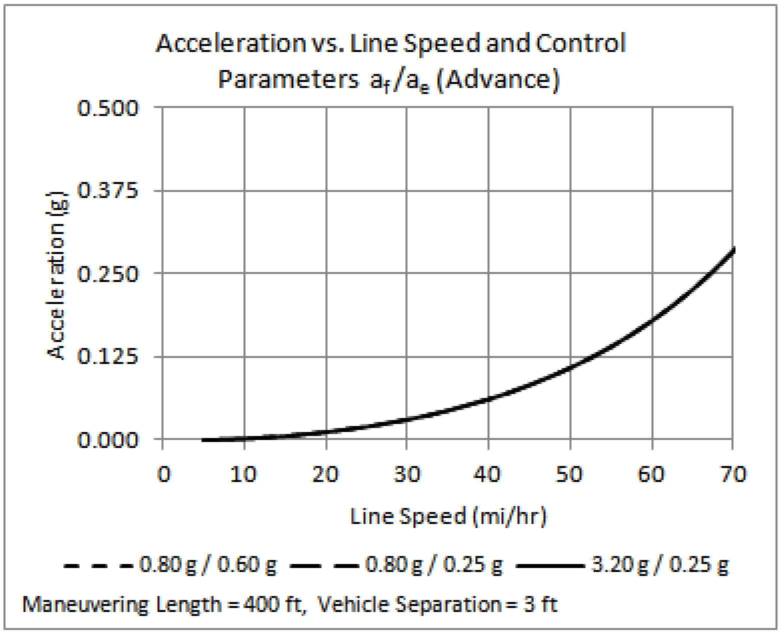
Conversely, advance maneuvers are problematic for cases in which a single vehicle finds itself in contention with a long, uninterrupted vehicle stream operating at minimum intervehicle separation. Other advantages can also be had via preferential slipping. For example, it will always be safer to maneuver by slipping. During a slip maneuver, the relative speed between the slipping vehicle(s) and a lead vehicle continuing at constant speed will be less than zero; they'll be receding from one another. Should the lead vehicle experience a failure, the slipping vehicle will already essentially be engaged in an emergency braking maneuver.

System control approaches that singularly restrict themselves to any particular approach would eliminate operational flexibility and perhaps result in other deleterious effects; in the case of slipping, perhaps increasing upstream diversions and consequent trip lengths, times, and energy as traffic density is increased. Nevertheless, the advantages of preferential slipping may outweigh the disadvantages, and decisions like this can only be made after much analysis is carried out. It is not clear how extensive are the present efforts of the development community regarding this issue.

Similarly, it is not known how far the development community has progressed with respect to the final and most important topic of platoon operations. Platoon operation is natural to consider—it would perhaps allow ATN designers to pack more vehicles onto a given length of guideway, thereby increasing capacity. The separation distances in this case are far less than those consistent with the brick-wall stop criterion—or even those that would result from any likely relaxation of the criterion. Thus, such a definition contemplates the possibility of collisions. This is not a fringe goal of the ATN development community; it is one long considered and sought by transportation researchers past and present, from research efforts in the 1960s to the U.S. Automated Highway System program of the 1990s to current-day research and demonstrations by major automotive companies. The results of doing so would be dramatic in terms of eliminating the "maneuvering barrier," as shown in Figure 3.5-38 and Figure 3.5-39.

In these figures, the curves associated with the three pairs of failure and emergency deceleration collapse into a single curve as separation distance is no longer defined by these parameters. It is instead held at a constant value regardless of speed, in this example 15 feet nose-to-nose, only 3 feet tail-to-nose. Moreover, the maneuvering barrier virtually disappears. A minimum maneuvering acceleration/deceleration of 0.125 g is not reached until a line speed of over 50 mi/hr, and a value of 0.25 g not until over 65 mi/hr.

A bit less concern need be given to adopting a preference between advance and slip maneuvers, given such close separations. Comparing Figure 3.5-38 and Figure 3.5-39, one can see that the difference between the two is less pronounced, albeit this is only true in the case of advancing a maximum of two positions. In situations requiring the maneuvering of vehicles over greater distances relative to the streams, slipping will always be preferential, since vehicles can be commanded to a complete stop and slip any distance.



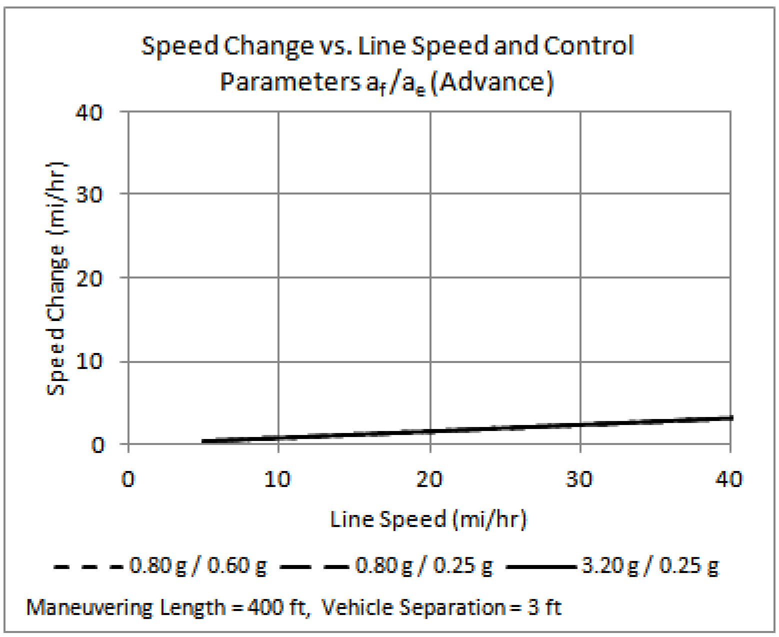


Figure 3.5-38. Minimum vehicle advance values: platoon operations.

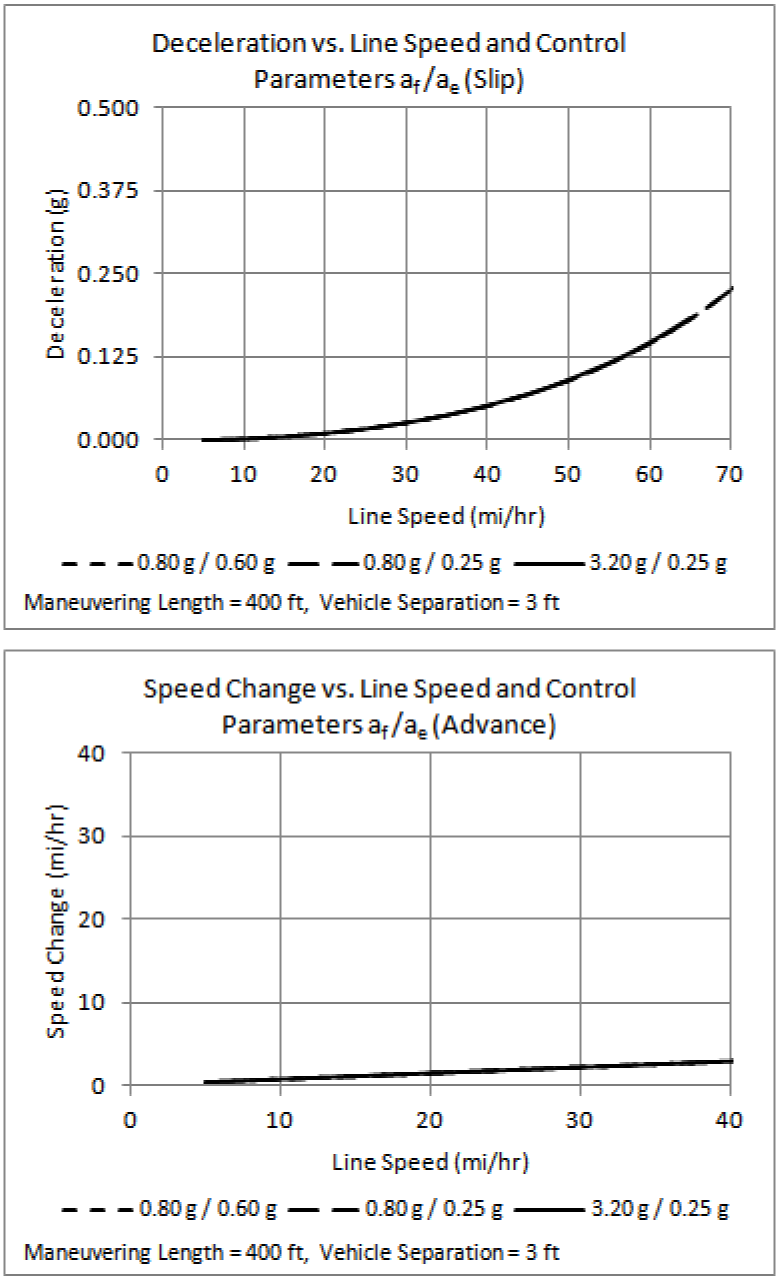


Figure 3.5-39. Minimum vehicle slip values: platoon operation.

Clearly, allowing vehicles to operate at close separations would have a tremendous effect on capacity. However, while one may initially see only advantage in this approach, it would involve operating within the zone of potential collision depicted in Figure 3.5-16, repeated below as Figure 3.5-40 for convenience. The only means available to significantly reduce vehicle separations and thereby increase line capacities is to operate on the left-hand side of this inverted "bathtub" curve.

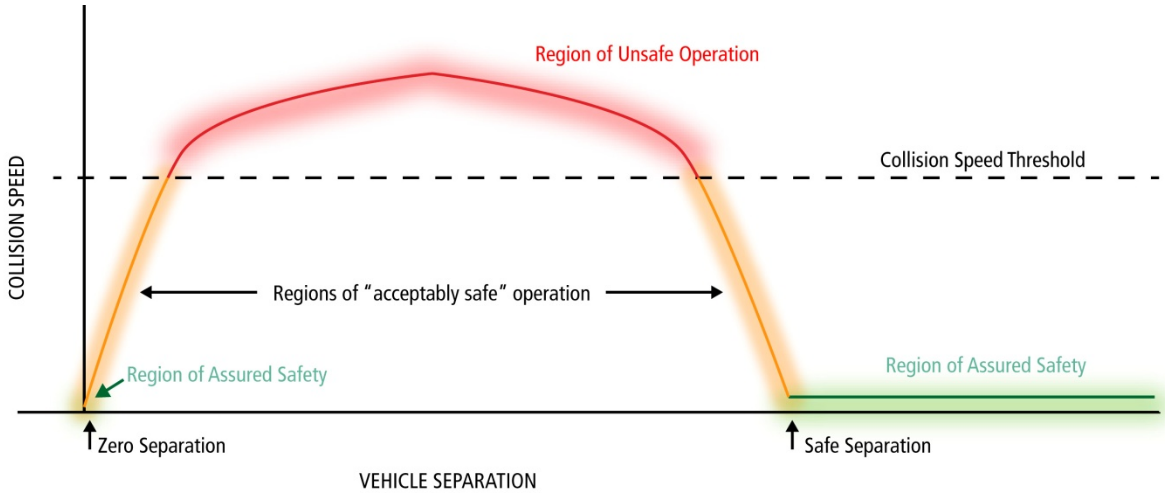


Figure 3.5-40. Collision velocity vs. separation distance revisited.

In this region, limiting collision speeds to below an acceptable threshold can require exceedingly short tail-to-nose separation distances—on the order of several inches for some of the higher failure decelerations that might be established by regulatory authorities[36], perhaps a few feet at most. Furthermore, as evident in the steepness of the curve in this portion of the bathtub, these separations must be maintained accurately and precisely, else the collision speed threshold could be easily exceeded. This must be accomplished reliably, day in and day out under a host of widely varying conditions. This is the reason that the fully realized ATN concept has been referred to in this report as being an all-weather, precision, human-rated motion control system. If achievable, however, these separations would indeed result in higher capacities, much less demanding maneuver requirements, and the ability to lay out more compact systems.

Still, this is an unprecedented operating mode for any transportation system. Not only would vehicles travel closely together, they would be required to merge such that these separations result in the merged stream. In fact, other than platoons of closely spaced vehicles formed in stations and departing in unison, merges are the only locations in a network that such platoons can be "safely"[37] assembled in so-called concatenating merges [22]. Having vehicles approach each other to form a "safe" platoon would require that they first traverse the region of unsafe separations shown in Figure 3.5-17. Furthermore, disassembling a "safe" platoon is problematic, as departing vehicles would open up gaps that, once again, are located in the unsafe region of the figure.

Moreover, beyond the technical implications, this mode of operation would represent an equally unprecedented passenger experience, to say the least. It is not hard to imagine the view out the side window of an ATN vehicle as it approaches its counterpart on an opposing feeder line, especially if merging into a space between two vehicles the size of which is the length of a vehicle plus perhaps one foot. Furthermore, and not the least in importance, operations such as these would almost certainly require passenger restraints, a feature not incorporated into current designs. All of this suggests that a substantial human-factors effort will have to be expended in order to fully evaluate the viability of ATNs.

[36] Note that while in this case failure and emergency deceleration no longer define "safe no-collision" separations, they now define "safe collision" separations.
[37] That is, solely from the perspective of safe longitudinal separation. No effort is made here to assess the overall safety aspects of such a merge.

This is the principal challenge for ATN designers, regulatory authorities, and the riding public. Sorting through all of these issues from the many perspectives involved will be a daunting task.

3.5.9 Reliability

Aerospace had prepared for a significant effort on this topic, but limited information prevented its execution. A quick assessment based on available information is worthwhile, however, because of the impact of reliability estimates on the underlying case for ATNs.

Much mention is made in ATN literature of reliability. High reliability is a cornerstone of arguments for eliminating the brick-wall stop criterion and for platoon operations. Mean Time Between Failure (MTBF) calculations have been made and used in fatality rate estimates in attempts to illustrate favorable safety characteristics relative to other modes of transportation. The use of existing components and sophisticated analyses is highlighted to provide assurances that ATN systems are built safely. While all of this is certainly important, it does not yet, based on available information, constitute proof of high-reliability design.

The use of existing components, for example, does not necessarily enhance reliability. The operational environment must be similar to the design environment for component MTBF values to be meaningful. And, as experienced systems engineers know, most failures occur at the interfaces between components and subsystems. Even more relevant to ATNs is the very significant issue of software reliability.

All of this and more was not available for evaluation. However, a few comments can be made about the topic in general. The reliability of complex systems is not a trivial matter. Comparisons to existing systems serve as hopeful goals, but the City must be aware that achieving acceptable levels of reliability for any new system is a significant undertaking. Up-front analyses serve to guide these efforts, but they are no substitute for physical testing. The principal drivers of reliability—quality, lack of complexity, and redundancy—represent a significant challenge in the design of complex systems.

3.5.10 What Is Capacity?

All of the above discussion has finally enabled a closing look at the issue of capacity. But first, it is important to take a look at the term itself. The use of imprecise, unqualified, or colloquial definitions of certain words can make communicating about and understanding of complex topics more difficult. For instance, one can discuss the "capacity" of a bucket brigade to put out a fire, but only a bucket has capacity in the technical sense of describing an ability to hold a volume of water. If the fire brigade were to instead use a hose, its "capacity" for fighting the fire would be expressed in terms of a maximum flow rate, a parameter more explicitly relevant to the task at hand and more easily understood.

The term capacity is usually used colloquially to express a qualified maximum capability, i.e., maximum performance under certain ideal, specific conditions. It is understood that should the conditions of actual usage differ from the conditions used to rate the capability, the maximum rating would not be achieved. The use of the word capacity is therefore less meaningful in an operational sense unless a distinction is made between rated capacity and operational capacity and the respective sets of parameters supplied.

The fire hose, for example, would have a maximum flow rating that depends on its diameter, length, and ability to sustain pressure. Should it be pinched, assembled into longer lengths, or supplied by a less capable pump, the operational "capacity of a fire hose" would have a different value. In the same way, the operational "capacity of a bucket brigade" would be limited not only by the size of the buckets but also by the rate at which they can be handed off plus spillage, drops, brigadier fatigue, and available replacements.

From this perspective, it is appropriate to question the meaningfulness of using the unqualified concept of capacity to either promote or judge the value of ATNs. As an example of the latter, it would be unfair to negatively judge ATNs solely on the basis of all of the capacity reduction factors that have been discussed here. *All* modes of transportation operate with unused capacity[38]. Conversely, as has been shown, it is inaccurate to judge ATNs by reference to a theoretical maximum line capacity that will never, on average, be used.

A more appropriate concept and term to use is that of operational capacity—this being the realistic systemwide average number of occupied vehicles and/or passengers that an ATN can move as desired during periods of peak demand after accounting for all the factors that conspire against it. And, as is now clear, operational capacity must also always be discussed along with quality of service. This and all of the topics covered thus far form the basis of the final topic—just what level of operational capacity can be expected of ATNs.

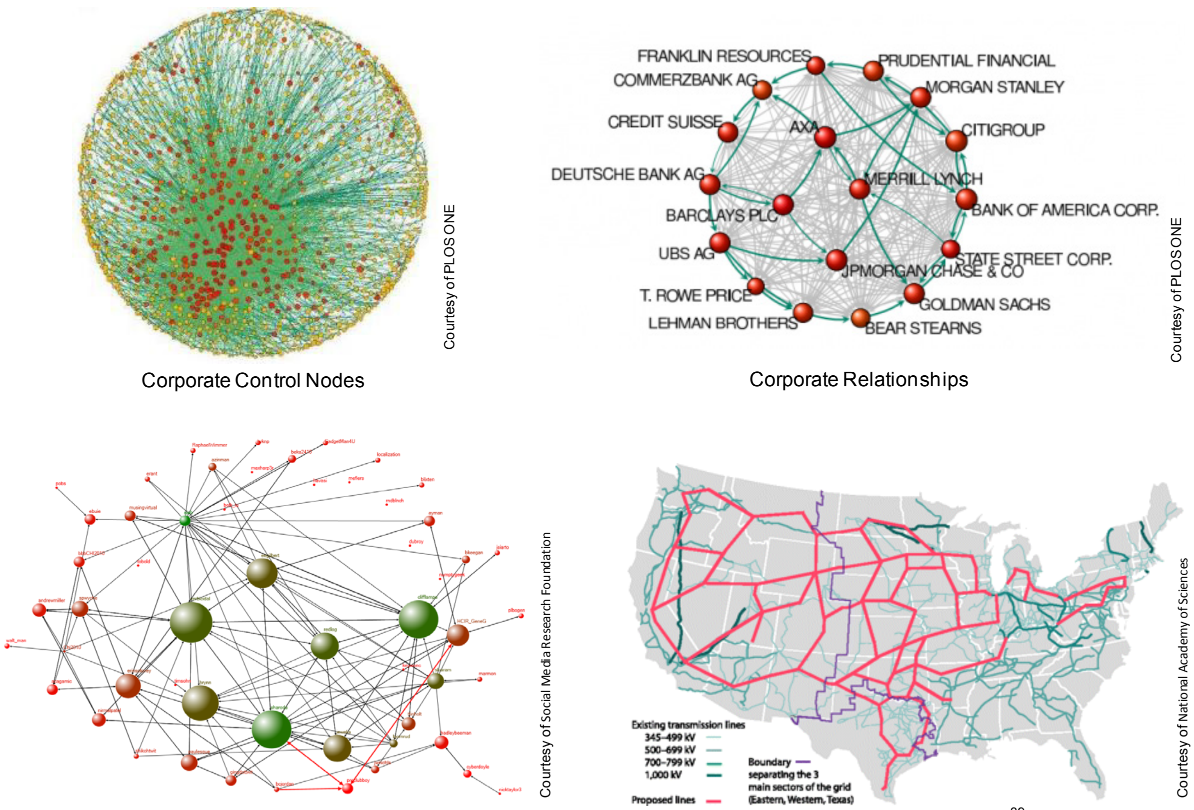
3.5.11 Network Behavior and Operational Capacity

Thus far, the basic line capacity equation has been deconstructed, illustrating how it is an inadequate estimator of ATN capacity. It has also been discussed that relevant estimates can only be done on a case-by-case basis based on simulations inextricably linked to specific control system designs. Many such case studies would need to be performed and the control systems themselves verified before any clear and comprehensive answer to this question can be given. So the question remains: Just what can be expected of ATNs? For the City's present purposes, a reasonable ballpark answer can be provided by looking at network behavior in general.

Since ATNs are "networks," they can be expected to behave like networks. In the decades since the origination of the ATN concept, a vast amount of theoretical and practical experience has been acquired in support of the design and construction of networks of all types, including modern computer and communications networks.

While most commonly associated with these two types of networks, the theory and modeling behind them have vastly broader utility, as shown in Figure 3.5-41. Regardless of type, all networks consist of links having a certain maximum transport capacity and nodes at which routing and timing decisions are made, and/or the "stuff" being transported is temporarily accumulated.

[38] In fact, ATNs, if properly designed, can perhaps do a better job of managing capacity, dynamically adjusting the number of seats in transit so that fewer travel empty—a potential characteristic oft cited by ATN proponents.



Corporate Control Nodes

Corporate Relationships

Social Network

United States Power Grid[39]

Figure 3.5-41. Networks: different yet similar.

Mapping network terminology to ATNs, guideway merges/splits, and stations/depots are the equivalent of nodes, and the guideway itself that connects these points are the links. Routing decisions for other than purely synchronous control schemes are made primarily in the vicinity of the merge/split nodes or some extent beyond. Timing decisions are made here as well in the guise of merge management and at stations where vehicles may or may not be held. Lastly, vehicles and passengers are buffered at stations/depots in the form of queues.

Unlike the networks shown, however, ATN are currently conceived as having only two or three links associated with each node. For stations/depots, there are only two—one in, one out. Merges and splits each have three; two in, one out for merges, and the reverse for splits. Also unlike the generalized network, merge/split nodes do not accommodate buffering[40] and they do not handle simultaneous bi-directional traffic. Lastly, they are functionally separate, i.e., merges are merges and splits are splits. They are unable to perform both functions simultaneously as in other networks, an implication of their two-in/one-out (merge) and one-in/two-out (split) design.

[39] C. D. Brummitt, R. M. D'Souza, and E. A. Leicht, "Suppressing cascades of load in interdependent networks," *Proceedings of the National Academy of Science (PNAS),* March 20, 2012, vol. 109 no. 12 E680-E689; online February 21, 2012, doi: 10.1073/pnas.1110586109

[40] The addition of sidings at points along the guideway has been proposed to serve as buffers. A number of other Internet-like network features have also been proposed in discussions of ATN design, but no quantified estimates of their performance impacts have been uncovered in this evaluation. The obvious infrastructure/performance tradeoffs must also be kept in mind as well as the impact of these features and operations on both the passenger experience and the underlying value proposition of the ATN concept.

Nevertheless, ATNs are similar to other types of networks: They are essentially elaborate collections of interdependent buffers (e.g., temporary storage locations, loading zones, staging areas, etc.) and links (e.g., wires, airwaves, or guideways), collectively known as service queues. The links represent “scarce resources” to which the client (the data packet or passenger) desires access. They are referred to as scarce because they are shared among the many possible routes between any pair of origin/destination nodes and because economical network design requires striking a balance among resources, demand, and quality of service. All of this means that the client can always anticipate waiting some amount of time in queues, regardless of the queues’ form or location within the network.

These waits are referred to in network jargon as service delays. The goals of a network designer is to lay out links and buffers to minimize service delays and infrastructure costs, provide a robust (i.e., fault tolerant) design via the ability to route around obstacles and failures, and balance loads across the network to maximize overall system throughput.

The very reason these factors are of such primary interest to network architects and operators is that delay and congestion are very real problems, requiring creative and proactive measures in both design and operations in accordance with the unique needs, demand levels, and traffic patterns of a particular application. And even despite experts’ best efforts at planning, implementation, and operation, network delays and congestion effects are by no means infrequent or negligible in their impact.

The reality is that any network, if not satisfactorily designed for its particular application, will exhibit these undesirable effects to a greater or lesser degree. Moreover, any network, no matter how well designed, implemented, and operated, has practical limits beyond which these effects become severe. All networks can always be overwhelmed by sufficiently high demand, variable spikes in usage patterns, failures of one or more network elements, and/or related factors.

It is of utmost importance for the City to recognize that *there is nothing unique or inherent about ATN theory, technology, design, or operations that makes ATN systems immune to such delays and congestion effects*. Service delays experienced within a particular ATN application (e.g., passenger wait times in stations and in vehicles while in input and output queues or as the result of merge maneuvering, etc.) are directly correlated to the operational capacity of a network. If scarce resources are overloaded, buffers fill up, wait times skyrocket, and congestion occurs. And a congested network is a network that is not transporting passengers, i.e., its operational capacity plummets.

For insight as to how this occurs, one can begin by taking a look at an individual queue. Queues, or waiting lines, are everywhere. When one stands in line at the bank, post office, or ATN station, you as a client are in a queue. The teller, postal worker, or ATN vehicle represents a “server” that provides the service you’re waiting for. The presence of either single or multiple servers is used to label the two generic types of queues: single- or multiserver queues.

The length of the queue over time depends on several factors: the volume and pattern of client arrivals (i.e., the number of clients and their interarrival time distribution, both of which typically possess at least some degree of unpredictability), the number of servers, and the “service rate” of each server (i.e., the number of clients that each can serve in a given period of time). The length of time each individual client spends waiting in the queue depends on these factors and the length of the queue at the time of the individual’s arrival.

A branch of mathematics called “queuing theory,” developed over the past 100 years to analyze, explain, and improve the performance of such queuing systems, provides formulas used to calculate waiting time and queue length as a function of the various parameters. Without delving too deeply here into their details or their applicability to specific types of queuing scenarios, let's stipulate there are three significant ramifications of queuing theory in regard to the behavior of heavily loaded networks, such as might occur in an ATN installation:

1. The delay experienced by a client not only gets worse, but gets *exponentially* worse as the system is more heavily loaded.

2. The delays not only get exponentially worse with increased load, but those delays become *increasingly variable* as the system approaches its maximum theoretical capacity. In transportation applications, *unpredictability* of delay is often interpreted by travelers as being as bad as, if not worse than, the delay itself.

3. To the extent that client interarrival times and service rates are themselves variable, service delays and overall system inefficiencies are further increased.

In practical terms in the context of ATNs, this means that the average delay is an exponential function of the average system utilization rate. At a utilization rate of 100 percent, the delay theoretically approaches infinity. Well before this point, however, a breakdown in vehicle flow will occur, resulting first in delays while in transit (i.e., congestion) and then gridlock, possibly taking hours to work through. Moreover, as the utilization rate increases beyond relatively modest levels, the *variability* in delays experienced by users will increase dramatically as well, occurring even in the ideal case of uniform demand (i.e., no surges). Unpredictable variability in demand, vehicle ingress/egress, or other perturbations common in transportation systems will result in additional negative effects on system performance.

The net effect of this collection of principal factors is represented generically in Figure 3.5-42, which shows a series of curves representing average delay as a function of system utilization for queue-server systems of various types. In all cases, the delay is of a highly nonlinear nature, rising exponentially as system utilization (i.e., demand) increases. Each curve also exhibits a "knee"—a point at which the delay begins to increase dramatically in response to very small increases in demand. It is at this point that networks become increasingly vulnerable to spikes in demand or minor diminishments in resources (e.g., the slow-moving truck that just entered the freeway or an ATN vehicle experiencing a battery failure). The location of the knee and the sharpness of the curve at this point vary from network to network depending on numerous variables, but the general behavior is always the same.

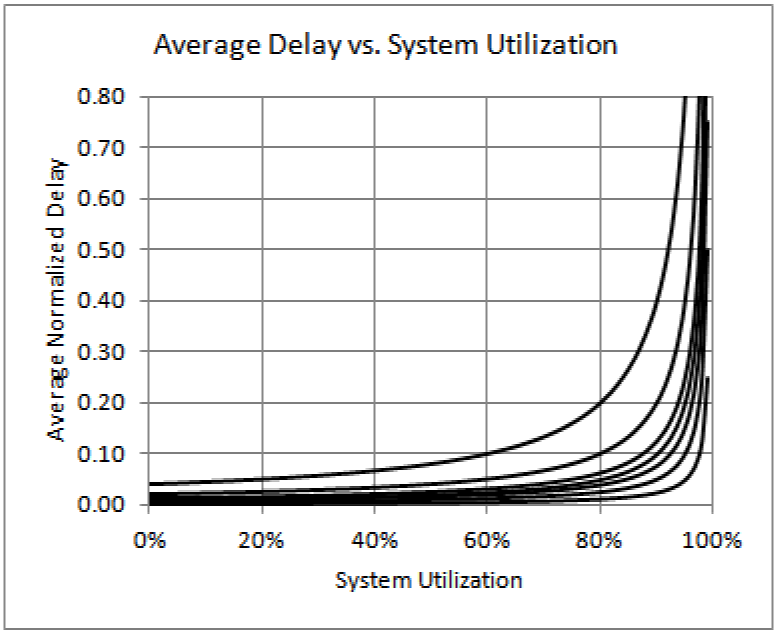


Figure 3.5-42. Average delay vs. utilization rate.

Elementary queuing theory is only of partial utility in analyzing the performance of simple queues and servers that constitute typical transit systems and is of even more limited value in assessing complex networks of interdependent queues such as airport runway and gate operations, multilane road networks—and ATNs. Nevertheless, the general behavior of these more complex systems is the same, as shown in Figure 3.5-43.

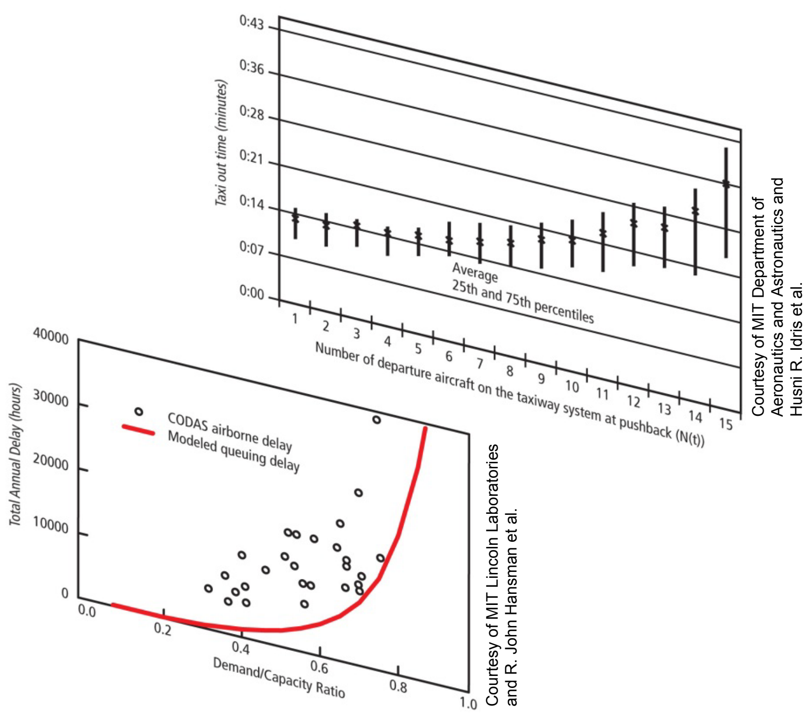


Figure 3.5-43. Common network performance characteristics.

The remaining question is: What performance characteristics can the City expect from ATNs? Networks similar in nature to ATNs possess a knee at a utilization rate of approximately 70 percent, a figure mentioned in at least one RFI response as an upper limit. An ATN system must be designed such that it possesses capacity adequate for smoothly servicing peak expected demand and, when doing so, be operated at some fraction of this maximum, this to account for variability in operations. Note that this variability does not include the expected peak demand, commonly referred to as surges, but, rather, unexpected peaks within peaks or other such disruptive and unaccounted-for events.

A number of sources citing different ATN applications that have been studied via simulations indicate that nominal operations in a range of 30 percent to 50 percent system average utilization rate can be generally expected. This applies to any given operational scenario and for any combination of factors that determine maximum individual line capacity.

3.5.12 Practical Network Performance: Summary, Outlook, and the Benefits of Automation

In this fairly lengthy but important discussion, it has been shown that the basic line capacity equation is an inadequate estimator of ATN system capacity. It is solely a statement of theoretical maximum line capacity. Its usefulness in estimating network capacity is as a parameter in a much larger and more complex set of calculations. These calculations can be performed only through mathematical simulations, which in turn are relevant only for particular applications, particular control system designs, and particular sets of assumptions, none of which have yet been verified via comprehensive physical testing.

Numerous factors are involved in such calculations, the principal ones involving the empty space that must be available and accounted for in the stream of vehicles operating on the network. This space is required to ensure safety, to enable the smooth merging of vehicles, and to prepare for merges via the maneuvering of vehicles.

When the net effect of all these factors is taken into account and fully represented in mathematical form, a more accurate, though still crude, quick estimate of ATN line capacity is given by:

$$Operational\ Line\ Capacity = R_u \times \left\{ \frac{3600}{(k_h \times H)} \times (VLF \times C_v) \times N_{occ} \right\}$$

where:

$R_u = \ Utilization\ Rate\ (nominal\ or\ maximum)$ (%)
$k_h = Headway\ Correction\ Factor$
$H = Nominal\ Headway\ (sec)$
$VLF = Average\ Vehicle\ Load\ Factor$ (%)
$C_v = Vehicle\ Capacity\ (seats/veh)$
$N_{occ} = Average\ Fraction\ of\ Occupied\ Vehicles$ (%)

Here, the utilization rate takes into account all of the network behavior effects. The nominal utilization rate represents the design target set low enough so that surges can be accommodated. The maximum value represents the point at which the quality of service becomes unacceptable, a point that will be tolerated only in short periods during surges. The headway correction factor is a number greater than one, which accounts for all those circumstances that tend to increase the separation required between vehicles beyond a best-case, constant-speed operation minimum.

All of these factors other than nominal headway and vehicle capacity will be highly dependent on numerous design and operational variables. From system to system, they will take on a correspondingly wide range of values. However, for purposes of illustration, if a set of values is assumed based on the previous discussion, the operational line capacity formulation can be compared to that for basic line capacity. Taking a value of 40 percent for the nominal utilization rate, 33 percent for the average vehicle load factor, and, say, 1.1 for the headway correction factor, an operational capacity that is 12 percent of basic line capacity would result ($0.40 \times 0.33 \div 1.1$).

This brings the discussion around to what *can* be expected operationally from the *automated* part of automated transit networks. The principal benefit of an automated network of adequate design and given the proper contol methodology will be to mitigate local congestion during periods of either average or peak demand. It can accomplish this by eliminating the number and behavior of "greedy vehicles" found in completely autonomous systems like conventional automotive transport. Vehicles that have their trips coordinated will encounter fewer contentions for resources and therefore fewer slowdowns or stops.

However, *this comes at the price of longer average trip mileage and times* as additional network resources are employed to balance load across the network. That is, in order to avoid local congestion, vehicles are diverted to alternate routes; one could say that they are essentially being *buffered in a moving queue*. The only other alternatives would be to buffer vehicles in static queues on the guideway (i.e., complete stops) or to decrease resource contention by limiting traffic—i.e., *by preventing access to the network entirely*. ATNs are no different from any other network, including that of conventional automotive transport, from the perspective of sizing a system to handle an anticipated demand. If demand exceeds capacity, congestion *will* occur. For automotive transport, it occurs on the network because individual drivers have no knowledge of others intentions. For ATNs, if the particular design will not permit network congestion and if network resources are fully utilized, *congestion will occur in stations*. This point seems self-evident upon reflection but is shrouded from view by claims of vastly superior performance as the result of automation.

The reader is asked to think about the many observations and decisions made when driving an automobile in a daily commute. It is realtively easy to keep a vehicle between the lines, a bit less so to execute cooperative maneuvers such as lane-changing into gaps in traffic, and perhaps even less so to judge safe separation distances and react to sudden anomalies. It is almost impossible to coordinate routing with other drivers over the broad area of the commute.

Given the opportunity and sufficient resources, ATN designers can, from a technical standpoint, provide systems capable of doing all of these things, *but this in and of itself does not translate into high capacities*. Only by operating ATNs in a manner that is truly unprecedented can higher capacities even be comtemplated, no less delivered. This, in turn, depends on a complete redesign of current ATN systems, *before-the-fact* regulatory willingness, and, most importantly, similarly *before-the-fact* public acceptance. This is a tall order and is at the heart of the decades-long chicken-and-egg problem known as ATNs.

And this brings the discussion to its final point. Efforts to promote ATNs as being high capacity may have resulted in what may be a disproportionate focus on this single factor, leading to one-size-fits-all designs that may turn out to be as inefficient as those that ATNs are attempting to outdo. Capacity is part of a tradeoff against quality of service. It may be more beneficial to discuss ATN capacity in terms of the right capacity instead of high capacity, extending the oft-made just-in-time analogy to the seat level as opposed to the vehicle level and broadening the scope of the ATN value propostion. In other words, value is also to be found in providing new services of superior quality and in the efficient use of resources. This suggests a broader view of ATN design, a topic that will be discussed later in this report after a look at other less dramatic but still important topics.

3.6 Station Operations and Throughput

It is clear that estimates of ATN capacity must include the performance of stations as well as of the network proper. For applications involving heavy localized demand, stations can be the dominant source of operational delays, acting as a choke point to seriously constrain overall passenger throughput even if line throughputs and local traffic loads were of such magnitudes that they could accept the demand. In other words, a network that performs well does no good if stations underperform.

A number of station configurations have been proposed over the long history of ATN research, all with the goal of meeting service demands and maximizing throughput, thereby minimizing wait times. There is, for example, the “traditional” linear station in which vehicles are queued nose-to-tail operates much like a taxicab stop: a first-in/first-out model in which passengers generally board vehicles at the head of the queue and exit from vehicles at its tail. This type of station has received extensive treatment in ATN literature, the principal variation being whether or not to configure them like cab stops with separate loading and unloading areas or to have passengers wait in their vehicles until arriving at a shared loading/unloading area.

The contemporary development community is proposing, in addition to linear stations, an alternative referred to variously as “sawtooth” or “finger” stations—essentially the familiar angled parking. The performance of this type of station has received only cursory treatment in the literature and therefore drew the most attention in a review of the RFI responses.

As there are a number of other configurations one could envision that could function in a similar manner, they will all be referred to collectively here as “nonblocking” stations for reasons that will be made clear shortly. Also, to avoid associating the design with any particular developer and to ignore minor design variations, the term “angled berth” will be used to encompass both the sawtooth and finger variants. A typical general arrangement for a nonblocking, angled-berth station having three berths is shown in Figure 3.6-1 on page 133.

In this section the performance of this variant of nonblocking station design is discussed in some detail. Performance analyses existing in the literature were found to be relatively crude and spanned an unacceptably wide range of throughput estimates and behavioral characteristics unsuitable for planning purposes. A more detailed model was constructed, returning the expected result of throughputs lying between the existing bounding estimates and clearly demonstrating bounding performance limits (i.e., marginal returns) relative to the number of berths. These inherent performance characteristics and limits will be of considerable importance in planning for the Airport and other applications, with angled berths able to perform as assumed in low-demand situations but having performance limitations relative to higher-demand situations.

3.6.1 ATN Station Performance in Perspective: Arguments and Counter-arguments

The ability of stations to process passengers must be matched to that of the local network as a matter of economical design, efficiency, and satisfactory overall system performance in terms of servicing local demand. Doubts as to the ability of ATN stations to process adequate numbers of passengers, especially during demand surges, is one of the principal sources of criticism of the ATN concept.

It is rather easy to understand the intuitive basis of this criticism. A bus or an APM vehicle can clear a large load of passengers in a very short period of time, say due to a surge in flight arrivals at the Airport. The APM vehicle previously considered for use at the Airport, for example, is about as long as three typical ATN vehicles and capable of accepting from 100 to 192 passengers, depending on the amount of floor space allocated to each, whereas the three ATN vehicles would accept 6 to 18 seated passengers given typical current designs, depending on their design width[41].

ATN vehicles are, of course, envisioned as being served up much more frequently (i.e., at much shorter intervals) than conventional systems, thereby mitigating this performance discrepancy somewhat. There is, however, no getting around the simple math that passengers other than the first 6 to 18 in the first group of 100 to arrive at an empty concourse and waiting vehicles would experience this situation as a comparative delay. In the best-case comparison between these two vehicle types and assuming ATN departure intervals of one minute[42] and fully occupied vehicles, the last group of ATN passengers out of an initial 100 will have waited approximately four minutes longer than if they had been served by the single APM vehicle.

However, one must complete the comparison and ask about the maximum and average wait times for the *next* group of 100 passengers in this test case. If the departure interval between the 100-seat APM vehicles exceeded five minutes, some of the next group of ATN passengers would, by comparison, have already been able to board and begin their trips. If the APM departure interval equaled 10 minutes, the last of the second group of passengers would experience no technical difference in time spent waiting between the two systems, and the majority of passengers would have waited less time[43]. The average wait time for the group will have been 2 minutes ((0+1+2+3+4)/5). This would recur on an ongoing basis, given a constant supply of passengers and vehicles departing on the given schedules.

Except in certain limited circumstances, however, one would not expect groups of 100 passengers to arrive like clockwork or form queues or "clouds" consisting of several hundred passengers. Situations such as those existing at large venues or train stations are examples of where this *is* likely to occur; the interarrival time between individual passengers is extremely short because they are all on the same schedule. In the more general circumstance, however, large queues or clouds can form precisely because the interdeparture time of *seats* is longer than interarrival rate of passengers. However, even in an application like the Airport, in which several fully loaded planes may arrive in a short period, passengers on their way to an ATN concourse would be "metered" by the deboarding process and visits to shops, restrooms, and baggage-claim areas. ATNs are, in fact, intended to take advantage of the consequent lengthening of passenger interarrival times at the ATN concourse due to effects such as these. This is the source of the "just-in-time" characterization of ATNs, and it is a reasonable perspective.

3.6.2 Angled-Berth Station Performance

The purpose of the above discussion was to acknowledge the truths contained within both the arguments and counter-arguments relative to this particular aspect of the ATN concept. The simplistic analysis and selected values were not intended as a definitive analysis of actual operational designs for either ATNs or conventional systems. Note, for example, that the above test case implicitly

[41] For purposes of this discussion, a mixed-size vehicle fleet is not considered. A mixed-sized fleet is, however, a reasonable system design option that is being considered by some in the development community and is discussed elsewhere in this report.
[42] This approximation is based on ASCE APM performance standards, a 5 mi/hr station speed limit, and a 30-second boarding-time allotment.
[43] Passenger psychological perception may, however, be a different matter.

assumed that three ATN vehicles would be operated as if they were a single unit, a possible but not general case of proposed ATN operations. The major point of the discussion is that vehicle capacity is but one factor in a more complicated determination of transportation system station performance in general. The more salient metric is the comparison between the interdeparture time of seats and the interarrival rate of passengers, which is examined here in detail for the proposed angled-berth ATN station design concept.

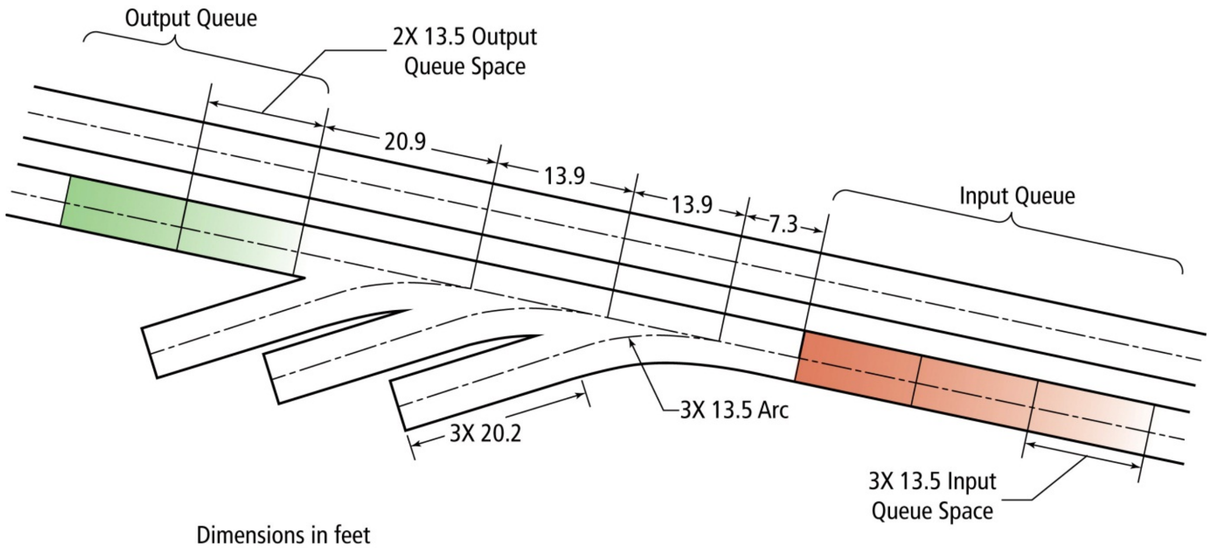


Figure 3.6-1. Angled-berth station geometry.

As the development community has pointed out, angled-berth stations do, indeed, have a number of desirable attributes suitable for particular applications. They are more compact in the direction of travel than linear-berth stations by virtue of their angled geometry, and they by definition co-locate passenger entry and exit platforms as in the linear station variant mentioned above. They are distinct from linear-berth stations in that they allow for a dynamic intertwining of exit and entry platforms, as an entering vehicle can unload its passengers at a downstream berth simultaneously with passenger loading at an upstream berth.

The principal impetus to this configuration, however, is the desire to avoid having parties of passengers that are slow to board at a downstream berth block the departure of an upstream vehicle that is boarded and ready to go. As the theory goes, vehicle operations will then become independent of each other, allowing an unimpeded flow of station traffic. This, in turn, is intended to decrease the average interdeparture time of seats.

This can be understood in the same terms as the performance of the simplistic model used in the previous section, in which lesser interdeparture times of smaller vehicles resulted in a lower average wait time as compared to that for larger vehicles operated with greater interdeparture times. Just as the three small ATN vehicles operating in unison in that comparison could be viewed as an independent subset of a large vehicle, so could individual ATN vehicles each be regarded as an independent subset of a linear queue of ATN vehicles. The linear queue would be forced by the slowest-boarding passengers to operate in unison at consequently longer interdeparture times, similar to the assumption earlier for the large vehicles in the test case. The ability to operate individual ATN vehicles independently with lesser interdeparture times is the analog of the three vehicles acting in unison in the test case. In other words, angled berths are intended to allow all of the various station operations—vehicle arrival, passenger loading and unloading, and vehicle departure—to take place in parallel and independently across berths, thereby decreasing average wait times relative to linear-berth stations.

However, this presumption of independent operations has apparently not been fully investigated. Figure 3.6-2 below shows two estimates of nonblocking station performance found in contemporary ATN literature [15, 18]. The straight line is a representation of the assumption of completely independent individual vehicle operations; the curved line is an estimate based on the simplifying assumption that vehicles in alternate berths depart simultaneously and the observation that they thereafter block the movements of vehicles into and out of the remaining berths during their transit through the station.

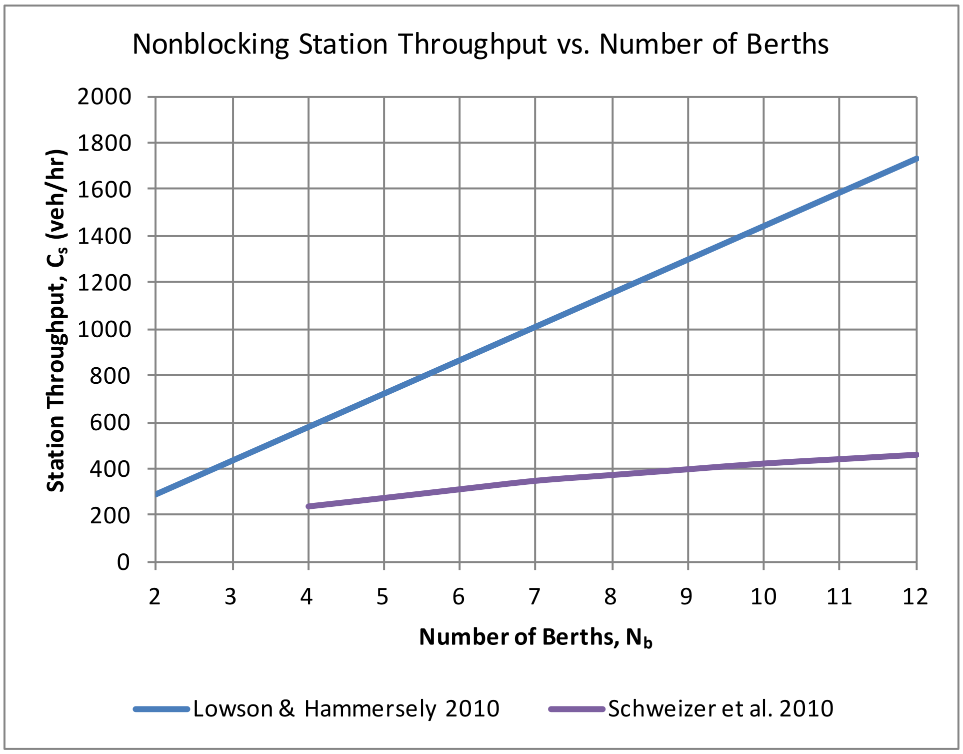


Figure 3.6-2. Nonblocking station performance estimates.

The observation upon which the lower curve is based is correct; while one source of interference has been mitigated by this form of nonblocking station, another has been introduced: A blockage now occurs on the station guideway as vehicles back out, momentarily pause, and finally accelerate downstream, thereby blocking upstream and downstream vehicles entering the station or in the process of departing, respectively. Although the "blockage time" is uniform and smaller in value as compared to its equivalent for passenger entry/exit operations, it is always present and effectively re-establishes the dependency between individual vehicle operations.

At the point in the project where this was noted, the projected maximum 2030 demand between Terminal A and ConRAC was 709 passengers per hour. Under the "standard" presumptions[44] of ATN operations including an average passenger load of 1.4 passengers per vehicle, the resulting number of vehicles that a station at Terminal A would need to process is 506 vehicles per hour. It became immediately apparent that this was of crucial concern for the Airport application.

[44] Note that other operational modes are possible. This topic is discussed later.

This is an analytically intractable problem via an algebraic approach, similar to that of predicting the performance of the network proper, especially when considering the less controllable stochastic (i.e., randomly distributed) processes of passenger arrival and boarding. In order to further investigate the issue, a discrete event simulation model was constructed to explore the behavior of angled-berth stations under an assumed set of conditions. The model is roughly based on the geometry shown in Figure 3.6-1[45] and accounts for the possible presence of vehicle input and output queues as indicated.

3.6.3 Early Investigations

The model was used in a set of early subanalyses to investigate the effects of several parameters of presumed importance, all relative to the number of vehicle berths:

1. Vehicle-in-motion options: Either technical or regulatory considerations can limit the number of vehicles in simultaneous motion on the station siding. Two bounding cases were examined: operation limited to either a single vehicle in motion or allowing any number of vehicles in motion, each governed by similar but distinct sets of control rules.

2. Output buffer size: Four different values of the number of output buffer locations were selected: a single location, a value equal to the number of berths, one-half the number of berths and one-and-one-half the number of berths (rounded down for odd numbers of locations). The number of input buffer locations was taken to always be equal to the number of berths.

3. Network headway: Initial investigations considered six seconds and three seconds. This was varied in order to understand the interaction between station and network performance and the source of any apparent limitations.

The evaluation approach was to first consider an optimistic bounding case, however unrealistic it may be, in which passengers are present in an infinitely long queue, choose to travel in parties averaging 1.4[46] passengers per vehicle, and board vehicles individually in times which are lognormally distributed (i.e., a skewed distribution more appropriate to this type of problem and which has an asymmetric profile differing from the common normal distribution with which the reader may be familiar). This bounding scenario also assumes zero bypass traffic on the main guideway proceeding to downstream destinations. This provides the station an opportunity to introduce vehicles onto the network at a rate up to that limited only by the specified network headway (i.e., a station, if able, would be allowed to fully saturate its local downstream guideway). Lastly, all vehicles entering the station are assumed to be empty (i.e., there is zero traffic inbound to the station) and are introduced as required, again at a rate limited only by network headway (i.e., a fully saturated upstream guideway).

In each case, station performance was simulated for a number of berths ranging from two to eight in increments of one. Slightly different parameters were used over time as the model was refined and as early results removed certain parameters from further consideration. This will be noted as they are discussed. The full parameter set and values used throughout the analyses is listed in Table 3.6-1.

[45] The geometric and operating assumptions went through a series of revisions during the course of the project, the details of which are omitted for brevity's sake. This accounts for the discrepancies between values noted in figures and tables in this section. Their principal effect is on magnitude; the general behavior discussed will not be affected.
[46] The occupancies of individual vehicles in the simulation are drawn from a party-size distribution having party sizes ranging from 1 to 4.

Table 3.6-1. Angled-Berth Station Performance Analysis Parameters and Values

Parameter	Value	Unit
Headway	3.0, 6.0	sec
Line speed	24.0	mi/hr
Line acceleration	± 0.1	g
Station speed	5.0	mi/hr
Station acceleration	± 0.1	g
Per-passenger load time distribution	Log (7.2, 0.7)	sec
Interberth spacing	14.3	ft
Input/output queue position length	12.0	ft
Berth entry time	2.0, 3.2	sec
Door open time	1.5	sec
Door close time	1.5	sec
Berth exit time	2.0, 5.0	sec

3.6.3.1 Station Maneuvering Control Logic

In this brief section, the notion of station control rules is discussed. These rules constitute the control logic governing vehicle motion in a station and can have a significant effect on its performance. Each rule represents a decision that a station controller is required to make. The control logic of current ATN designs is unknown. A reasonable set of rules was assumed here and encoded in the simulation model. It follows that different sets of rules can result in different performance and that perhaps more sophisticated controllers can possibly increase performance beyond levels noted in this section. Overall behavioral characteristics, however, are likely to be similar by virtue of the basic design.

The simplest set of control rules applies to the case of limiting motion on the station siding to that of a single vehicle. A more complex set is required if multiple vehicles were allowed to be in motion on the station siding at any given time. A combined rule set is listed below. For many of the individual operations requiring control, the two sets would be identical; the differences between the two operating modes are as indicated.

Tracing the journey of a vehicle from the guideway upstream of the station to its stop at the station to pick up passengers and its departure into a downstream flow of vehicles, the rules are listed as they are encountered along with, for convenience, restatements of the assumptions made to define this very special, optimistic bounding case:

1. Traffic upstream of the station is fully saturated at the designated headway and consists entirely of empty vehicles.

2. Vehicles depart from the guideway as required by the station, as represented by an empty location in the input buffer. Vehicles not needed are simply made to disappear, leaving completely empty the station bypass so that the station has maximum opportunity to introduce vehicles onto the network.

3. Vehicles leaving the guideway slow down at the mainline deceleration rate to station speed. The length of the deceleration lane is defined as the distance between the split and beginning

of the first input buffer location. The distance is calculated from the line speed and deceleration rate.

4. All vehicle motion between the beginning of the first input buffer location and the end of the last output buffer location is governed by station speed and acceleration/deceleration limits. Jerk is not considered; potentially low values of the jerk parameter are taken into account in later subanalyses via the use of modified time-equivalent accelerations/decelerations.

5. An entering vehicle can proceed directly to an open berth if:

   a. Individual motion: The input buffer and siding are both completely clear.

   b. Simultaneous motion: The input buffer is completely clear and the siding is clear upstream of the empty berth (i.e., departing vehicles may be in motion downstream of the open berth).

6. An entering vehicle stops at the most downstream location in the input buffer if the input buffer is clear and if:

   a. Individual motion: Another vehicle is in motion anywhere on the siding or if all berths are full.

   b. Simultaneous motion: Another vehicle is in motion on the siding upstream of the empty berth or if all berths are full.

7. If any of the input buffer locations are occupied, the vehicle stops in the immediately adjacent upstream input buffer location.

8. If the input buffer is full, vehicles do not enter the deceleration lane; they disappear.

9. Vehicles proceed from the most downstream input buffer location into an empty berth when a berth is open and the siding is completely clear[47].

10. Vehicles remaining in the input buffer shift forward in unison, opening up an upstream buffer location.

11. Departing vehicles back out in accordance with the berth exit time parameter if:

    a. Individual motion: An opening exists in the output buffer and the siding is completely clear.

    b. Simultaneous motion: Sufficient openings exist in the output buffer and the siding is clear downstream of the departing berth (i.e., multiple vehicles may back out nearly simultaneously, and arriving vehicles may be in motion upstream of the departing berth(s)). Departure command priority is given to the longest-waiting boarded vehicle *after* the above rules are enforced (i.e., on occasion, a ready vehicle may see its neighbor

[47] This is accomplished in a two-step process: a) Vehicles stop at the entry to a berth according to station speed and acceleration/deceleration limits, and b) vehicles proceed into the berth according to a separately specified berth entry-time parameter. This was done for the purpose of modeling convenience and flexibility; the obvious discrepancy between this and a more realistic continuous motion is slight and accounted for on an overall per-berth cycle-time basis via judicious setting of the entry-time parameter.

complete its boarding and depart first; given the random variations in boarding times and party size, the next-to-depart vehicle will also be located randomly among the berths).

12. Departing vehicles proceed to the most downstream output buffer location(s) possible.

13. Vehicles always stop at the last downstream buffer location (similar to a freeway on-ramp metering signal).

14. Vehicles remaining in the output buffer shift forward in unison, opening up an upstream output buffer location.

15. Vehicles accelerate to line speed at a rate limited only by the network headway.

And this is for a rudimentary station controller that needs to coordinate only minimally with the network!

3.6.3.2 Individual vs. Simultaneous Motion

Since it is not known how regulators might approach the issue and since stations of more than a few berths and serving fairly high demand have yet to be introduced, the basic station control issue of whether or not to allow simultaneous vehicle motion on a station siding is a potentially significant consideration. The results of this subanalysis are shown in Figure 3.6-3. As one would expect, limiting the number of vehicles that are allowed to move simultaneously in a station to a single vehicle severely restricts station throughput. If stations operations were limited in this way, the figure shows that a fairly linear *reduction* in throughput relative to the number of berths can be expected. This occurs because the average distance that departing vehicles must travel increases linearly as berths are added, increasing average vehicle interarrival times at the output queue. Note that the average interdeparture time varies from 17 seconds to 28 seconds per vehicle, far exceeding the network headway.

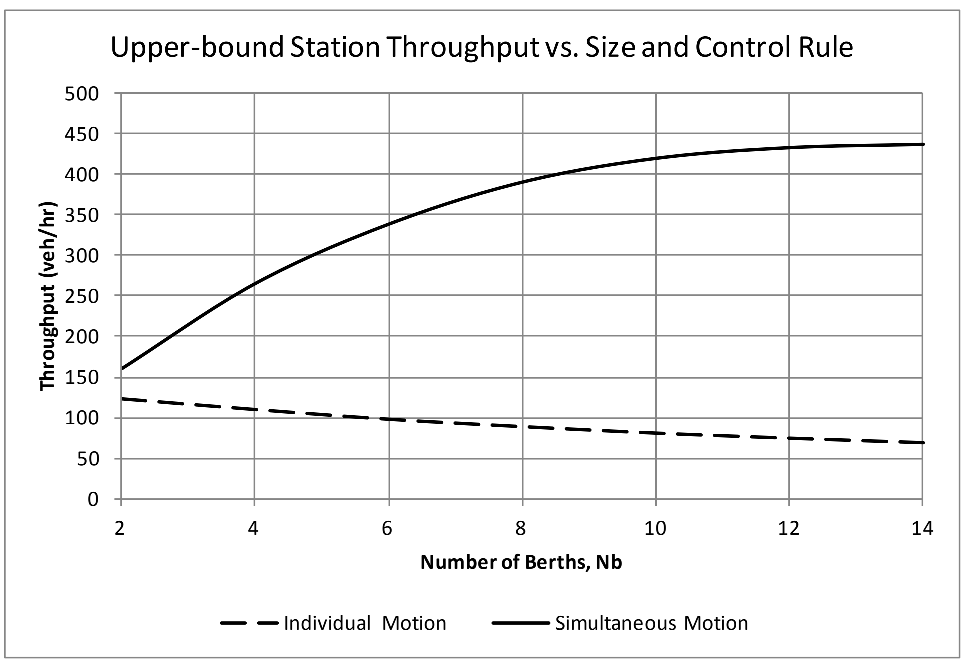


Figure 3.6-3. Upper-bound station performance.

For the case of allowing multiple vehicles to be in motion simultaneously, the simulation reveals a pronounced roll-off of throughput beginning at approximately four berths, leveling off at 12. Note that this occurs below the 600 vehicles per hour that the guideway could accept, given a six-second headway limitation. As only a single set of parameters and values was considered here, this particular subinquiry is insufficient to draw general conclusions as to the magnitude of throughput, but the fact that throughput doesn't reach a headway-limited value strengthens the observation that the roll-off is, at least for this case, due strictly to behavior within the station and is an indication of apparently marginal returns in terms of the number of berths.

Note that for this subanalysis, the numbers of input *and* output buffer locations were both set equal to the number of berths. As is discussed in the following section, this does not represent a limitation in this subanalysis; when the effect of buffer size is considered, a consistent set of results is obtained.

3.6.3.3 Output Buffer Size and Network Headway

Additional simulations continued to demonstrate the insensitivity of upper-bound station throughput with respect to network headway for this particular test case, taking the number of locations available in an input buffer to be always equal to the number of berths. The insensitivity to headway can be seen by reference to Figure 3.6-4 and Figure 3.6-5, in which the results for network headways of six seconds and three seconds are nearly identical. The implication once again is that stations are unable to process vehicles at a rate equal to the maximum the network could accept even at the lower rate corresponding to a headway of six seconds.

The indication of marginal returns relative to the number of berths is also strengthened since the results are also nearly identical for cases in which the number of output buffer positions is greater than or equal to the number of berths (i.e., station performance is not being limited by a deficit of output buffer positions).

The number of positions available in an output buffer proves to be very significant, however, if less than the number of berths, except, that is, for a station consisting of only two berths, for which all results converge to a single value. Allowing vehicles to enter and depart the station siding simultaneously results in increased throughput as compared to the individual motion case, but the small number of berths and average service cycle time conspire to limit vehicle arrival at the output buffer to intervals much larger than network headway. Neither of the two output buffer sizes possible for two berths—one and two positions—act to impede traffic flow; they are empty by the time the next vehicle arrives.

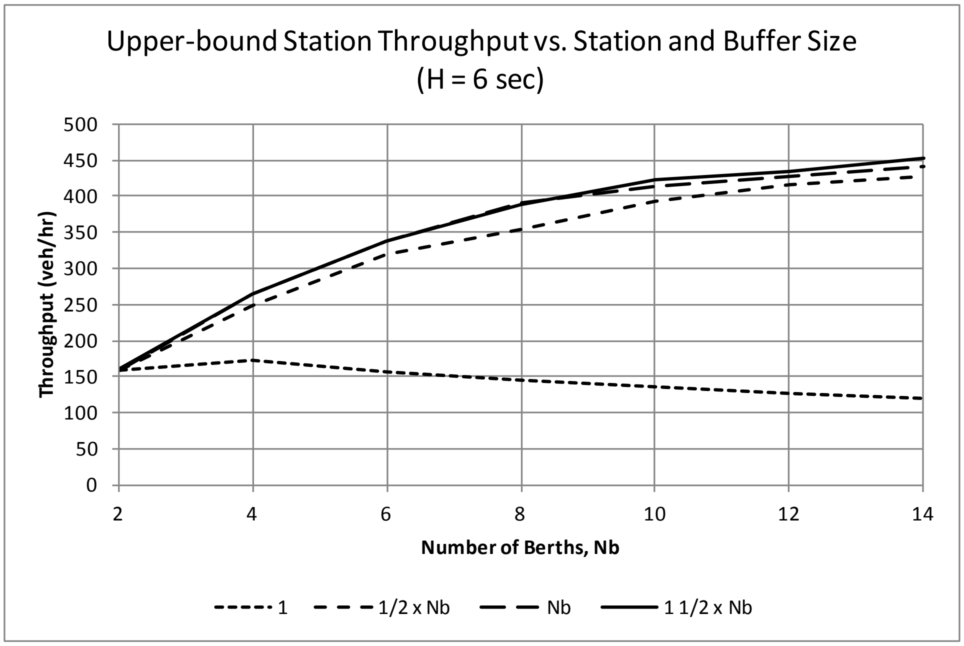


Figure 3.6-4. Upper-bound throughput vs. station and buffer size (6-second headway).

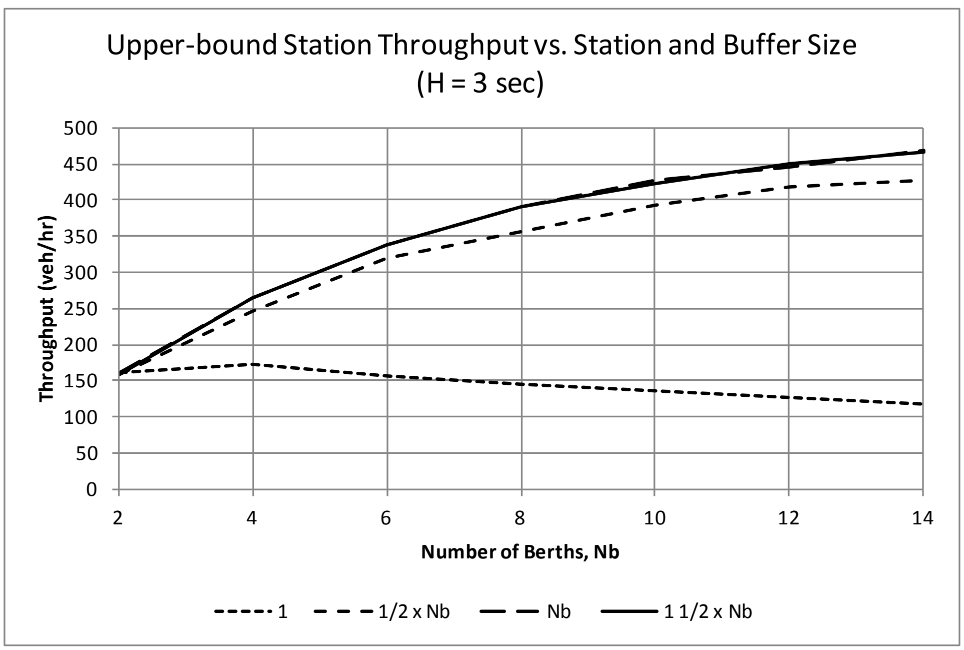


Figure 3.6-5. Upper-bound throughput vs. station and buffer size (3-second headway).

For stations having three berths, a slight gain in throughput is realized even if only a single output buffer position were available; the additional berth increases the rate of arrivals at the buffer. Beyond three berths, however, the more frequently occupied output buffer begins to force the station to behave in a manner similar to the individual mover case. The values are again slightly higher by virtue of simultaneous station entry and exit operations, but, since there’s only a single output buffer position, vehicles exit berths one by one. Performance continues to decrease as berths are added for the same reason governing the individual motion case: The average length of travel along the siding increases. The slopes of the two lines are identical.

For the intermediate case of the number of output buffer locations equal to one-half the number of berths, the result at three berths is identical to that for the single-location output buffer case. This occurs because the rounded-down value of the output buffer size calculation is the identical value of one. This effect is again apparent at five berths, indicating that for smaller stations able to take some advantage of the "parallel processing" of vehicles, the output buffer size can become a limiting factor.

As the number of berths and output buffer locations are increased, the likelihood of multiple vehicles being ready and able to depart increases. The rules of simultaneous vehicle operations allow multiple vehicles to back out of their berths and proceed up to an unoccupied output buffer location. However, in doing so, they more frequently block other vehicles that are waiting to depart, resulting in the noted roll-off in performance.

3.6.4 Integrated Station-Network Performance

One last analysis was performed to provide some insight as to the performance of angled-berth stations in a more realistic environment in which passengers are arriving as well as departing and some traffic is bypassing the station on its way to downstream locations. The same simulation model was used. A single set of basic traffic parameters was considered against variations in several key parameters:

1. A rather high percentage (75 percent) of upstream traffic was assumed to be destined for the station in a 40 percent/60 percent split between inbound occupied and empty vehicles. This could be representative of an outbound rush hour. Empty vehicles were assumed to be available in the inbound vehicle stream on an as-required basis.

2. The remaining 25 percent of upstream traffic was allowed to bypass the station, which then, of course, occupies space on the guideway downstream of the station.

3. The simulations were run for six- and three-second network headways.

4. Since this simulation includes passengers deboarding vehicles at the station, a per-passenger unload time distribution similar to that used for boarding was included, in this case a lognormal distribution of log seconds (5.6, 0.6), about 20 percent lower on average than for boarding.

5. As before, a continuous and unlimited supply of passengers was assumed to be waiting in the station concourse.

6. In addition, after noting some extremely low acceleration/deceleration and jerk values being reported for in-station vehicle maneuvers, the effect of these parameters was examined using time-equivalent acceleration/deceleration values of 0.05, 0.10, and 0.20 g.

7. Simulations were run for two-, four-, six-, and eight-berth stations.

The results of these simulations are shown in the composite of plots in Figure 3.6-6. On the horizontal axes, the range of upstream traffic volume is listed. It is truncated in each case at a maximum value of two-thirds of theoretical maximum capacity consistent with the given network headway. The range of station throughputs, or outbound traffic levels, is listed on the vertical axes. Note that the level of total outbound traffic is implied by the sum of inbound occupied vehicles, which are unloaded and made available for outbound passengers, and inbound empty vehicles, as they are supplied on an as-needed basis. In other words, all vehicles leaving the station are occupied.

The straight line represents the ideal case in which 100 percent of demand, both inbound and outbound, is processed. Note that at any given value of upstream traffic flow, a point on this line is at a value of 75 percent of this flow, consistent with the assumption that 75 percent of all traffic is inbound to the station. Deviations from this line represent wave-offs—vehicles that were denied entry to the station because of congestion within. The occupied/empty proportion of these wave-offs would be identical to the occupied/empty proportion of the inbound vehicle stream under this set of assumptions. Note the potentially significant level of wave-offs even for larger stations at the lower value of network headway.

Of course, since the assumptions made for this set of simulations were a bit more realistic, station throughputs in no case approach the maximums investigated in previous sections. As the stations are operating below their unconstrained maximums, the diminishing return with the addition of berths is less dramatic than observed earlier, although still apparent. This can be seen by observing the smaller increments of throughput with respect to station size at any chosen value of upstream traffic flow. However, the nature of a station's performance limits of any particular size has been illustrated and remains a concern relative to the high-demand portion of the Airport project.

3.6.5 Angled-Berth Station Performance Summary

ATN station design and control continues to be as great of a challenge as the design and control of the network itself and will require significant maturation in understanding and design before station performance can be predicted with confidence for the general case. As of this writing and based on the information provided in the RFI responses, current angled-berth designs have apparently not been called upon to serve demand high enough to adequately test their performance limits. The development community has proposed other station designs, is correct in pointing out that station performance cannot be considered in isolation from that of the network, and is engaged to varying degrees in studying the issue.

It is most important to note that station design is not strictly a matter of controlling vehicle motions. Of equal, if not greater importance, is the development of an understanding of the behavior of passengers in the station concourse and during the boarding/deboarding process. The development community is likewise engaged to varying degrees in studying this absolutely essential issue as well. A thorough understanding is required in the case of both experienced passenger interactions and when encountering an ATN system for the first time. As is the case for establishing vehicle operating standards that are both safe and realistic in terms of performance, the City can expect that a great deal of human factors work will also likely be required with respect to station design to bring ATNs closer to larger-scale viability.

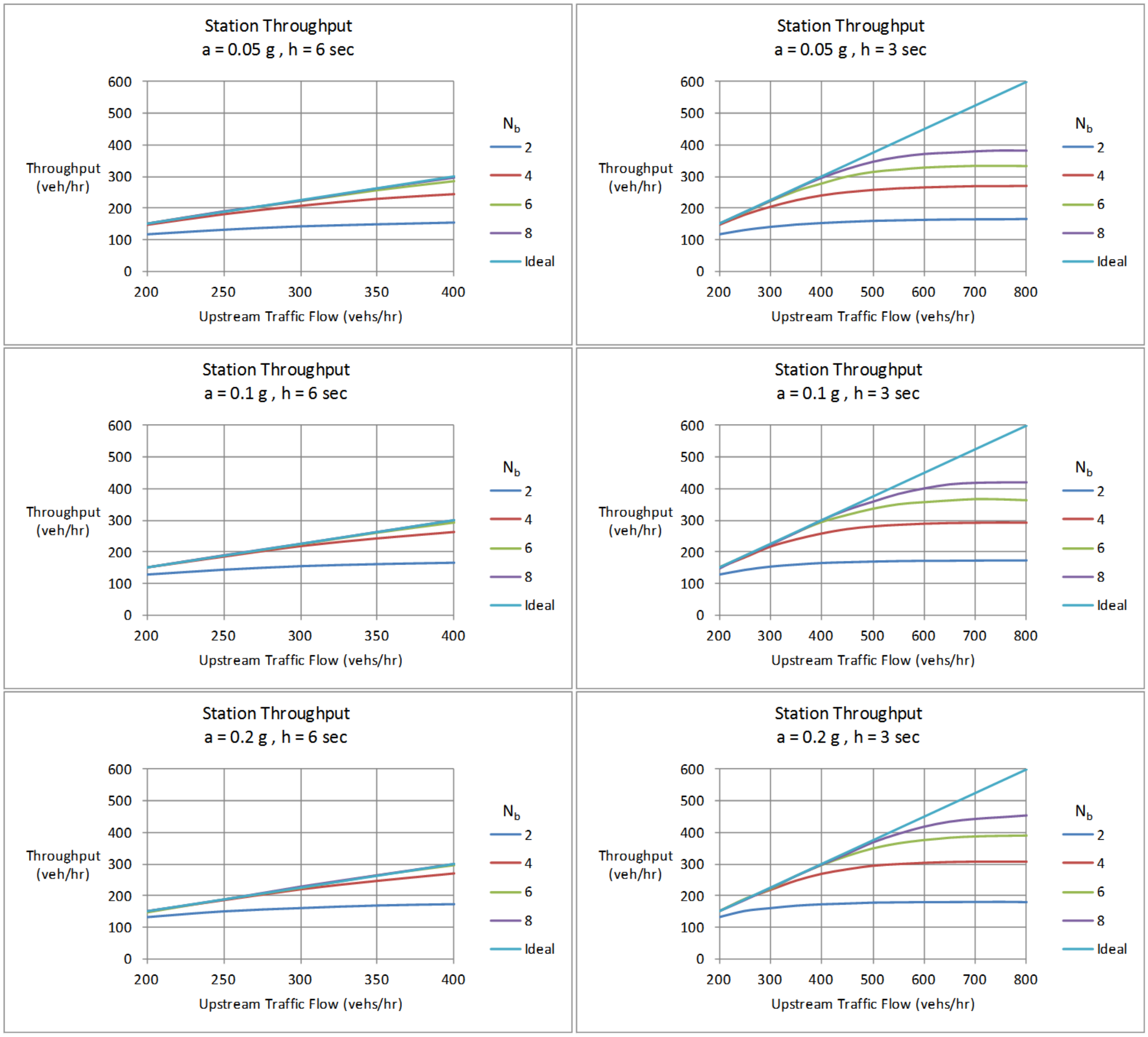


Figure 3.6-6. Integrated network/station performance.

3.7 Vehicle HVAC Power Requirements

Heating, ventilating, and cooling the cabin of battery-powered vehicles has been and continues to be one of the principal challenges faced by automotive engineers. HVAC power requirements can be of the same order as that for propulsion. They can therefore have significant effects on range, battery charging provisions, vehicle duty cycle, fleet size, etc., and consequently on the overall business case for the Airport and future applications within the City.

Although it is, of course, recognized as a design factor, very little information on the topic was provided in the RFI responses. For example, very close independent confirmation of reported power consumption values indicate that they consist solely of the power necessary for propulsion. Similarly, descriptions of vehicle construction seem to indicate only modest attention to thermal issues. It was therefore necessary to develop a first-principles HVAC power requirements estimate. It was also judged worthwhile to explore the potential for significant reductions of energy usage via some very simple vehicle and system design modifications.

The results confirm, but also quantify for the specific case of City of San José climate and weather, the significant impact of HVAC needs on overall energy requirements. The results also confirm the considerable reductions achievable through greater attention to thermal design, specifically by means of vehicle insulation and guideway covers. Although not possible to accomplish within project scope, this represents yet another interesting performance/cost design trade, one which is perhaps uniquely suitable to the ATN concept.

The analyses described herein were performed by the National Renewable Energy Laboratory (NREL) in collaboration with The Aerospace Corporation. NREL employed its test-verified CoolCalc vehicle thermal analysis tool throughout. This tool enables vehicle HVAC assessments of more than sufficient accuracy for preliminary design purposes to be conducted very quickly and economically, certainly relative to other, more detailed methods.

3.7.1 Baseline Vehicle and Design Day Definition

A mathematical model of a “typical” ATN vehicle was constructed assuming the baseline parameters listed in Table 3.7-1. These values were gathered and estimated from a composite of RFI response and other data. A graphic representation of the model is shown in Figure 3.7-1.

Table 3.7-1. Baseline ATN Vehicle HVAC Parameters

Parameter	Value	Units
Number of Thermal Zones	**3**	**#**
Cabin Volume	172	ft^3
Total Volume	218	ft^3
Opaque Surface Area	75	ft^2
Glazed Surface Area	65	ft^2
Heating Setpoint	70	°F
Cooling Setpoint	75	°F
Internal Mass	13.7	slug
Fresh Air Requirement	20	CFM(1)/pass
Zone Air Mixing	2.87	CFM
Internal Heat Load	200	W
A/C System COP(2)	1.8	n/a

(1) CFM = ft^3/min

(2) COP = Coefficient of Performance

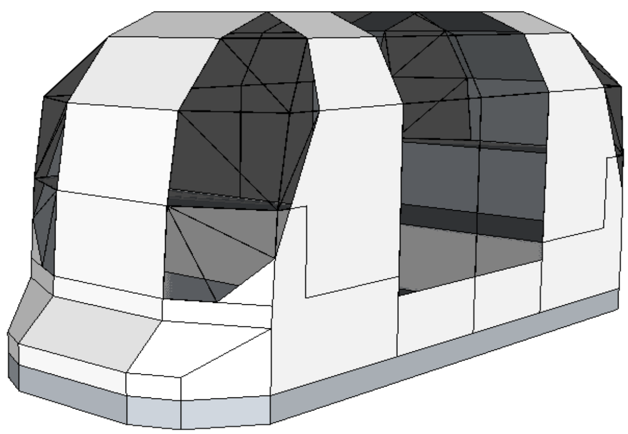


Figure 3.7-1. Baseline ATN vehicle geometry.

The vehicle is modeled with three interior compartments, only one of which—the passenger cabin—is thermally conditioned. The rate of air cross-mixing between the three zones was assumed to be 1.0 air change per hour (ACH), resulting in the value for zone mixing of 2.87 cubic feet per minute (CFM) listed in the table. The assumed internal heat load is intended to account for lights and other miscellaneous electronic equipment. The passenger fresh air requirement and heating/cooling set points are values suggested in the 2009 ASHRAE Handbook – Fundamentals [3] and in MIL-STD-1472G [4]. A typical value of 1.8 was assumed for the air conditioning system coefficient of performance (COP), accounting for air blower parasitic losses. The electrical heating system was assumed to have a COP value of 1.0. These coefficients are used to calculate electrical power requirements from thermal loads.

A principal means of heat transfer across the interior boundary of the vehicle shell is through convection currents driven by airflow from interior HVAC vents. As this flow rate increases from zero to a maximum relative to a variable blower speed, interior convection shifts from natural to forced convection, increasing the rate of heat transfer. This increased ability to transfer heat is expressed by parameters known as convection coefficients. The accuracy of HVAC power requirement estimates is improved by taking into account, or correlating, this variation of convection coefficients with changes in HVAC system airflow rate. Such correlations were previously developed at NREL via computational fluid dynamics (CFD) simulations of a light-duty vehicle (LDV). The four principal correlations—those for the roof (i.e., ceiling), walls, windows, and floor surfaces—were applied to the ATN baseline vehicle model based on its similarities with the LDV. These correlations are shown in Figure 3.7-2, in which the variation of the convective heat transfer coefficient for the roof surfaces relative to interior airflow rate is of particular note.

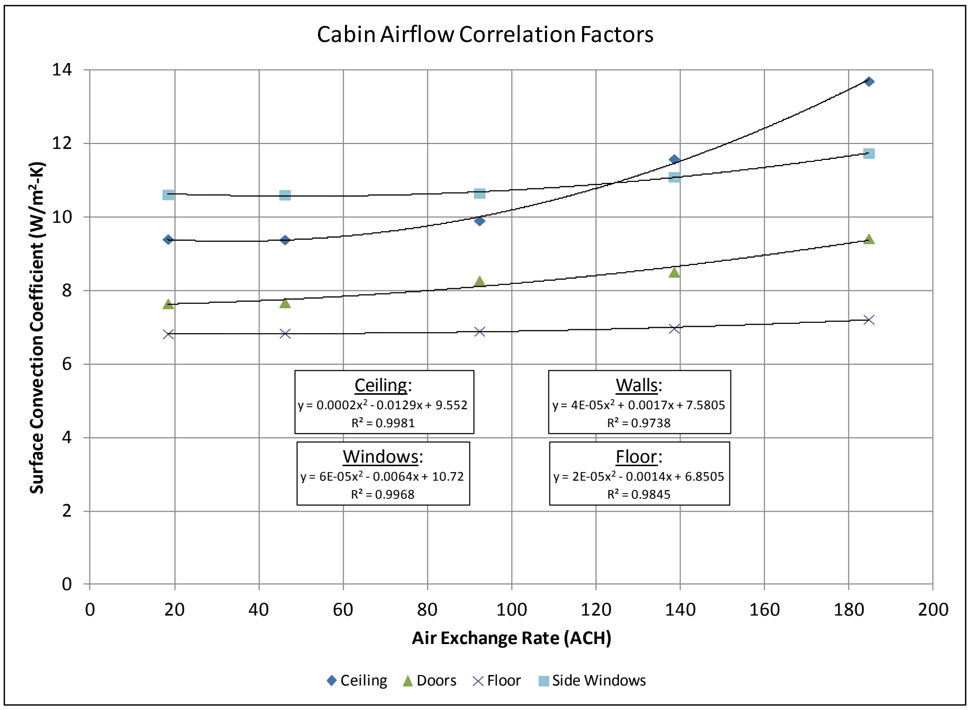


Figure 3.7-2. Convection coefficient/interior airflow correlation factors.

A set of realistic worst-case weather and operational parameters are required to perform a preliminary HVAC sizing capable of maintaining satisfactory levels of passenger comfort on the hottest and coolest days of a typical year, referred to as "design days." The pertinent parameters and their selected values are listed in Table 3.7-2. The selected temperatures and solar loads were taken from actual Typical Meteorological Year (TMY) weather data for San José. For the summer design day, diurnal variations in ambient temperature and solar irradiance typical to June 15 were used in the analysis. For the winter design day, the ambient temperature was fixed at the daily minimum and solar loads set to zero as the worst-case heating demand is assumed to occur at night.

The heat generation rates of vehicle occupants were taken from the 2009 ASHRAE Handbook of Fundamentals. The natural infiltration rate of outside air into the vehicle cabin was taken as 0.6 ACH based on tracer-gas tests previously conducted at NREL on a variety of vehicles. In addition to this natural infiltration (or "leakage") of air into the vehicle, 6.0 ACH is expected to result from the opening and closing of vehicle doors during passenger loading and unloading. This value is based on the assumptions that one-half of the cabin air is exchanged with ambient air in each station when the doors open/close and that this occurs every five minutes.

Table 3.7-2. Baseline Design Day Assumptions

Weather Conditions	Design Day		Units
	Summer	Winter	
Ambient Temperature	97	32	°F
Relative Humidity	17	92	%
Direct Solar Load	970	0	W/m^2
Diffuse Solar Load	89	0	W/m^2
Wind Speed	2	25	mi/hr

Simulation Parameter	Design Day		Units
	Summer	Winter	
Occupants	5	5	#
Metabolic Heat Generation Rate	126	108	W/pass
Insulation Thickness	0	0	in.
Natural Air Infiltration Rate	0.6	0.6	ACH
Air Exchange Rate through Doors	6.0	6.0	ACH
Shading	no	no	yes/no

3.7.2 Baseline Design Day HVAC Power Results

Due to the geographic orientation of the Airport and the fact that the major portion of the guideway aligns with this orientation, the simulations were carried out assuming a north-south vehicle alignment. The HVAC power estimates for the baseline design day simulations are shown in Figure 3.7-3, indicating values of approximately 3.7 kW and 2.4 kW for cooling and heating, respectively. After applying the respective COP values, the corresponding amounts of electrical power required are estimated to be 2.1 kW and 2.4 kW.

The curves of required power for cooling illustrate the impact of solar loading and swings in ambient temperature throughout the summer design day. The required power increases sharply as the sun rises and counterintuitively pauses slightly at noon, peaking at approximately 3 p.m. This occurs because of the assumed vehicle design geometry and north-south orientation. At a little after 9 a.m. and 3 p.m., the vehicle's side window areas are in broad view of the sun. At noon, as the sun passes over the assumed opaque front panel and roof of the vehicle, the thermal load decreases slightly, the side windows during this period playing a less significant role. At 3 p.m. the combined effects of maximum solar load through the vehicle's windows and higher ambient temperature result in a peak thermal load.

Note that the figures do not represent a complete hour-by-hour estimate of HVAC loads for the winter design day. As the worst case is reasonably assumed to occur at night, solar incidence is set to zero and the values of all other variables fixed. The power required for heating therefore reads as constant because, although the cooling power curve illustrates the interesting observation made above, it is only accurate at the peaks. This fulfills the intent of the analysis: to estimate peak HVAC loads during the worst-case hours of the worst-case days.

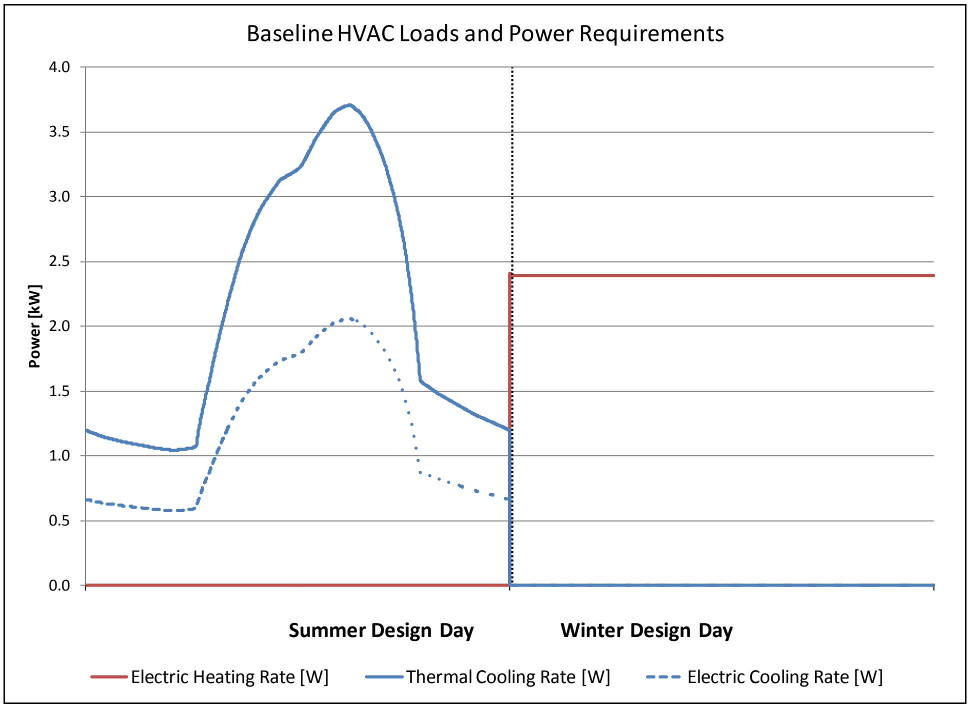


Figure 3.7-3. Baseline HVAC sizing results.

3.7.3 Parametric Design Day Peak HVAC Power Results

In order to understand the effect of several parameters on the sizing of an ATN vehicle's heating and cooling systems, a set of parametric design day simulations was performed. The effects of vehicle occupancy, insulation thickness, air exchange rate, vehicle speed and solar shading were investigated, as these are expected to have some of the largest impacts on HVAC system sizing and overall energy consumption. The parameters were considered one at a time, holding the values of all of its companions constant at the baseline value. They are discussed below individually.

3.7.3.1 Peak Power Requirements vs. Average Occupancy

Vehicle occupancy was varied from one passenger to a maximum of five. The results are shown in Figure 3.7-4. They are reported in a pair of bars for each occupancy level: cooling power on the left for the summer design day and heating power on the right for the winter design day. As expected, the peak cooling power required for the summer design day increased linearly from 1513 watts for one occupant to 2070 W for five occupants. Likewise, for the winter design day, the peak power required for heating increased from 1729 W to 2411 W. The incremental HVAC power requirement (140 W/person for cooling, 170 W/person for heating) translates to an increase of approximately 10 percent in peak required power per occupant. This is governed by two primary factors: the metabolic heat generation rate of the occupants and the per-occupant fresh air circulation required.

Looking at the set of leftmost bars across pairs, the incremental increase in required cooling power to account for the additional 126 W of metabolic heating per passenger can be clearly seen. This occurs on the summer design day. Conversely, a lower value of metabolic heating (108 W/person) reduces the required heating power on the winter design day. This is shown in the set of rightmost bars. The "savings" from relying in part on the metabolic heating from passengers is indicated by the dashed-line rectangles at the tops of the winter design day bars.

The other major factor relative to occupancy level is the fresh air requirement of 20 CFM per occupant. This component increases the climate control requirement for both summer and winter design days, as the cold winter air and warm summer air must be heated or cooled to the respective temperature set points. As can be seen in the figure, the fresh air requirement can have an impact on ATN HVAC power requirements of approximately the same magnitude as that of metabolic heating.

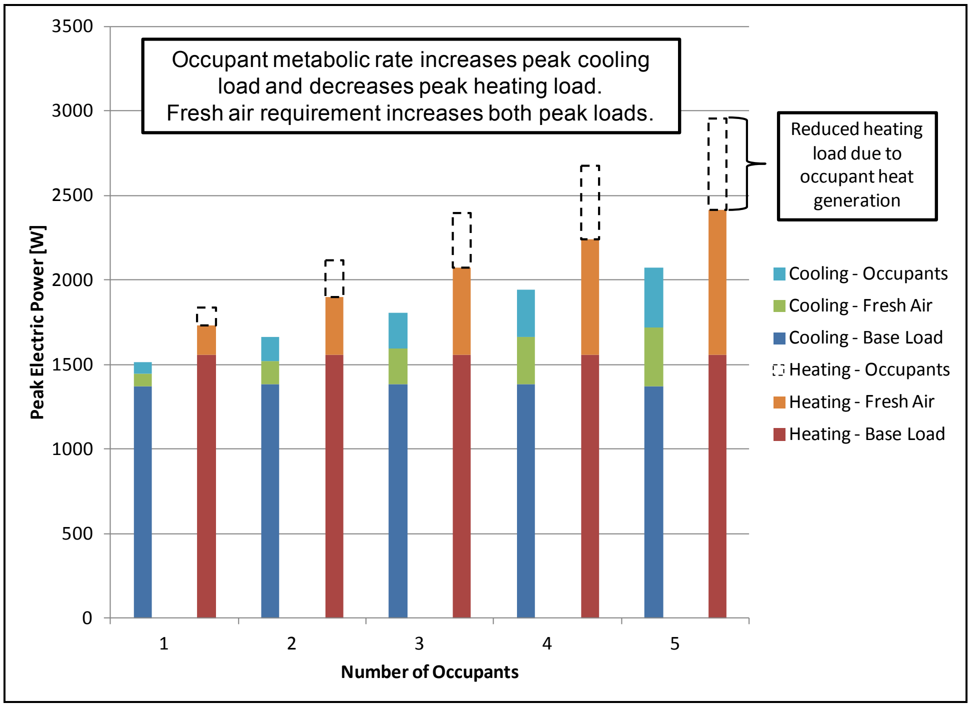


Figure 3.7-4. HVAC power vs. average occupancy.

3.7.3.2 Vehicle Insulation Thickness

Thermal design of ATN vehicle cabins is not a common discussion topic but could perhaps be another significant factor toward a goal of maximum energy efficiency and operational cost savings. It is unknown from the RFI responses how much attention has been given to this topic in current vehicle designs.

To evaluate its effectiveness, the summer and winter design day simulations were performed for insulation thicknesses ranging from the baseline zero to 3 inches in 0.5 inch increments. Closed-cell polyurethane foam was chosen for use in the analyses. This results in a range of insulative properties as expressed by a measure known as the R-value, ranging from a baseline value of 0.207 m^2-K/W to 3.520 m^2-K/W. The baseline value was calculated based on descriptions of typical vehicle construction as reported in the RFI responses.

The benefits and limits of cabin insulation are immediately apparent as shown in Figure 3.7-5: up to 10 percent for cooling power and 18 percent for heating power, with most of the savings attributed to the first inch of insulation.

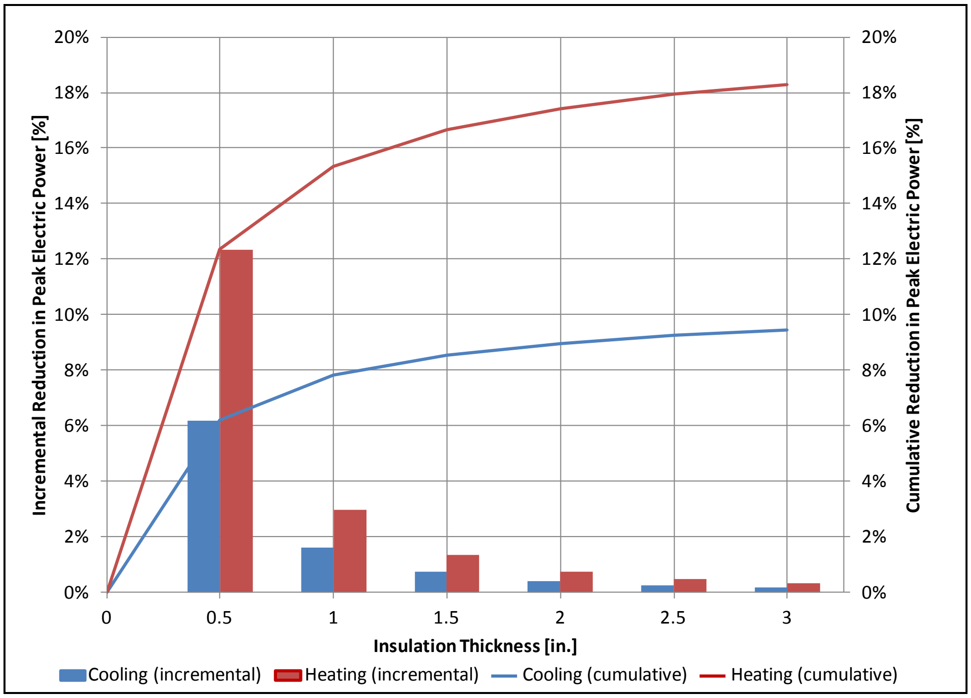


Figure 3.7-5. Potential HVAC power savings from cabin insulation.

3.7.3.3 Vehicle/Wind Speed

The effects on heat transfer and consequently on HVAC power requirements due to relative airspeed over the surface of an ATN vehicle is unavoidable, of course. They are important to know, however, from the standpoint of vehicle and overall power system sizing, empty vehicle management, and cost of operations.

As shown in Figure 3.7-6, peak heating power requirements at zero relative wind speed can be approximately 25 percent less than that required in the region of line speeds of interest. Conversely, peak cooling power requirements can be about 20 percent more.

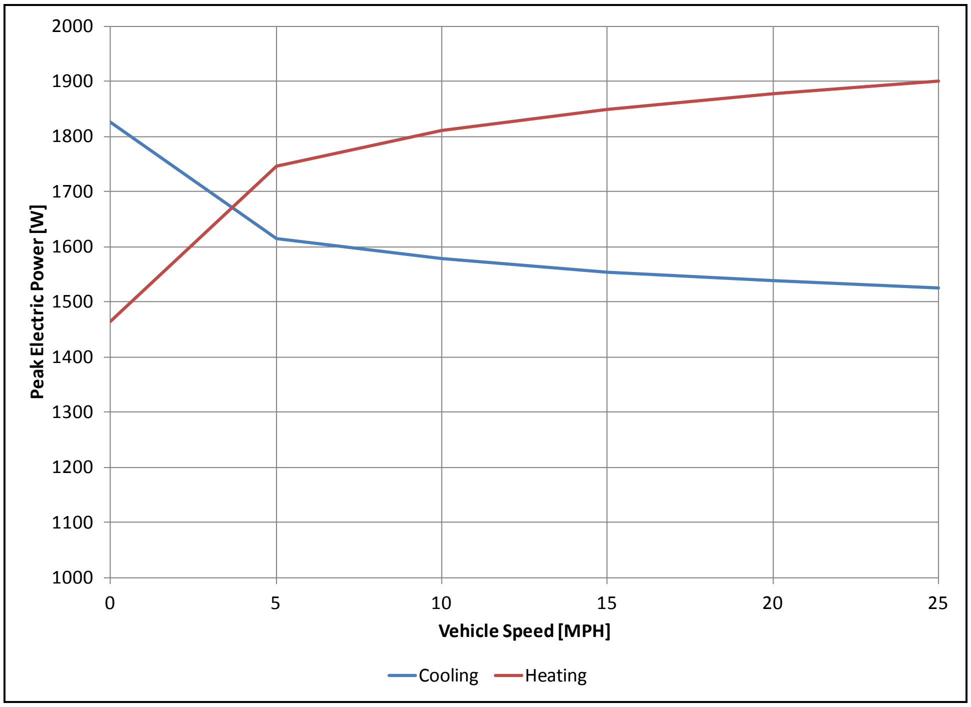


Figure 3.7-6. HVAC power requirements vs. vehicle/wind speed.

3.7.3.4 Average Cabin Air Exchange Rate

The frequent stops made by ATN vehicles can represent a significant challenge relative to vehicle HVAC power requirements. An exchange of air between vehicle cabin and station concourse will occur at every stop. To the extent the temperature and relative humidity of the air are different between these two volumes, the vehicle HVAC system will need to be of greater or lesser size. This suggests the prudent approach of considering HVAC from a systemwide perspective. At least some in the development community are currently doing this. The principal design trade is whether to take advantage of time in-berth and direct power pickup to run vehicle HVAC systems at maximum (e.g., in a manner similar to preconditioning techniques suggested since the earliest days of electric automobile research) or to simply force an exchange of air, essentially using station HVAC to handle the largest share of the job.

The analysis discussed in this section is intended to gauge the importance of the issue in an ATN system via preliminary estimate. The rate of air exchange is dependent on the frequency with which stops are made, the fraction of interior air replaced by concourse air, and, as noted above, on the relative differences in the condition of the air in each volume. The baseline assumptions made for purposes of this analysis are that the full cabin air volume is replaced at each stop, the stops occur at five-minute intervals, and the concourse air has properties that result from a 50/50 mix by volume of air at atmospheric ambient conditions and air conditioned to the desired temperature/humidity set points. (A suggested further analysis is to consider concourses that are either fully enclosed or fully open to the atmosphere.)

The assumed baseline values of stopping frequency and exchange percentage equates to a baseline average air exchange rate of 6 ACH. The stopping frequency was then varied from a low of 1.25 minutes to a high of 10 minutes, resulting in a corresponding range of air exchange rates from 24.6 ACH to 3.6 ACH. The resulting impact on required heating and cooling power is shown in Figure 3.7-7.

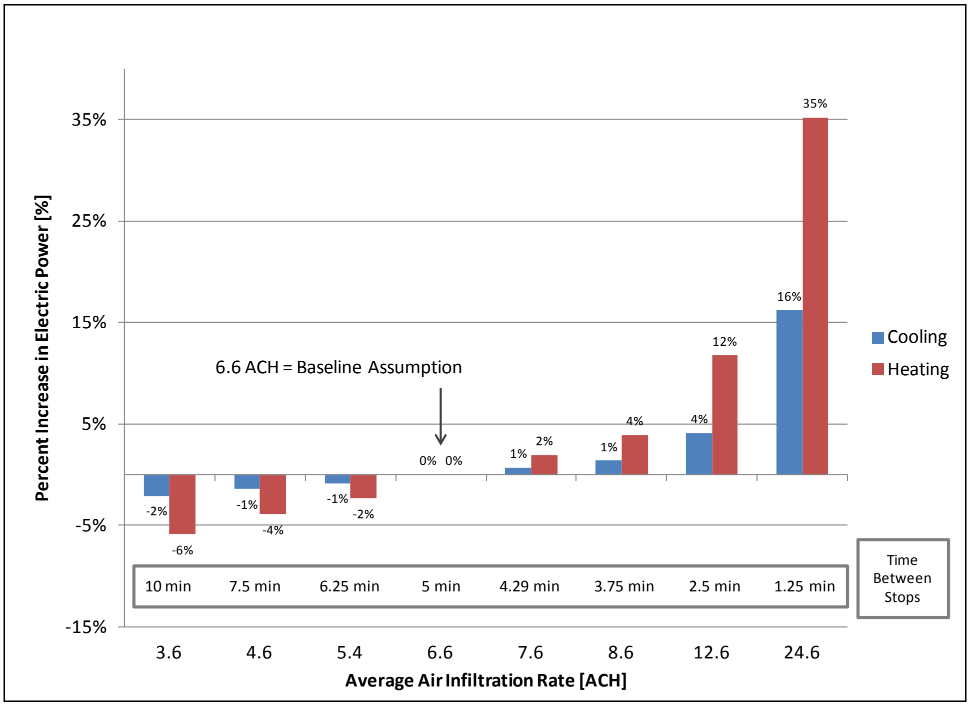


Figure 3.7-7. HVAC power vs. cabin air exchange.

The results are interesting and dramatic. They indicate that, in general, for larger ATN systems in which travel distances and consequent trip times are larger relative to stopping frequency, the HVAC power demands are reduced (from the assumed baseline, that is). Conversely, for compact ATN systems, cabin air exchange can result in fairly significant increases in peak vehicle HVAC power demands.

3.7.3.5 Guideway Sunshade

A final parameter that was evaluated was the presence of a guideway sunshade. One would expect the effect of a sunshade on variations in cooling power requirements throughout the day to be significant under certain conditions for obvious reasons. An illustration of a mathematical model of a notional sunshade design is shown in Figure 3.7-8.

As the orientation of an ATN vehicle with respect to the sun will obviously change as it circulates around a network and on the time of day, bounding analyses were performed for south-facing and west-facing vehicle orientations with and without the sunshade. The analyses were performed for the summer design day of June 15.

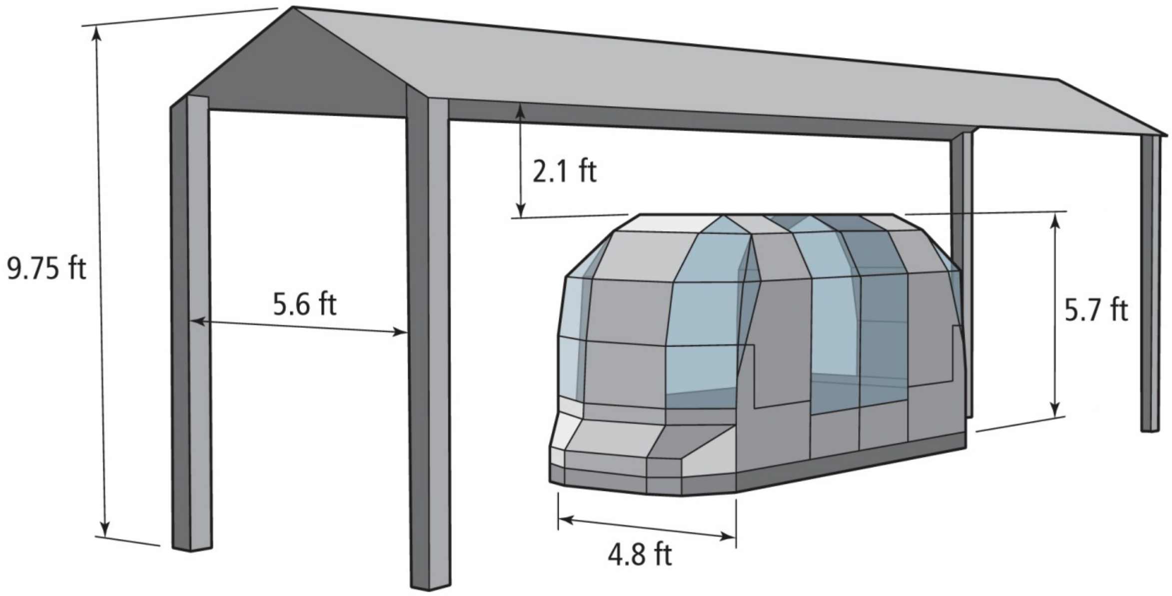


Figure 3.7-8. Guideway sunshade model.

Two cases were analyzed: one in which the vehicle/guideway/sunshade assembly was oriented north-south, and a second in which the assembly was oriented east-west. The results are shown in Figure 3.7-9 and Figure 3.7-10, respectively.

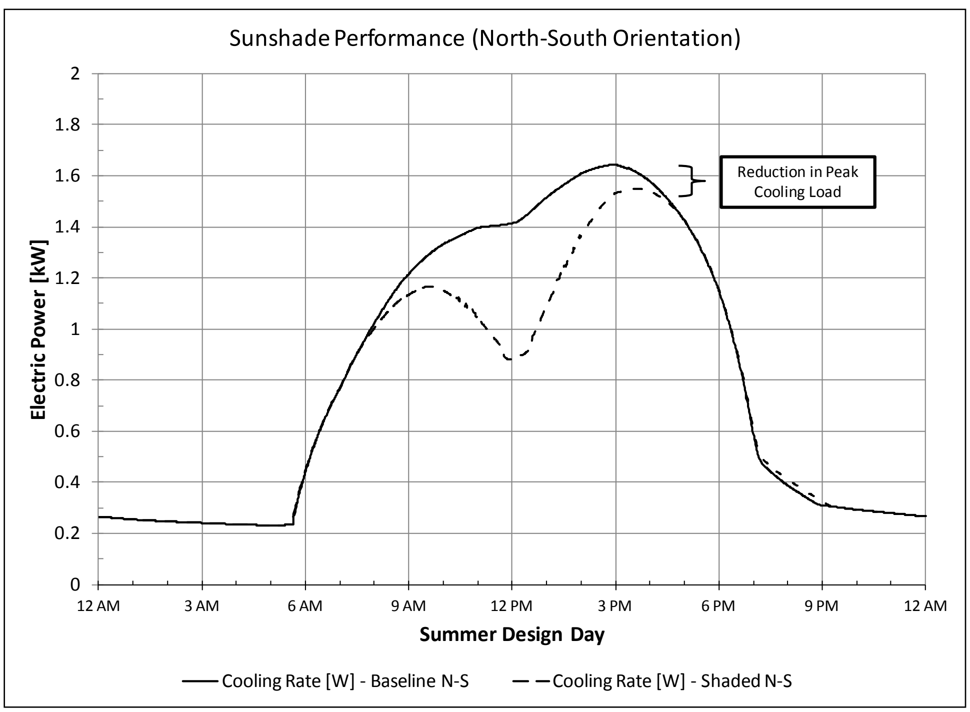


Figure 3.7-9. Guideway sunshade performance: north-south orientation.

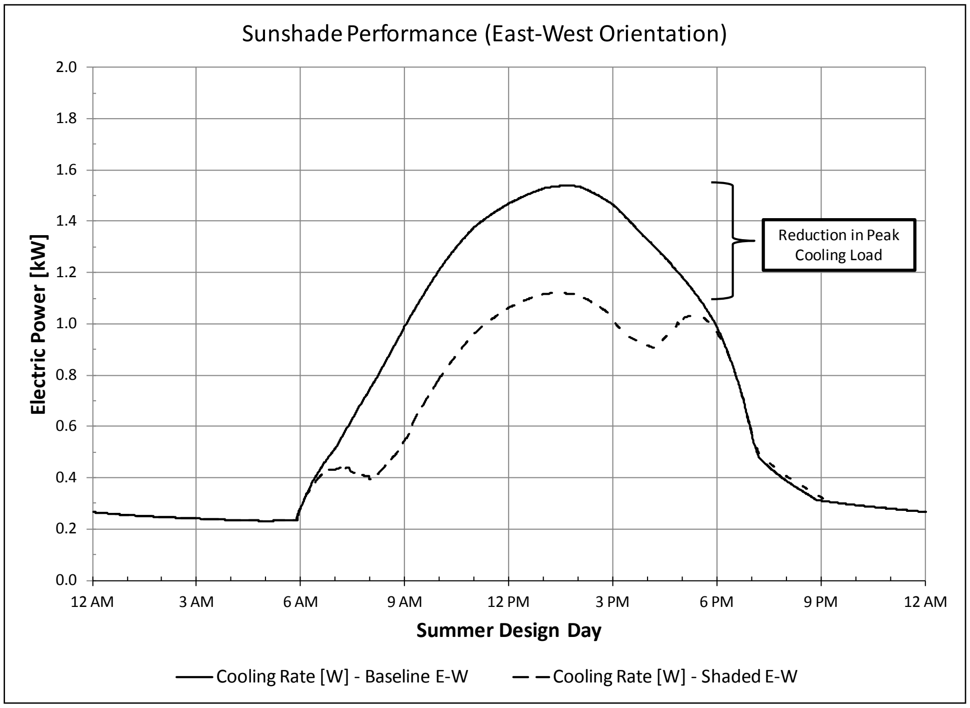


Figure 3.7-10. Guideway sunshade performance: east-west orientation.

In the first of these figures, the baseline result of Figure 3.7-3 in which the guideway is oriented in the north-south direction is indicated by a solid line. The sunshade is reasonably effective in reducing the peak solar load at 3 p.m., as indicated by the dashed line, and also rather significantly during the off-peak noon hour, a period of high travel demand. It is also fairly effective in reducing the *total* energy required for cooling throughout the day.

A much greater effect is seen in the east-west orientation. This is shown in Figure 3.7-10 for both peak and overall power requirements. In this orientation, the vehicle's side windows have their broadest view of the sun at approximately 12:30 p.m. The peak in solar load shifts accordingly and increases to nearly match the peak estimated for a north-south orientation. However, the narrow sunshade is fairly effective in blocking much of the incident radiation at this time, resulting in a required peak cooling power nearly 27 percent lower than the no-sunshade baseline. The effect of the sunshade is, in fact, fairly uniform throughout most the day for this orientation.

The Airport is, of course, oriented in a generally north-south direction. Taken *in toto*, these results suggest that the opportunity exists for the optimization of a sunshade design—one, perhaps, which is oriented in a more westerly direction along the predominant and generally north-south portion of the Airport network, and in a slightly southerly direction along east-west portions of the network. This would give the sunshade the appearance of a twisted ribbon from a bird's-eye perspective as its orientation changes as the guideway curves underneath it.

Overall, the analysis suggests a possibly significant peak power and overall energy consumption advantage in considering guideway sunshades. (Although not discussed here, there is even a small benefit (~1%) on the heating power side via the sunshade blocking heat radiated by the vehicle to a cold nighttime sky.) Considerable effort would, of course, be required to develop optimal designs and trade off the use of a sunshade against other considerations, but the potential usefulness of a sunshade was considered to be large enough that it was included as an option in the system power estimates discussed in Section 3.10.7.

3.8 Seismic Stability of ATN Vehicle/Guideway System

An obvious issue for an ATN installation in the City of San José is that of seismic response, but in this section it is discussed not in the familiar sense of structural damage or collapse, but from the point of view of potential secondary effects. In particular, it is of interest to know if a seismic event could generate forces sufficient to overturn vehicles or exceed the ability of the ATN control system to safely guide them during the period when they would presumably be automatically brought to a stop.

The issue here is not the ability of civil engineers to design suitable guideway structures but the requirements to which the guideway structures and the rest of the ATN subsystems must be designed. As in the case of other performance and design requirements, reliance on codes and standards developed to govern the design of existing "systems" (i.e., buildings, bridges, etc.) must be approached with the differences between those systems and the unique characteristics of ATN systems in mind.

In the case considered here, it is noted that ATN vehicles are intended to be lightweight and are therefore more easily upset than a heavier vehicle. Moreover, the upsetting forces need to be calculated by considering the structural interaction between vehicle and guideway. ATNs are not heavy enough to be considered "dead weight." Although the use of existing structural design codes may result in guideway designs that may happen to limit these forces to acceptable levels, the question still needs to be asked and answered: Will a requirement such as this result in a new *class* of structure that must be fully researched and verified in order to arrive at a satisfactory set of design guidelines simultaneously assuring both safety and economic viability?

Since the inquiries and literature searches made as part of this evaluation did not uncover any detailed ATN-specific seismic analyses, it was decided to perform a preliminary analysis intended to either rule in or rule out the issue as one requiring attention. Using seismic and geological information specific to the Airport, it was found that it would, in fact, be possible for a seismic event to overturn or otherwise disrupt an ATN vehicle. This would obviously be more of a concern with a noncaptured-bogie (i.e., unconstrained, rubber-tired) vehicle, but any type of design would need to account for a seismic event in its design loads, displacements, and control system response. The City would need to account in its decisionmaking and planning activities for the effort required on the part of the development community and regulators to address this issue.

The analyses described below were performed by ATA Engineering Inc., San Diego, CA, at the direction of The Aerospace Corporation.

An illustration of a vehicle/guideway system responding to a seismic event is shown in Figure 3.8-1. Following from the above discussion, a wheeled vehicle was chosen for the analysis. All items in the figure are drawn to approximate scale based on "typical" dimensions derived from the RFI responses. The guideway proper is illustrated to reflect the existing CPUC APM requirement of having a safety walkway running the length of a guideway.[48]

The irregularly drawn sets of arrows are intended to indicate the displacements and accelerations of both the seismic input at the base of the guideway and of the responses of the guideway and vehicle separately. In general, one can expect an amplification of displacements and accelerations between input and response, although this depends greatly on many factors associated with the nature of the input and the structural design of the system. Knowledge of the characteristics of the seismic input

[48] A dual guideway may share a common walkway.

allows one to design and/or isolate a structure, "tuning" it to avoid major amplifications. This is much like touching a tuning fork, "detuning" it to stop its ringing.

For present purposes, a "typical" guideway structural design was gleaned from photos and dimensioned illustrations provided in the RFI responses. Recognizing, of course, that the designs described therein are not being suggested as final and also to examine the sensitivity of the response to possible design variation, a range of structural properties was taken into account in a parametric analysis. The intent was to hopefully encompass various design approaches such as using reinforced concrete or steel girders/trusses for guideways and support columns in any combination. The range of design variations also included parameters pertaining to foundation design and the presence of isolation devices.

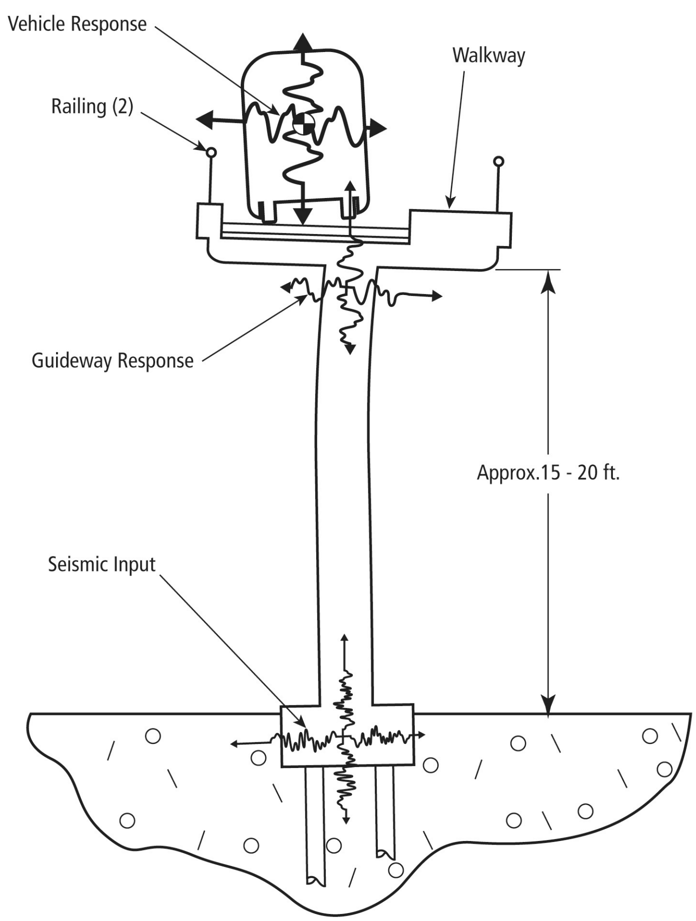


Figure 3.8-1. Seismic response of vehicle/guideway system.

Similarly, a representative set of baseline values was chosen for the vehicle and varied parametrically across multiple analyses to determine their individual impact on the response. These included educated guesses of the location of the center of gravity and values of translational and rotational inertias based on reported vehicle weights and dimensions. A typical "bounce" frequency of 1 Hz was used, as was an approximation of lateral stiffness based on that of typical automobile tires. The complete set of baseline values is shown in Table 3.8-1.

Table 3.8-1. Baseline Values: Seismic Analyses

Nominal Properties of ATN and Vehicle		
Soil Properties		
		units
Mass density	0.000093	slugs
Shear modulus	7949	lb/in^2
Poisson ratio	0.35	n/a
Foundation Properties		
Construction	Reinforced concrete	
Length	6.56	ft
Width	6.56	ft
Height	1.64	ft
Density	~145	lb/ft^3
Column Properties		
Construction	Reinforced concrete circular column	
Height	20	ft
Radius	10	in
Density	~145	lb/ft^3
Reinforcement	2%	by volume
Guideway Properties		
Construction	Reinforced concrete single lane	
Span length	65	ft
Dimensions		
Density	~145	lb/ft^3
Reinforcement	2%	by volume
Vehicle Properties		
Weight	2860	lb
Height	70.9	in
Length	145	in
Width	57.9	in
Center of gravity (1)	23.6	in
Center of gravity (2)	23.2	in
Suspension frequency	1.0	Hz

(1) vertical – taken as 1/3 vehicle height

(2) horizontal – taken as 1/2 vehicle width

This range of properties was incorporated into a finite-element mathematical model. Additional assumptions made for the baseline model included a rigid rectangular footing, columns having 2 percent steel reinforcement by volume, use of low-strength concrete, and reduced cross-sectional properties based on standard knockdown methods that account for the potential of partial cracking during a seismic event. Local soil properties, including shear wave velocity, density, and shear modulus, were taken into account using commonly accepted methods. The soil properties themselves were taken from site-specific data. The soil type classification at the Airport is reported as being a brown silty loam known as Oxnard Silt Loam.

The type of analyses performed is known as a response spectrum analysis (RSA). A response spectrum analysis calculates the peak responses of a system (in this case acceleration) as a function of the natural dynamic frequencies of a structure. The response can be derived in relation to a single spectra (or event) or, more often, as a spectrum of responses enveloping a range of seismic events. The design response spectrum considered here was taken from a San José-specific geotechnical report that documents probabilistically derived maximum predicted earthquake response spectra based upon local fault zones and geotechnical properties. In particular, a 5 percent damped response spectrum representative of a 475-year "return period" was used. The 475-year return period corresponds to a 10 percent probability of exceeding the response maximums in 50 years and was selected for preliminary design purposes.

This response spectrum was applied as a lateral excitation at the foundation of the guideway. An identical spectrum scaled to two-thirds was applied at the foundation in the vertical direction, a common civil engineering assumption.

The response of interest is the lateral acceleration of the vehicle, expressed in term of an "overturning moment." That is, will the lateral acceleration response, acting through the center of gravity of the vehicle, be high enough to overcome the "restoring moment" due to the vehicle's weight, thereby overturning the vehicle? A square root sum of squares (SRSS) method was used to combine individual modal responses[49] and, since vertical and lateral peak excitations are not likely to occur simultaneously, also used to combine the effects of the lateral and vertical excitations. The results of the various analyses are listed in Table 3.8-2. A positive value of the overturning moment indicates an overturning vehicle and is marked as unstable. A negative value indicates the opposite and is marked as stable.

As shown, the majority of design and seismic conditions considered result in instability of the vehicle. Stability is achieved when the vehicle suspension and column stiffness is softened considerably, resulting in the vehicle being isolated from the seismic input. In addition, stability is achieved when the vehicle center of gravity (CG) is assumed at one-fifth the total height of the vehicle and located at a distance of one-half of the total vehicle width. The only other stable condition results when the lower-level design spectrum is assumed. This spectrum corresponds to 50 percent probability of exceedance in 50 years (72-year return period) and is not recommended for design purposes.

The results and conclusions of this study should be considered to be preliminary, and it is recommended that further seismic analyses should be performed once overall ATN system design is better defined. However, it is observed that vehicle isolation will be beneficial in improving stability performance. In addition, guideway/vehicle restraints or barriers could further prevent the occurrence of vehicle ejection during a seismic event. This study did not consider the structural integrity of the ATN system under seismic loading; thus, no direct conclusions can be drawn with regard to its structural performance.

[49] Referring to a subcalculation within the overall analytical method.

Table 3.8-2. Seismic Response Results Matrix

Seismic Responses					
Case		**Nominal**	**Stiff Column**	**Rigidized Foundation**	**Stiff Column and Rigidized Foundation**
Parameter Varied	**Units**	**None**	**EI Increased by 10**	**Fixed Soil B.C.**	**Increased EI by 100 and Rigidized Soil B.C.**
Lateral Displacement (Vehicle/Guideway I/F)	in	14.7	NA	NA	NA
Lateral Displacement (Guideway/Column I/F)	in	14.6	NA	NA	NA
Vertical Displacement (Vehicle/Guideway I/F)	in	0.05	NA	NA	NA
Vertical Displacement (Guideway/Column I/F)	in	2.6	NA	NA	NA
Car CG Lateral Acceleration	Gs	1.3	1.6	1.6	1.1
Car CG Vertical Acceleration	Gs	0.7	0.7	0.7	0.7
Lateral OT Moment	in-lbs	86687	105837.1	109294.2	71734.3
Restoring Moment	in-lbs	-66208	-66207.7	-66207.7	-66207.7
Vertical OT Moment	in-lbs	45741	48288.2	45216.3	45712.5
Total OT Moment	in-lbs	31807	50124.8	52070.4	18853.7
Stability Check		Unstable	Unstable	Unstable	Unstable

Seismic Responses					
Case		**Soft Column**	**Soft Foundation**	**Soft Car**	**Stiff Car**
Parameter Varied	**Units**	**EI Decreased by 10**	**Soil Springs K Reduced by 10**	**Decreased Suspension K by 10**	**Increased Suspension K by 10**
Car CG Lateral Acceleration	Gs	0.58	0.68	0.41	0.84
Car CG Vertical Acceleration	Gs	0.68	0.77	0.22	2.40
Lateral OT Moment	in-lbs	39013	45930	28027	56678
Restoring Moment	in-lbs	-66208	-66208	-66208	-66208
Vertical OT Moment	in-lbs	45350	51044	14484	159199
Total OT Moment	in-lbs	-6386	2459	-34660	102780
Stability Check		Stable	Unstable	Stable	Unstable

Seismic Responses					
Case		**Stiff Guideway**	**Soft Guideway**	**Minimum Car Weight**	**Maximum Car Weight**
Parameter Varied	**Units**	**EI and J Increased by 10**	**EI and J Decreased by 10**	**Car Weight = 1870 lbs**	**Car Weight = 4510 lbs**
Car CG Lateral Acceleration	Gs	1.27	1.44	1.12	1.82
Car CG Vertical Acceleration	Gs	0.54	0.93	0.94	0.51
Lateral OT Moment	in-lbs	85876	97137	49523	193953
Restoring Moment	in-lbs	-66208	-66208	-43290	-104405
Vertical OT Moment	in-lbs	35488	61287	40826	53222
Total OT Moment	in-lbs	26712	48647	20892	96718
Stability Check		Unstable	Unstable	Unstable	Unstable

Seismic Responses				
Case		**Car CG Variation**	**Seismic RS Input Changed**	**Seismic RS Input Changed**
Parameter Varied	**Units**	**Vert CG = H/5, Lat CG = W/2**	**RS = 10% Damped 475-Year Return**	**RS = 5% Damped 72-Year Return**
Car CG Lateral Acceleration	Gs	1.28	1.03	0.64
Car CG Vertical Acceleration	Gs	0.69	0.55	0.35
Lateral OT Moment	in-lbs	52012	69467	43002
Restoring Moment	in-lbs	-117102	-66208	-66208
Vertical OT Moment	in-lbs	80903	36471	23150
Total OT Moment	in-lbs	-20923	12251	-17371
Stability Check		Stable	Unstable	Stable

3.9 State of the Art Revisited

ATNs are currently tentative, low-performance, handmade versions of what they aspire to be. At present, ATNs operate in unchallenging environments such that many issues don't come into play. The technical requirements associated with the Airport application range across a spectrum from those which are consistent with the capabilities of existing designs to those that would likely require performance upgrades, and on to those that likely exceed current capabilities by a considerable margin.

Ultimately, ATNs are intended to perform in a manner most similar to automobiles but are currently being designed like trains, especially with respect to safety. The development community seems to be suggesting that safety measures long associated with each of these two conventional systems, the brick-wall stop criterion and passenger restraints, *both* be eliminated in order to clear the way for ATNs. Both of these safety-related requirements affect performance and are perceived as barriers to economic viability. This seems to be based on the contention that the sensors, electronics, software and electromechanical components that constitute the automated control system will be able to virtually eliminate the possibility of collisions. This is a questionable proposition that will require considerable effort to verify.

Although in the process of a welcome change, current thinking regarding the ATN concept seems to be limited by its own definitional strictures, resulting in a one-size-fits-all portrayal of ATNs. The ATN development community in particular seems to be falling into the same trap as in previous attempts to develop the concept, in which vehicle and infrastructure size growth occurred in an attempt to increase throughputs to a level perceived as acceptable. In the process, the basic premise of the concept as a viable alternative to the private automobile is being negated. The alternative is to envision a range of ATN designs appropriate to a corresponding range of applications, potentially expanding their number and the role of ATN technology.

3.10 The Airport Reference Design

As is now clear, the RFI process revealed a number of uncertainties and unknowns regarding the maturity of the ATN concept. Clear limitations existed in the design guidance that was given, but by studying the responses it became apparent that the requirements of the Airport application challenged the reported performance of current designs. SJDOT leadership did not find satisfactory any of the intermediate design solutions that could be proposed with reasonable confidence based on this limited information. This inhibited the execution of a more conventional transportation planning exercise and required a major redirection in project tasking, as discussed in earlier sections. In addition to taking on efforts to better understand the performance of key subsystems, this resulted in the development of the “reference design” discussed here.

3.10.1 Purpose of a Reference Design

A reference design is the emerging-technology counterpart to conceptual designs produced as part of the traditional infrastructure design-build process, the latter involving conventional technologies. Although also conceptual, a reference design is deserving of its separate nomenclature because it differs in its consideration of and implications relative to next steps.

A conventional conceptual design provides reasonably assured estimates of project performance, cost, and risk based on well-established reference material. After considering a number of options and arriving at a preferred conceptual design, the next steps in a conventional acquisition include, for example, arranging for funding and hiring architectural and engineering firms to produce a final design. A reference design also forms the basis for estimations of performance, cost, and risk, but these are understood to be much less assured, and a reference design is by no means a statement of a preferred concept—there is simply too little known in the context of an emerging technology to be that specific.

A reference design is used to explore and illustrate what may be a viable system architecture comprising technologies that are in a rapid state of flux and not yet available at conventional levels of risk nor even fully understood. A key purpose of a reference design is to help identify and understand where best to apply resources in order to drive the uncertainty and unknowns associated with these estimates to conventional levels. Thus, a reference design is useful for focusing the attention of interested parties on appropriate next steps in terms of research and development that may be conducted by a wide variety of specialist contributors. For the Airport application in particular, the challenge is to identify a potential architecture that may allow a nearer-term design/build project but can also simultaneously accommodate anticipated future developments.

Thus, it follows that a reference design does not represent an actual specification or the intent of any particular developer. The City and developers may or may not choose to use elements of the reference design, and developers may be in possession of information that would render aspects of the reference design moot. At the highest level, the purpose of a reference design is to promote a constructive dialog.

3.10.2 General Discussion of Airport Challenges

The layout of the Airport and its associated trip demand patterns is a bit problematic from the standpoint of ATN capabilities. The Airport consists of two terminals, companion parking structures, and associated roadways in a very compact arrangement in the roughly east-west direction and very long in the roughly north-south direction, with a relatively narrow corridor between the terminals and their companion parking structures. This is, of course, a most natural design from the standpoint of the available real estate between the runways and the Guadalupe River. Outlying automobile parking areas are located to the northeast of Terminal A and to the southeast of Terminal B, the southernmost terminal.

Access to the various air carriers is provided internally rather than in the “strip mall” fashion found in many airports. This, of course, funnels travelers to a single entry at each terminal. Airport officials also made very clear that a principal requirement of an ATN design is a positive passenger experience. For purposes of system layout, the relevant measure is walking distance, required to be less than 500 feet but as short as possible. This requires station resources to be concentrated at the terminals and necessitates that the stations here be capable of high throughputs.

Adding to the expected demand asymmetry due to inbound and outbound rush hours is the location of the rental car facility, ConRAC, in the parking structure opposite Terminal B. This creates demand between Terminals A and B at levels that are significant relative to the uncertain ATN station capacity of some of the proposed designs. As discussed in Section 3.3, the demand between these two locations is one of the principal design drivers.

The pedestrian footbridge between Terminal A and its companion parking structure represents a physical obstacle that may result in a very suboptimal guideway layout of perhaps marginal value to both users and stakeholders, especially when looking ahead, when the core Airport system might be extended and be required to carry pass-through traffic. Add to all of this the stage of development at which ATNs are currently, and it becomes clear that laying out a satisfactory ATN system at the Airport that is capable of providing valued service now and into the future is quite a challenging problem.

Aesthetics were also a major consideration. Best efforts were made to reconcile technical and aesthetic requirements. This is, of course, an area in which there would be much opportunity in an actual design for making a visual statement compatible with the overall architectural theme of the Airport.

3.10.3 General Description

3.10.3.1 Guideway Layout

The overall layout of the reference design is shown in Figure 3.10-1. The guideway layout accommodates additional station locations specified by the City later in the project and consists of five “loops,” designated as such for convenience in the identification and assignment of individual guideway segments and for general discussion purposes. As the various loops share guideway, most identified loops do not actually close on themselves as implied by the term. A number of other loops can be identified by selecting different combinations of guideway segments if one so chooses. The designations chosen here are as follows:

- Loop 1 consists of the spur to and return from a single station located near the VTA light rail North First Street Station. The routing generally follows that found to be preferable in studies performed by Arup. The open ends of the loop are coincident with a merge and a split on Loop 2. A potential eastward extension of Loop 1 is shown in the figure.

- Loop 2 is the main loop of the system, encircling almost the entire Airport property generally east of the terminals. Loop 2 serves three stations at the Economy Lot automobile parking area and two at Lot 4. The portion of Loop 2 aligned with the main terminal corridor serves as the easternmost portion of a dual guideway between Terminals A and B but does not

Legend

	R_{min} (ft)	Loop-dependent maximum line speed (mi/hr) Low	Med	High
Loop 1	328	17.5	24.8	35.0
Loop 2 begin	328	17.5	24.8	35.0
Loop 2 L4 arrival	141	11.5	16.2	23.0
Loop 3 TA departure	150	11.8	16.8	23.7
Loop 3 TA arrival	177	12.9	18.2	23.7
Loop 4 TB departure	201	13.7	19.4	27.4
Loop 4 TB arrival	144	11.6	16.4	23.2
Loop 5	n/a	17.5	24.8	35.0
Acceleration transition				
Deceleration transition				
Station sidings		5.0	5.0	5.0
Station locations				

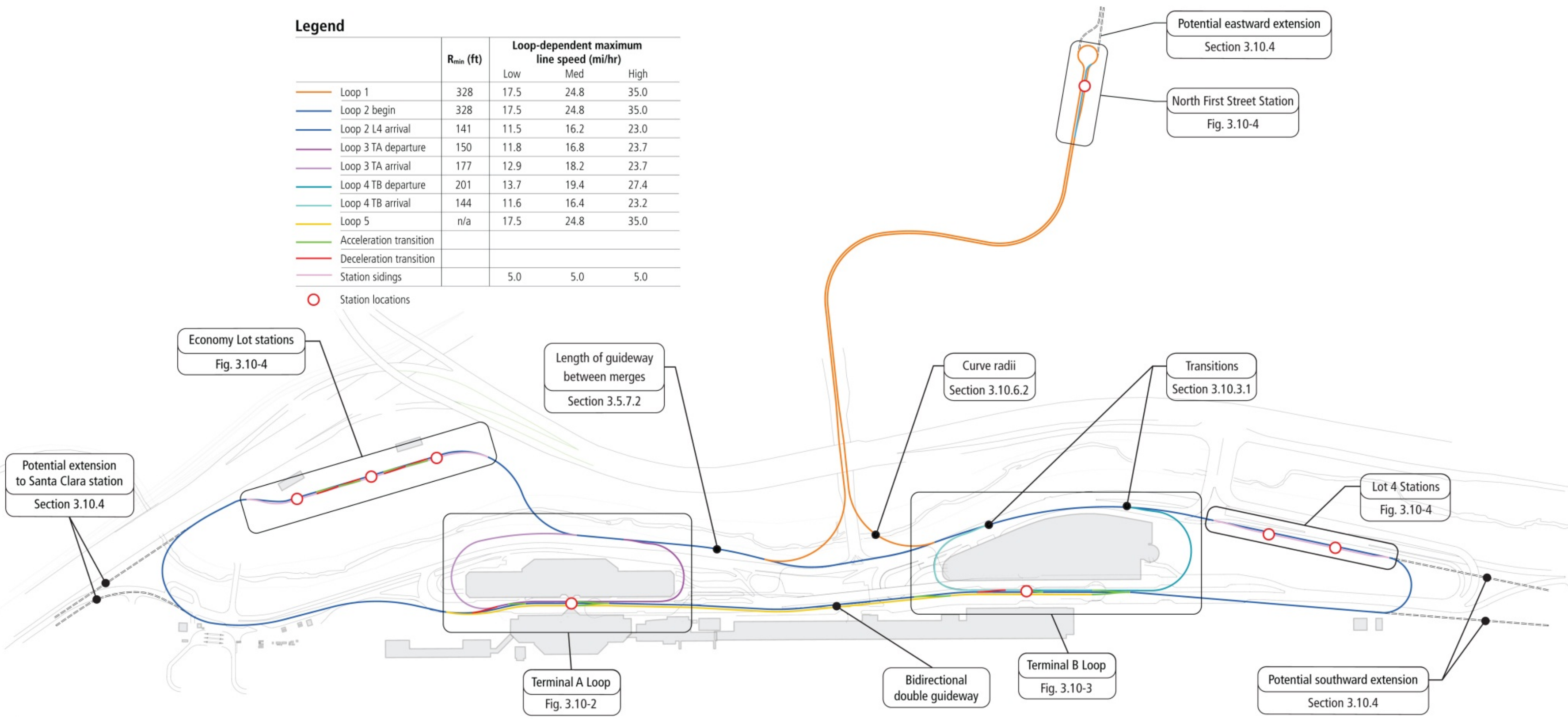


Figure 3.10-1. Reference design general layout.

directly serve either of the terminal stations. This portion of Loop 2 is instead conceived, as is the remainder of its generally north-south guideway, as a high-speed pass-through to accommodate potential future expansions in which the Airport might not be the destination, its network being then part of a larger network. Two such potential expansions are shown in the figure: one at the northern extremity of Loop 2, which might go on to serve the Santa Clara CalTrain station and/or north San José developments, the other at its southern extremity, which may connect to the Diridon Station and/or destinations in downtown San José. A routing to a station serving the preferred parking area south of Terminal B was also considered but not included.

- Loop 3 also has open ends. It generally encircles the Terminal A parking structure and is identified in two parts: Terminal A arrival and Terminal A departure. As implied, Loop 3 directly serves a station at Terminal A, but only the eastern portion of the station, as is later described. The open ends of Loop 3 coincide with a merge and a split on Loop 2 east of the Terminal A parking structure. A merge and a split with Loop 2 are also located on the closed portion of Loop 3 west of the structure. This merge/split pair is the means by which Loop 2 directs traffic to/from the Terminal A station.

- Loop 4 generally encircles ConRAC and has an identical arrangement of merges and splits with Loop 2 to serve the eastern portion of the Terminal B station. It is also designated in two parts: Terminal B arrival and Terminal B departure.

- Loop 5 is less of a loop and more of a linear portion of guideway. It is the westernmost portion of the dual guideway between the terminals and is primarily dedicated to serving the western portions of the Terminal A and B stations. A split and a merge with Loop 2 are, however, located at the northern and southern tips of Loop 5, respectively, so that traffic to/from all other station also can be directed to the western portion of the Terminal A and B stations. The principal and alternative traffic patterns enabled by this arrangement of guideway and apportioned stations will be discussed in the following paragraphs and sections.

Traffic was assumed to circulate in a counterclockwise fashion, mimicking the flow of conventional traffic. This is certainly not essential. Traffic could be reversed, even at different times during the day, with minor modifications to the layout. Traffic reversal on a portion of Loop 2 was considered, for example, a point discussed in a later subsection.

Transitions between loops are provided in several places in the immediate vicinity of the Terminal A and B loops (Loops 3 and 4). These are shown in Figure 3.10-2 and Figure 3.10-3, respectively. Transitions were used at locations where they couldn't be easily avoided by taking advantage of a large radius of curvature on two merging or diverging lines, blending the lines at a point of tangency, as at the Loop 1/Loop 2 merge and split. Transitions were also used where necessary as acceleration and deceleration segments between loops operating at different speeds. A good example of a heuristic used during layout is the attempt to place as great a distance as possible between adjacent merge points. No spiral transitions were specified but could certainly be added where necessary, possibly at the entrance to the southernmost curve of Loop 2 leading to the Lot 4 stations.

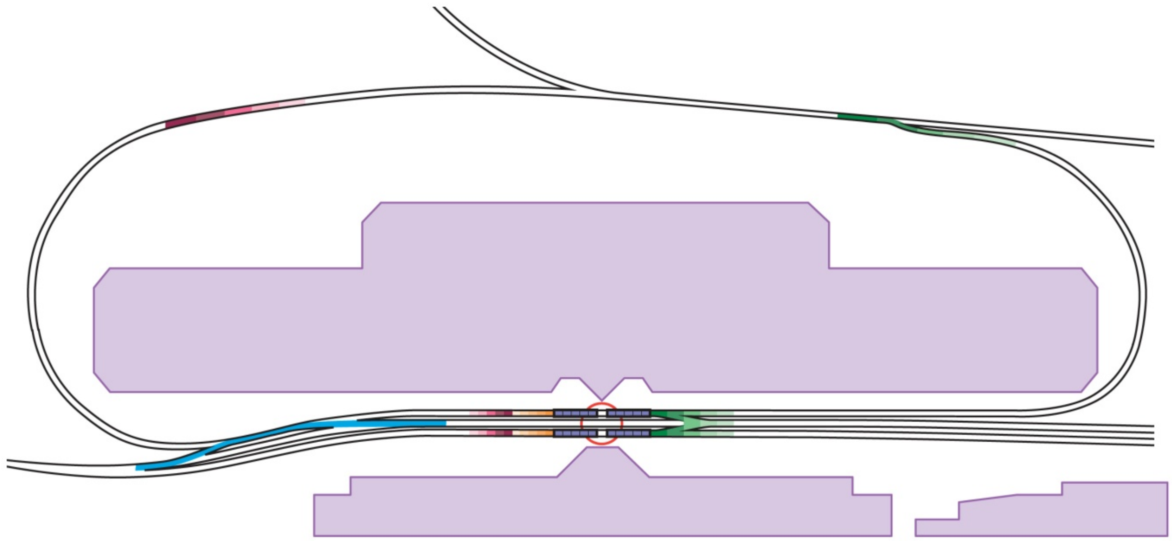


Figure 3.10-2. Terminal A Loop (Loop 3).

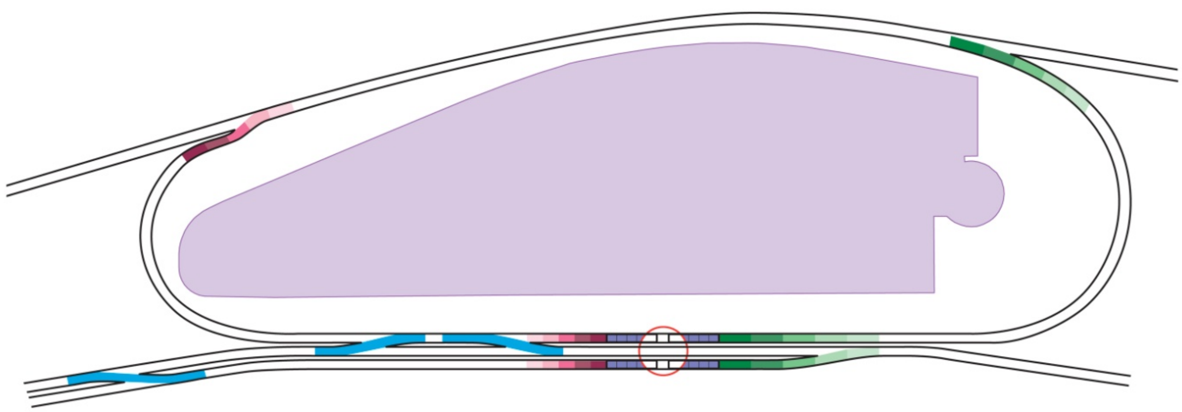


Figure 3.10-3. Terminal B Loop (Loop 4).

The guideway layouts associated with the outlying stations are shown in Figure 3.10-4. Each station existing in a series is provided with its own acceleration and deceleration ramps along with an interconnecting siding to its neighbors. This was done to preclude potential congestion and consequent in-vehicle waits due to interactions between these closely spaced stations.

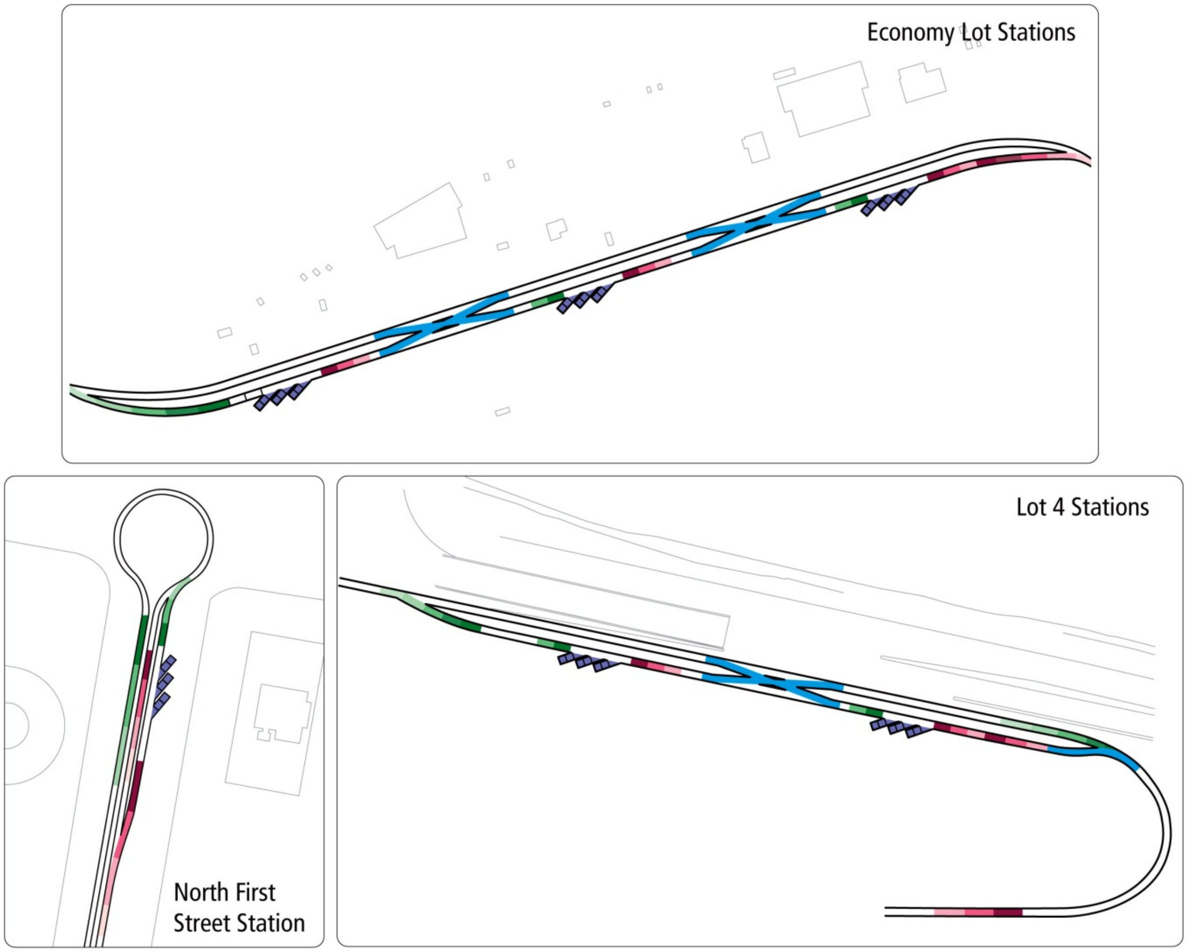


Figure 3.10-4. Outlying station guideway.

As mentioned, various loops are intended to operate at different nominal and maximum speeds as determined by the maximum allowable lateral accelerations acceptable to passengers and the curve within a loop having the minimum radius. The maximum speeds are listed in Figure 3.10-1 along with maximum allowable speed on station sidings, set at 5 mi/hr. The maximum design speed was set at 35 mi/hr, limited by the routing constraints of Loop 1.

This is a key tradeoff in routing depending on potential future plans. The curve radii specified here assumed an eventual eastward expansion of Loop 1 and resulting high traffic levels from that direction. As discussed in Section 3.5.5, slowing for tight turns serves to diminish throughput, thus the largest radii that seemed possible was specified. No attempt was made, however, to investigate any possible violation of physical constraints. The geometry was set as shown to illustrate this option. No such limitations exist for Loop 2, which takes advantage of the natural layout of the Airport to enable curves having very large, sweeping radii.

Thus, among the principal factors determining the geometry of the guideway layout are the physical constraints, future expansion considerations, and passenger experience in terms of station locations, trip times (as reflected in the exploration of higher maximum speeds), and comfort while in transit. For the latter, acceleration levels equal to or slightly less than those specified in the APM Standards for seated passengers were used: 0.25 g for lateral acceleration in curves, 0.13 g lateral acceleration and jerk in transitions, and 0.25 g for longitudinal acceleration and jerk for all speed-change transitions, including station acceleration and deceleration ramps. These last values were chosen to be consistent with the passenger retention curves discussed in Section 3.5.4.1.

Another principal factor is redundancy. The guideway layout was deliberately constructed with multiple routes between stations rather than as a single loop serving all stations to illustrate the performance/cost trades associated with the network characteristics of ATNs. This redundancy can easily be seen by inspection of Figure 3.10-1. No attempt was made to catalog all possible trips given the number of stations and routes, but a list of 35 was compiled. A topic with which the reader is now familiar, the availability of redundant routes provides additional resources with which to manage traffic and to serve as optional routes in the event of a failure in a particular location or during servicing and expansion.

All told, the network consists of approximately 140 distinct geometric segments totaling almost precisely six miles in length. If constructed off-site of steel and shipped via standard 40-foot carrier, slightly less than 800 deliveries would be required. The topology of the complete network is listed in Appendix C. For those who may have an interest, the entire network can be reconstructed from this listing. One will find a few errors which do not materially affect any estimate or conclusion based on this geometry.

3.10.3.2 Station Configurations

Angled-berth stations, each provisionally three berths in size, are used at all station locations except at Terminals A and B, the performance of this station design being adequate for the level of anticipated demand at the outlying locations. The layout of these stations was shown previously in Figure 3.6-1. Each includes three vehicle locations in an input buffer and two in an output buffer. Two of the berths are intended as "working" berths and one as a "staging" berth. The reason for this is discussed in a following subsection.

The stations at the terminals are of a more unusual arrangement. Here the vehicle berthing arrangement is of the linear variety that is more traditionally associated with the ATN concept. However, these are arranged in four blocks as shown in Figure 3.10-5, partitioning each station in both the north-south and east-west directions. The east-west partitions are referred to as banks, which are further partitioned north-south to form the blocks, and are so labeled. The designations "inner" and "outer" were used to identify the banks according to their position inside or outside of the main Loop 2. Each block is thus referred to by a unique, if cumbersome, identifier such as Terminal A, Inner Bank, North Block (TA IB NB).

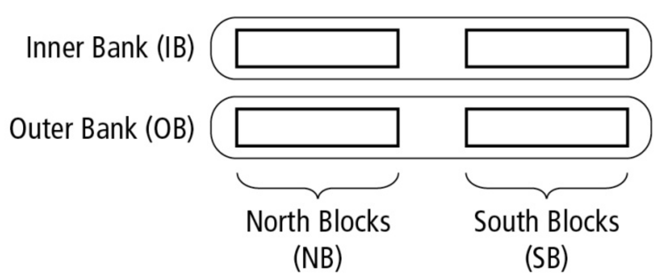


Figure 3.10-5. Terminal stations vehicle berthing arrangement.

The north-south partitioning into blocks was done with Terminal A in mind. It was not known at first how long the terminal stations would need to be. That coupled with the strong passenger-convenience proscription mentioned earlier and the need to preserve the function of the existing pedestrian bridge led to this maximally compact arrangement. As will be discussed shortly, there was also a need for a support structure to straddle the subterranean baggage conveyor located directly under the pedestrian bridge.

As will be discussed in Section 3.10.4, this partitioning is also the result of envisioning a reconfigurable, multimode operational model, which adapts to hourly changes in the demand profile, particularly with respect to surges. This concept appeared in at least one of the RFI responses and likely elsewhere.

What is most unusual from an ATN perspective is that these berths are not offline in the usual sense. They are located directly in-line, the inner bank in-line on Loop 3 at Terminal A and Loop 4 at Terminal B. The outer banks at both locations are in-line on Loop 5.

For reasons that will become clear after reading further, the number of berths contained within each block depends on the results of a tradeoff involving vehicle seating capacity. The reference design geometry assumes a worst case of five berths per block for a total of 20 per station. An input buffer having a capacity of five vehicles was also accounted for in the geometry. No output buffer was found to be necessary, but a more accurate simulation of the arrangement may find one necessary. This can be accommodated with minor adjustments to the guideway geometry.

3.10.3.3 The Magic Link, Magic Return, and Accumulators

In an attempt to deal with several of the current uncertainties and unknowns, the relatively high level and asymmetry of demand between Terminals A and B relative to current capabilities, and to provide the City with some sort of satisfactory ATN configuration for the Airport, the notion of the “Magic Link” discussed in the early configuration studies (Section 3.3.1) was revisited as more than an item of analytical interest. It was wondered what form a physical instantiation might take. This led to the consideration of two additional concepts: those of an associated “Magic Return” and of vehicle “accumulators.” The term “magic” became the convenient vernacular in discussions among the Aerospace team and is similarly used here as a shorthand description in subsequent discussion.

The system resulting from this collection of concepts, although unorthodox, eliminates a number of the uncertainties and unknowns associated with the current state of ATN design maturity. It also directly addresses a number of perennial and justifiable criticisms of the ATN concept. It eliminates, for example, concerns associated with the throughput of angled-berth stations, concerns about demand surges, concerns about congestion resulting from directing both empty and occupied Terminal A/Terminal B traffic onto the network, and concerns associated with the circulation and positioning of empty vehicles.

The concept further delivers some very attractive levels of passenger service and also provides for some interesting side benefits. Perhaps most importantly, it is based on evidence that it may be reasonably achievable in a likely shorter term than fully realized ATNs. It provides, in fact, an opportunity to complete the development of and introduce the high-precision motion control technology requisite for such systems and incrementally establish new regulatory boundaries. As it represents the addition of resources, it does not, of course, come without a cost. Its cost must, however, be traded against the cost of alternatives. In terms of risk, the concept essentially exchanges development risk for integration risk; with the exception of the motion control technology and associated regulatory effort, all of the technology is mature.

The overall arrangement of the concept is shown in Figure 3.10-6. The upper portion of the figure is a schematic plan view of the guideway and station block arrangement. The Magic Link consists of both runs of the dual guideway. The figure shows how the blocks are located directly in-line with the guideway, as described earlier. The transitions between Loop 2 and Loops 3 and 4 are a key feature; they enable traffic flow between the terminal stations on Loop 2.

The middle portion of the figure is another schematic plan view that shows a subterranean "Magic Return." Unlike the elevated guideway, this cut-and-cover trench is a single conduit branching into a "Y" at both ends to mate with each of the station banks. The bottom portion of the figure shows the system in cross section. The return is trenched to a depth such that it clears the Terminal A baggage tunnel; alternatively, the baggage tunnel could be reconstructed and relocated to a greater depth.

The most striking feature, of course, is the stacks of vehicles. The term "accumulators" has been used here because that is what they do—accumulate or store empty vehicles when not required and serve them up when needed, the mechanical equivalent of the electronic capacitor. Concepts for mechanisms to manage vehicle motions in a station are in the ATN literature[50]. For example, just as angled-berth stations strive to overcome delays due to slow boarders, "docking-type" stations have been similarly proposed[51] in which vehicles are translated laterally via some sort of mechanism in and out of positions in a linear queue of berths. It is advisable to avoid the cost and complexity associated with such mechanisms, except if the benefits are considerable as compared to alternatives.

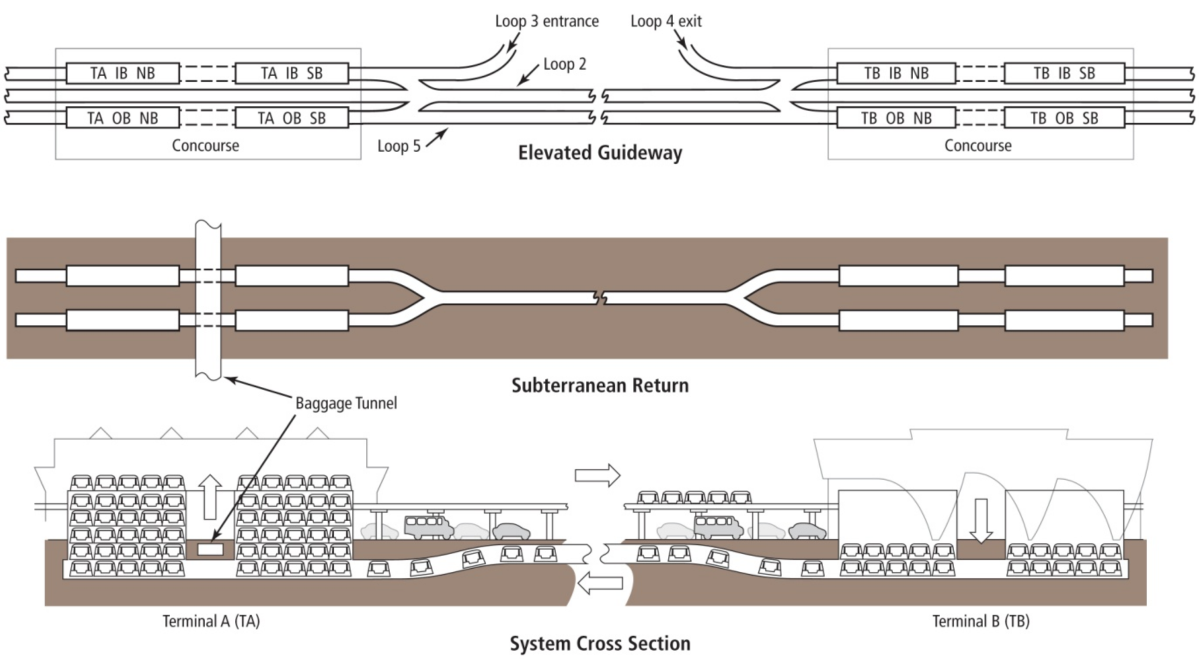


Figure 3.10-6. The "magic" subnetwork.

[50] It is not known if accumulators have been suggested.
[51] Irving, page 65.

In general operation during demand surges, an entire group of vehicles is raised to concourse level in a station. Passengers board the vehicles, after which the vehicles are lowered to guideway level. They then proceed as a fully configured platoon to the opposite terminal station, accelerating simultaneously to line speed after the last vehicle clears the departure station and similarly decelerating before the lead vehicle enters the arrival station. Vehicles from the outermost blocks perform an additional maneuver at station speed before platoon departure and after platoon arrival to close the gap between the two platoon segments. Upon arrival and final maneuvering, the now-occupied vehicles ascend to concourse level, discharge their passengers, and then descend two levels into the destination accumulator stack. They descend one level after the arrival of each subsequent platoon. When they reach the bottom, they proceed via the Magic Return at station speed back to the origin station, where they ascend one level at a time back to concourse level. Depending on details of a final design, the accumulator stacks consist of five to seven levels.

A detailed discussion of the operations and performance of this system is given along with that of the remainder of the network after the following subsection, which describes the associated design of the Terminal A ATN Station concourse.

3.10.3.4 Station Concourse Design

Numerous configuration options were considered for the Terminal A station concourse. The principal design challenges are to replace the function of the existing pedestrian bridge and to provide vertical circulation so that pedestrian and ATN vehicle cross traffic can both proceed unimpeded. There is simply no other way to accomplish this, even if a more "conventional" station design were used.

The configuration preferred by SJDOT staff is shown in plain view in Figure 3.10-7 and in cross section in Figure 3.10-8. The first figure illustrates the integrated pedestrian/ATN user flow in the concourse, which is located one story above the existing pedestrian bridge. Upon arrival in the concourse, signage will direct travelers to one of the four ATN vehicle blocks, depending on their destination, or directly ahead down a central aisle to the Terminal A parking structure. Outbound ATN users will be directed into queues outboard of the vehicle blocks, one queue per vehicle berth. Arriving ATN users will exit their vehicles inboard of the vehicle blocks and proceed to either the terminal or parking structure via the center aisle.

Figure 3.10-8 shows the necessary increase in the level of the concourse in comparison to the existing pedestrian bridge. The guideways themselves are positioned at the latter level, a height consistent with that being proposed by the development community. The figure shows the relationship of each of the two vehicle banks with its respective guideway loop, as well as the Loop 2 pass-through, which is located between the accumulators. Note that only a single lane of existing conventional at-grade traffic need be allocated to accommodate the accumulator stacks.

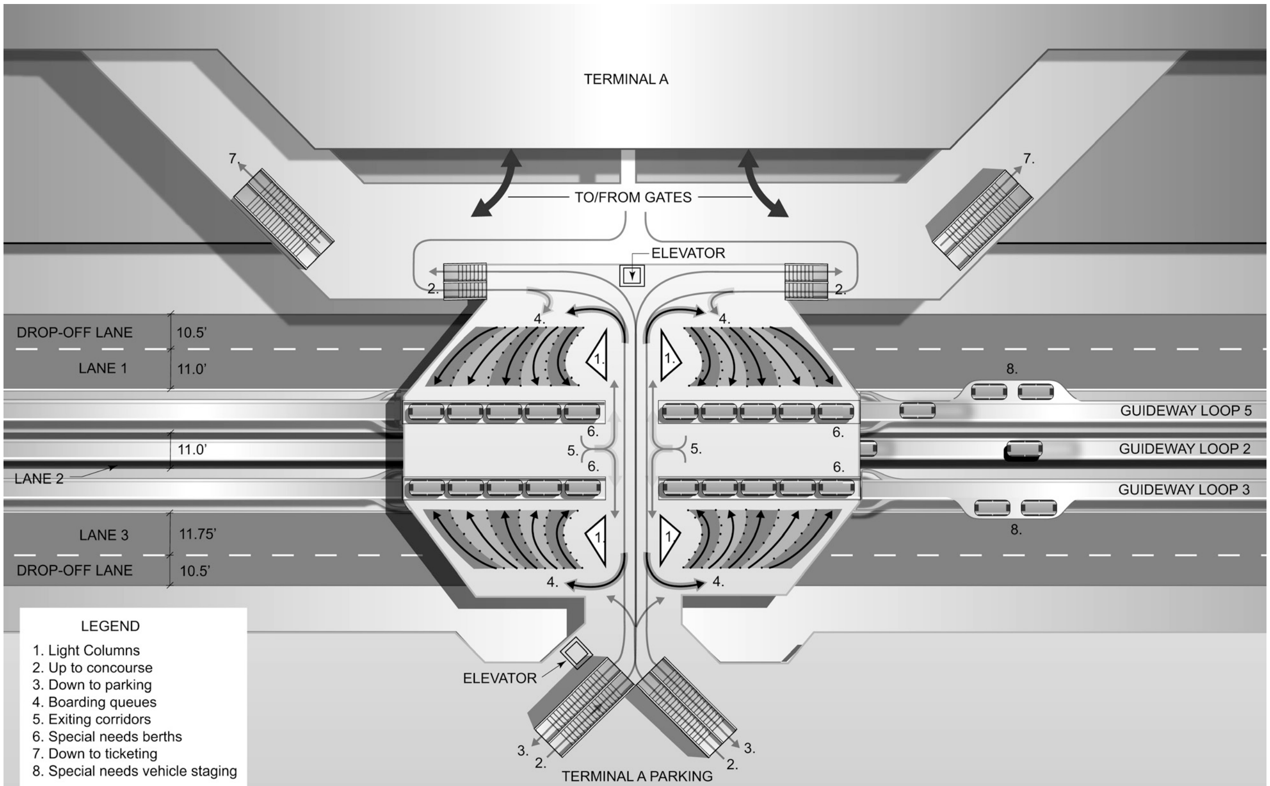


Figure 3.10-7. Terminal A Concourse plan view.

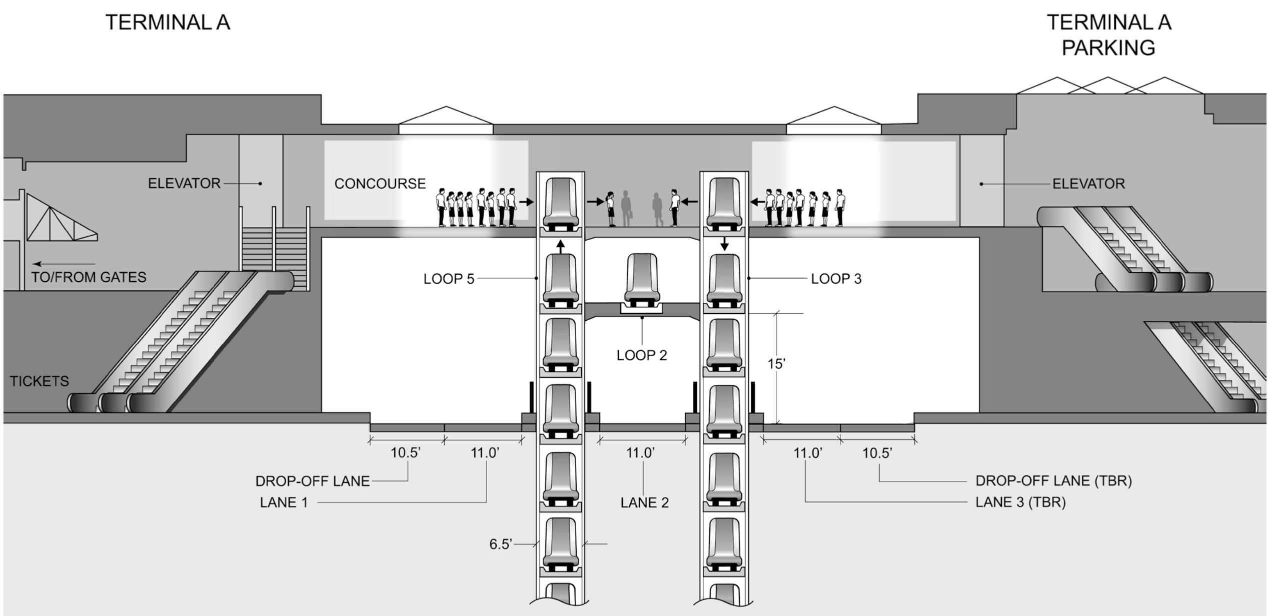


Figure 3.10-8. Terminal A Concourse cross section.

Airline passengers arriving on the second floor of Terminal A will be presented with a panorama of their options as shown in Figure 3.10-9—the existing escalators down to curbside pickup or an at-grade crossing between the accumulator stacks to the taxi queue, and a clear view through a glass wall to signage announcing the ATN concourse, accessible via two additional escalators and an elevator for disabled persons.

Upon arrival in the concourse, a traveler's view will appear as shown in Figure 3.10-10. Changeable signage linked directly to the ATN control system will indicate the current destination for each of the vehicle blocks. Below the destination announcement will be a queue-length indicator enabling passengers to easily ascertain the shortest queue. Numbers on the indicator or its location will correlate to queue lanes marked in the flooring. Light tunnels can be installed, piercing both roof and floor, helping to illuminate the concourse and replacing at curbside some of the light lost due to shading from the concourse structure.

The boundaries of each queue are further demarked by a series of stanchions, each topped by a trip information panel, similar to those of current designs. The information panel will ask for responses to a series of simple questions that will collect travel metrics and inform the system as to near-term demand so that it may allocate vehicles in as timely a manner as possible. The series of panels helps to preclude delays caused by passengers who are slower to respond to the inquiries. Passengers selecting queues will be directed to proceed to the open queue position closest to the vehicle block.

If fares are charged, the transaction could be executed here or at kiosks located conveniently either at concourse level or in the terminal at the base of each escalator. In either case, tokens could be issued and deposited in vehicles to confirm boarding, forming the basis of a concourse management system that could also ensure travel preferences. For example, passengers desiring to travel alone in a larger vehicle would be ensured of this because the encoded tokens of other passengers attempting to board would alert the system to the attempt, preventing departure and allowing action to be taken.

Conversely, it may be possible to configure the concourse management system to inquire about both party size and travel preferences, directing both the formation and split of parties and allocating them to vehicles as required. In surge situations to a common destination, the concourse can be managed more simply. Queues will form, equalized in length with the help of the queue-length indicator, and passengers will simply board the vehicles, occupying all seats.

A number of these concepts have been discussed throughout the ATN literature. However, as mentioned earlier in this report, the issue of concourse management is likely to require a considerable amount of study and experiment before acceptable designs can be produced. A later section will discuss related vehicle design options that may provide a simpler means to ensure travel preferences.

While on the topic of travel preferences and vehicle design options, a number of discussions were held with SJDOT staff on the topic of ADA compliance. It may be possible to provide seamless and indistinguishable transit service to disabled persons without requiring an entire vehicle fleet to be ADA compliant. This may be possible via select staging of ADA-compliant vehicles and advance notification of special needs to the system. In the case of the terminal concourse, the berths in each block closest to the central aisle and nearest the elevator could be designated for serving disabled passengers. These berths could be rather quickly supplied with ADA-compliant vehicles from staging areas immediately upstream or downstream of the stations. As above, a later section will discuss vehicle options relative to this topic.

External views of the terminal concourse and accumulator stacks are shown in Figure 3.10-11 through Figure 3.10-15. Note that most of the triple guideways between the terminal and parking structure could be replaced with dual guideways if four additional transitions are added to the layout, two north and two south of the terminal.

Figure 3.10-9. Approach to concourse.

Figure 3.10-10. Terminal A Concourse interior.

Figure 3.10-11. Curbside exterior view of Terminal A Concourse and accumulator stacks.

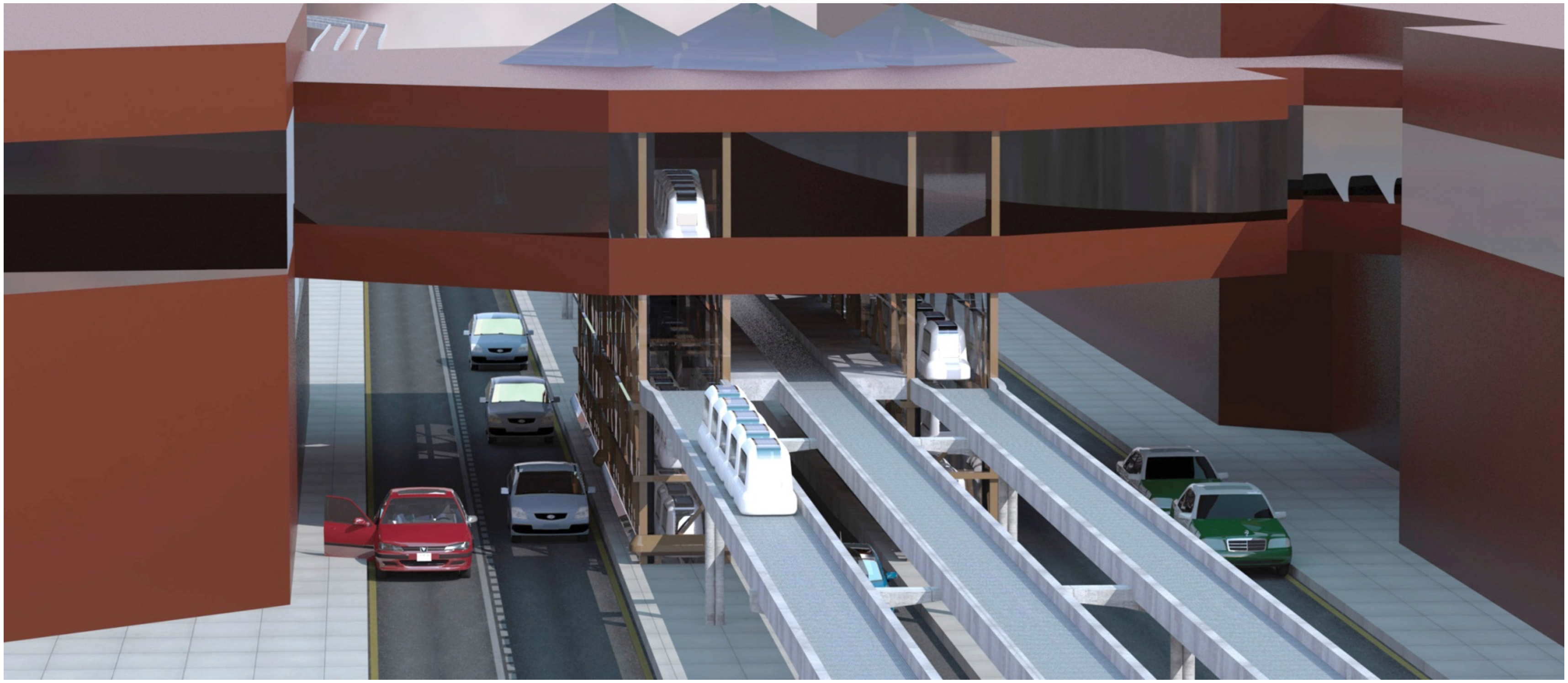


Figure 3.10-12. Elevated exterior view of Terminal A Concourse looking north.

Figure 3.10-13. Alternate elevated view of Terminal A Concourse looking north.

Figure 3.10-14. Exterior view of Terminal A Concourse looking south.

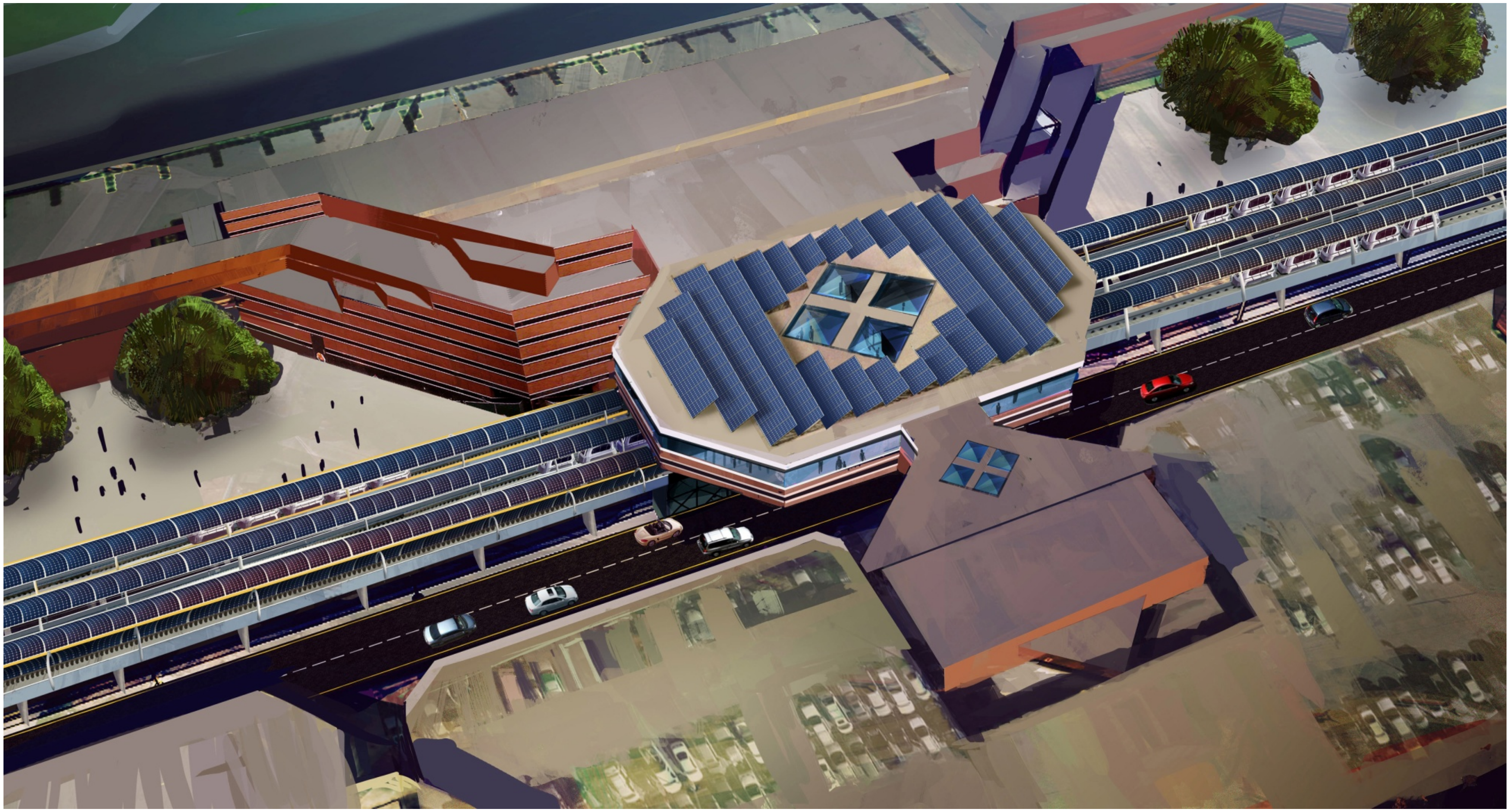


Figure 3.10-15. Bird's-eye view of Terminal A Concourse.

As mentioned in the opening description of the Magic Link, the use of the Magic Return and the accumulators to serve the terminal concourses, although unorthodox, eliminates a number of concerns associated with current ATN designs. Nevertheless, other empty vehicle supply options are certainly conceivable and warrant further consideration. For example, additional elevated guideway to serve as storage spurs, placing vehicle storage in the parking structures or in dedicated, newly constructed depots or simply attempting to store vehicles in transit are each possible singly or in combination. However, it is necessary to conduct a comprehensive set of cost/performance/risk tradeoffs to arrive at a defensible conclusion, an effort falling outside the budgetary constraints of this project.

Briefly, though, the City should be aware of the basic tradeoffs. One can begin by noting that the same vertical circulation difficulties would present themselves at Terminal A regardless of the selected option as long as a network layout having a central corridor pass-through guideway were required. Beyond this and as mentioned, the underlying design driver is the rather high and asymmetric demand between the two terminals such that a significant fraction of traffic in peak hours would consist of empty vehicles on the network, bleeding off capacity. Larger vehicle sizes would help mitigate this to some extent but at the cost of greater overall energy usage, a point detailed in the following subsection. Headways shorter than the current six-second capability would similarly mitigate the issue. This would increase capacity while the empty vehicle traffic would remain the same—still, though, at the expense of higher energy usage. The interference from empty vehicle return traffic can also be mitigated by the use of the alternative infrastructure mentioned above as temporary storage, repositioning vehicles during periods of off-peak traffic. However, this would result in larger fleet sizes as vehicles, once used, would be placed in reserve.

The combination of the Magic Link, Magic Return, and the accumulators provides an opportunity to avoid all of these difficulties. The Magic Return, in particular, provides an interesting side benefit—it takes advantage of stable subterranean temperatures to provide year-round thermal conditioning of vehicles. Its potential as a “renewable” energy source should certainly be considered in overall performance/cost trades. The cost of a cut-and-cover trench needs to be considered, of course. The cost of the one-half-mile trench considered here has been estimated at approximately $25M, including utilities and ventilation but excluding the relocation of any existing underground services. Lastly, the use of accumulators seems rather complex at first blush—and it is relative to more conventional fixed infrastructure. The reader should note, however, that similar devices are part of a mature, 30-year-old, $100B annual automated vehicle storage (AVS) global market. Increasingly, such devices are being used to make more efficient use of space in dense urban environments and as a component in automobile manufacturing and sales logistics. Numerous electromechanical and electrohydraulic designs are conceivable for driving such a device, including the opportunity for “regenerative descent,” identical in concept to regenerative braking and used here subsequently. Lastly, reliability and maintenance are certainly considerations, and a thorough assessment is in order. However, perhaps all that needs to be said at present is that such devices are used to actuate the control surfaces on commercial airliners.

Thus, as mentioned earlier, this combination of design elements was selected for the reference design to overcome some basic present uncertainties and operational limitations and to reduce overall levels of near-term risk by trading development risk for integration risk. The operation and performance of the Magic Link subnetwork and the rest of the network are discussed in more detail in the following subsection.

3.10.4 Reconfigurability and Forward Compatibility

This short but exceedingly important subsection discusses in a bit more detail the issues first discussed in Section 3.4.2.3 of physical “scalability” and of managing the introduction of technologies and systems that are in the process of maturation and consequently in a high state of flux. This is a crucial topic with respect to the Airport project or any other smaller-scale project for that matter if it is seen as an "anchor application" of future expansion.

As before, the ability to extend or reconfigure an ATN network is a feature essential to the practical viability of ATNs. Although this is a nuts-and-bolts issue, it is not a trivial one and is a challenge different from that of original construction. The City must demand detailed plans and procedures for doing this and a physical demonstration of the capability[52].

A perhaps more important topic is the issue of keeping pace with a likely rapidly developing technology.[53] As also mentioned near the opening of this report, large infrastructure projects are obviously not easily upgraded. This is especially true of some potentially conceivable ATNs designs, which can be highly integrated systems. This means multiple functions are performed by fewer physical components. Think integrated circuits as opposed to printed circuit boards having many physically distinct electronic components.

There are pros and cons to each approach too numerous to detail here, but at a high level significant performance advantages may be possible using highly integrated designs at the possible costs of more down time due to a lesser level of redundancy and of having to replace a more complex and expensive unit, should any single integrated component fail. However, robust designs for high-reliability integrated subsystems and improved manufacturing techniques can drive these costs down to the point where the integrated system has both the performance and cost advantage. In the electronic component example, it is a common experience that it is frequently less expensive (although not necessarily as environmentally sound) to buy a new television rather than have an old malfunctioning one repaired.

The example of battery-powered vehicles can be used as a starting point to illustrate the issue for ATN systems. An ATN design using such vehicles is an example of a system that is not as highly integrated as other possible approaches. In currently available versions of this type of design, propulsion, braking, and power distribution functions are allocated to physically distinct components existing in more or less physical isolation. For example, power is brought to stations and depots where vehicle batteries are charged through some sort of direct contact or inductive charging interface. The vehicles, of course, then carry the stored energy with them via batteries, powering rotary-synchronous A/C motors for propulsion and a portion of braking. Thus, half of the power distribution system can be thought of as residing in facilities and the other half in vehicles, while all of the propulsion/braking subsystem resides exclusively in the vehicles.

Conversely, for designs using linear induction motors, the propulsion/braking subsystem resides half in the vehicle and half on the guideway, while the power distribution function is allocated to facilities and the guideway via conductors running its entire length, and with only a minor amount of on-vehicle storage for emergency purposes. Thus, the power distribution and propulsion/braking functions are allocated to physical components of the system in an entirely different manner, resulting in a very different set of physical interfaces.

The purpose of the preceding paragraphs has been to illustrate that the functions of a system's subsystems can be allocated in numerous ways between the various major physical components. While each of these two examples possesses roughly similar levels of integration, one can postulate

[52] Precisely when to do this in an overall plan to acquire an ATN system is discussed in Section 4.4 along with other topics of this nature.
[53] Assuming, of course, that a defensible value proposition(s) can be first made to justify overall development efforts.

designs integrated to a much greater degrees. For example, in either of the present two cases, control and control communications can be carried out by onboard and wayside sensors, actuators, and radio frequency links to central and/or zone controllers. For those maneuvers that cannot be accomplished autonomously by vehicles, sensor data is relayed to the controllers, and commands are returned to vehicle and wayside actuators over the same radio links. However, it is conceivable that an opportunity exists to integrate power distribution, propulsion/braking, control sensing, and communications into a single component. A system based on this would be considered as one possessing a high degree of integration—the ATN equivalent of an integrated circuit.

There are pros and cons associated with each of these approaches. Each approach merits a future comprehensive evaluation. However, if well-executed, a more highly integrated system design not yet in existence could possess some very desirable characteristics from a host of perspectives, including those of cost, performance, and environmental considerations and of the consequent business cases that can be made.

Tradeoffs such as these are very complex and must be done with a particular application in mind (i.e., there is no intrinsically better or worse approach for all cases). It is far from clear at present which approach is most desirable for the City's purposes. In fact, as mentioned earlier, the RFI process was notable for the responses it did not draw from a number of known ATN developers. Plans for such advanced integrated systems may very well exist.

The question is how to move forward in gaining experience with a technology and deploy actual systems for revenue operations while accounting for desirable technical advances that might not be available for some time, as doing otherwise would permanently relegate an initial deployment and any extension of it to what might be inferior cost and performance characteristics. One answer is to incorporate what are known as forward-compatible design features. At the expense of a mildly sub-optimal design, systems can be designed such that the major portion of them is retained but having features to accommodate anticipated and more advanced future subsystem upgrades.

For example, given that an ATN guideway is one of the costliest line items and perhaps the most visible, it is a natural candidate to explore for forward-compatibility opportunities. One example is shown in Figure 3.10-16. This very simply illustrates how a guideway structure may be conceived to allow for forward compatibility. In this concept, the function of the roadway and walkway[54] is allocated to physically separate items. The guideway is relieved of these functions, serving only its principal function of providing structural support. The possible overhead structure shown is incidental to the discussion but can possibly share in the structural support function while simultaneously serving as a secondary sunshade/solar panel support.

The roadway element is an item for which advanced designs may provide significant downstream benefits. Thus, were the City to specify a forward-compatible guideway structure design, it would preserve for itself the means to upgrade its system to take advantage of future engineering advances and perhaps undertake an initial deployment sooner than otherwise while minimizing the risk of entering a technological cul-de-sac. An alternative is, of course, to wait while the numerous ATN design approaches are matured elsewhere and their relative advantages and disadvantages more fully understood through experience.

[54] Note: A walkway is specified in CPUC regulations.

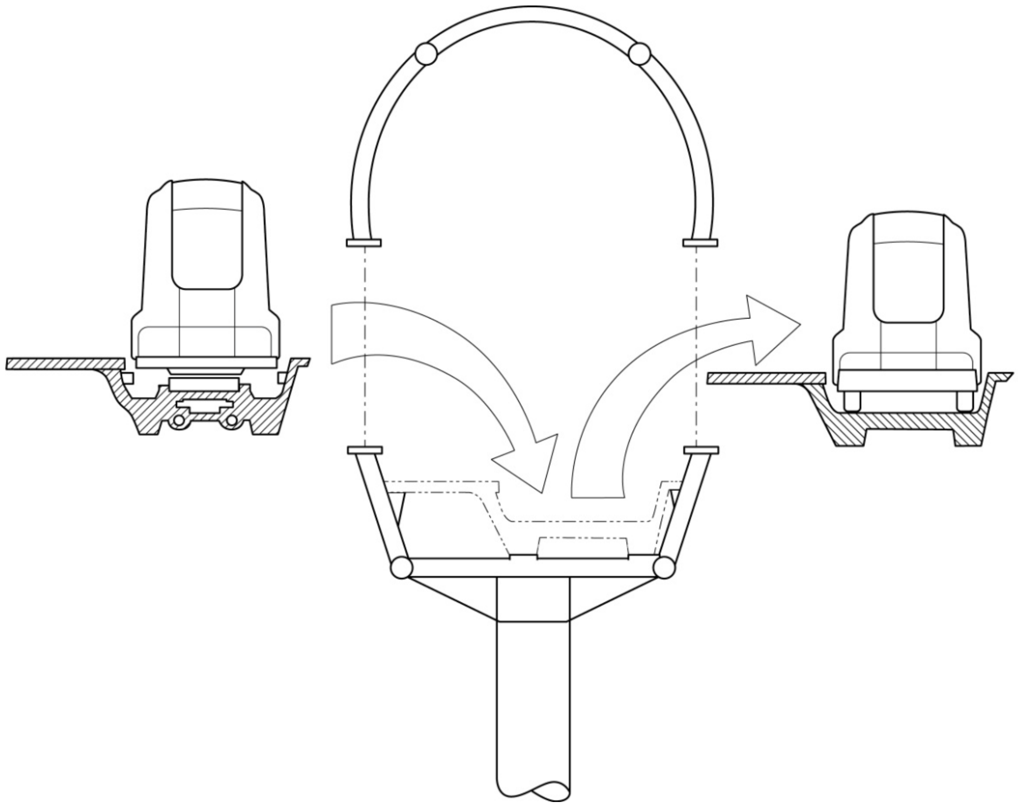


Figure 3.10-16. Forward-compatible guideway structure.

Given well-designed forward compatibility features, it is possible the change-out of the roadway module could be accomplished with reasonable system downtime. It should also be noted that the forward-compatible interfaces between guideway structure and integrated roadway module could be viewed as perhaps an excellent candidate for standardization that would do nothing to inhibit innovation through the simultaneous pursuit of multiple ATN designs.

As a final note, even if no advanced, highly integrated power/propulsion/communications module were anticipated, this design concept could still be beneficial by providing a means to easily replace the worn road surface of rubber-tire vehicle designs, perhaps with roadbeds of advanced designs using advanced materials providing superior performance relative to wear, noise, ride comfort, drainage, and perhaps other figures or merit.

3.10.5 Vehicle Design and Manufacturability Assessment and Options

The space, material, and energy efficiency of an entire ATN system is critically connected to the design of the passenger-carrying vehicles. Just as it is desirable from the perspective of energy conservation and urban planning to encourage the users of conventional, personal road vehicles to use a vehicle no larger and heavier than is necessary, so it should be for ATN systems. In the further development of ATN systems, it makes sense to strive toward a range of vehicle sizes, matching particular sizes to the expected most frequently occurring party sizes for any particular application.

It is also crucial for the City to be cognizant of the general design and manufacturability aspects of current vehicles, as this has a direct impact on cost and schedule and on passenger experience via vehicle integrity. This section discusses various aspects of vehicle design derived from an assessment of the RFI responses and overall system considerations relative to the Airport reference design.

3.10.5.1 Vehicle Packaging

For the Airport application, over 80 percent of passengers arrive and depart as parties of one or two. Of the remaining 20 percent or so, it is not known what percentage is inseparable—a parent with several small children, for instance. It is quite likely, however, that most multipassenger parties are separable, especially considering the short travel times involved. Furthermore, as mentioned in Section 3.5.5, cultural determinants may diminish the appeal of a transit option providing less-than-personal service, inhibiting the acceptance of ATNs on a broader scale.

The effects of vehicle size on the cost and performance of the Airport reference design is considered in subsequent subsections. Presented here are the results of work performed in collaboration with the Pasadena Art Center College of Design to envision vehicles smaller and lighter than those being currently proposed, which may help address these issues while, together with specific operational features of the overall system, could provide transparent, ADA-compliant service when required.

Beginning with a look at ADA compliance, it is certainly possible with a minor revision to ADA regulations to envision such vehicles. Based on the guidance given in the ADA Vehicle Accessibility Guidelines in Section 1192.173 for Automated Guideway Transit Vehicles and Systems (the closest apparent category to ATN vehicles), the vehicle pictured in Figure 3.10-17 provides adequate ingress/egress and head clearances, reasonable luggage capacity, and room for a wheelchair-using passenger plus one seated attendant. It can also accommodate a reasonable range of now-smaller electromechanical propulsion and safety components in an efficient overall size and weight.

The ADA Section 1192.173 reference to Automated Guideway Transit Vehicles and the text of regulations themselves seem directed toward large vehicles capable of carrying many passengers such as the familiar Automated People Movers, thus leading to specific requirements that would prohibit such a concept. The specific text of Section 1192.57 (Interior circulation, handrails, and stanchions) states: “(b) Handrails, stanchions, and seats shall allow a route at least 32 inches wide so that at least two wheelchair or mobility aid users can enter the vehicle and position the wheelchairs or mobility aids in areas, each having a minimum clear space of 48 inches by 30 inches, which do not unduly restrict movement of other passengers.”

However, a vehicle concept such as this coupled, as mentioned, with certain other system features and operation, could certainly meet the spirit and intent of the law. Given the potential benefits with respect to system capital and operating costs, including energy efficiency, an inquiry into a potential modification seems warranted.

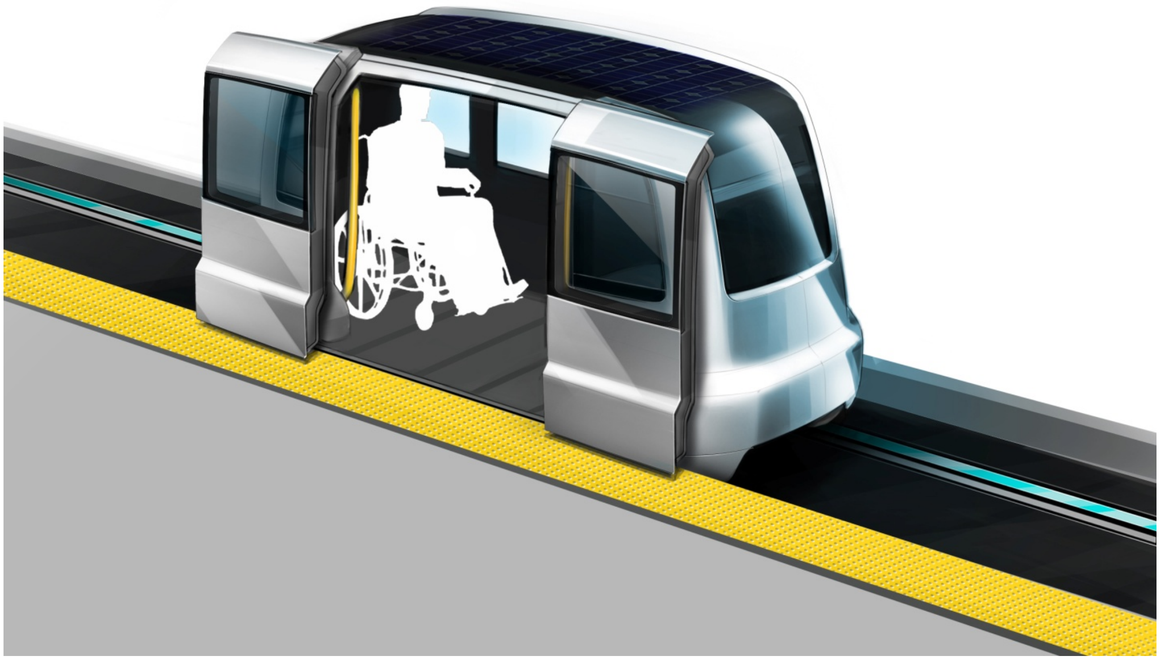


Figure 3.10-17. Dedicated ADA-compliant vehicle.

For passengers not requiring these accommodations, the same vehicle can easily be offered in an alternative configuration having a central bulkhead, as shown in Figure 3.10-18. The “swing” area required to provide ease of ingress/egress for a passenger using a wheelchair can be converted to sufficiently large “aisle ways” into two completely private passenger compartments.

The bulkhead has several significant secondary advantages: It would act as a major structural component, enabling a more rigid and weight-efficient design; it would serve as a convenient door-latch “hard point,” perhaps simplifying door design and ensuring a more secure sealing of the cabin against weather and noise; and it could serve as a convenient mounting place for multipurpose information displays.

Perhaps most interestingly, it opens up another potentially advantageous tradeoff by creating two separate thermal zones in the passenger cabin. It may be possible to isolate one of these zones in periods of low demand when serving predominantly one-passenger parties. Another layer of operations and control system complexity would be required in order to ensure that a mix of vehicles having one and both compartments thermally preconditioned is available when needed, but managing HVAC separately for each zone or compartment can perhaps further improve overall system energy efficiency. Furthermore, if the station or concourse management system is designed as suggested in Section 3.10.3.4 to provide party formation and split capability, it could also be used with minor modification to direct one- and two-passenger parties to the appropriate vehicles based on thermal preconditioning. Isolating the compartment can be easily accomplished by operating a single door.

Manufacturing ADA-compliant vehicles not having the bulkhead would require rather minor production-line modifications to the vehicle structure in the form of floorboard and ceiling edge stiffeners and perhaps cross-members.

The outer dimensions of the concept vehicle are 120 inches x 51 inches x 72 inches (L x W x H), a perhaps useful 24 inches shorter in length than the most compact of current designs. The Terminal A and Terminal B concourses based on 10-berth vehicle banks, for example, could be designed to be 20 feet less in overall length.

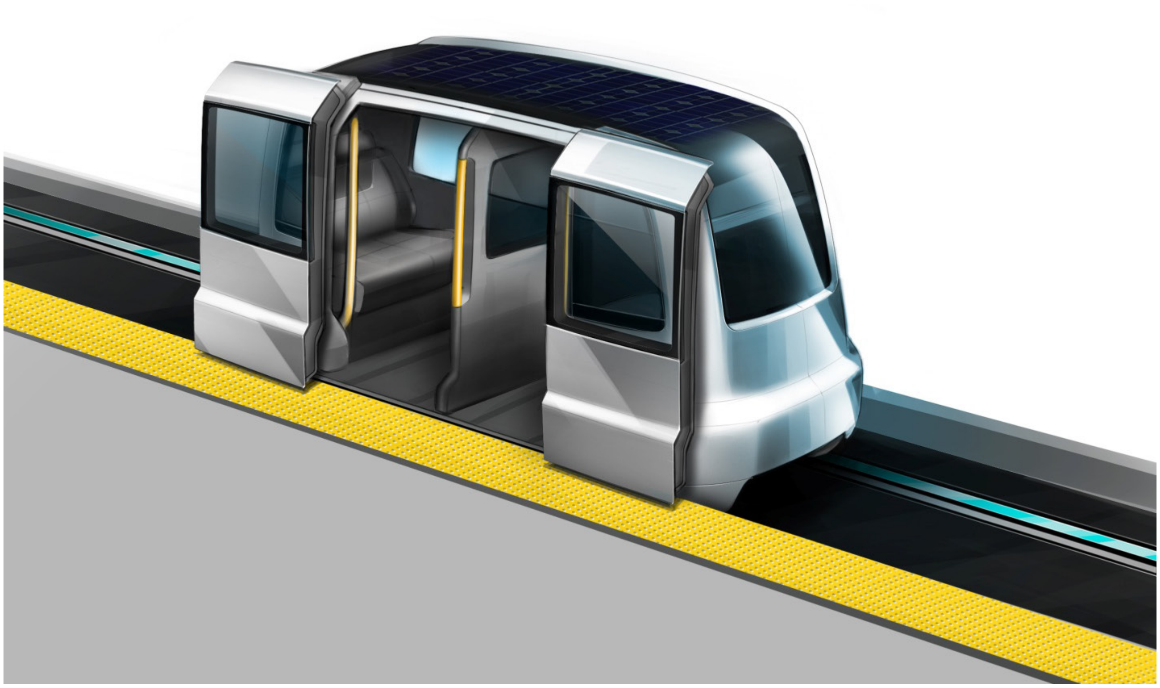


Figure 3.10-18. Non-ADA-compliant vehicle.

An overall assessment of current vehicle design reveals a range of attention paid to structural efficiency and automotive-grade packaging and design for manufacturing. ATN vehicles are at present essentially hand-built prototypes, as one would expect. Present low production volumes do not, of course, warrant significant investment in these areas as yet, but even accounting for manufacturing methods appropriate to much lower production volumes, there appears to be plenty of opportunity to reduce the exterior dimensions of the current ATN vehicles without reducing passenger room and comfort.

3.10.5.2 Vehicle Manufacturability and Production Volume

Judging solely by the RFI responses, the prototype nature of current ATN vehicles relative to production automotive standards is clearly apparent, again as one would expect at this early stage. A range of construction techniques are used. Some vehicles seem to have been designed with a very basic body-on-frame approach, others use more sophisticated structural components in a slightly more unit-body design using exterior and interior body panels applied to a hand-fabricated reinforcing framework, and others approach a full monocoque construction, in which the body skin itself is a principal structural component. All this results in varying degrees of part count, labor intensity, and structural efficiency as reflected by the rather wide range of vehicle weights per seat. Suspension design is similarly represented by a range of seemingly very basic approaches.

While appropriate—well-done, in fact—for demonstration purposes and for limited production, production rates beyond a few dozen vehicles is likely to be problematic. First of all, the rate of production is restricted by the time it takes to lay up and trim the body panel moldings, largely by hand. Second, the dimensional accuracy of the finished moldings and for the steel-tube chassis in aggregate will be very difficult to control, leading to major issues with the weather-tightness of the door assemblies in particular and myriad other perceived quality issues on the finished vehicle. This method of construction will be very labor-intensive, with a high proportion of semi-skilled labor being invested in fit and finish management during the whole vehicle assembly. Delivered vehicles will vary enough dimensionally from one to another to make it difficult to install replacement components for routine maintenance or accident damage repair.

Based on conventional and specialty automotive experience, the economical break points for changing manufacturing techniques are likely to occur at initial production quantities of approximately 30 and 2,000 units, and thereafter a sustained production level of 2,000 units per year with corresponding costs of approximately $150,000, $90,000 and $70,000. Greater improvements are, of course, possible with increased production volumes and, perhaps, for smaller vehicles.

3.10.6 Reference Design Performance Estimates

The performance estimate of the reference design begins with the revised 2030 O/D matrix of Table 3.10-1 provided by Arup based on improved data acquired after completion of the reference design layout. In this estimate, the demand between Terminal A and Terminal B/ConRAC is considerably reduced from initial estimates. While this had the potential to eliminate concerns about the effects of this design driver relative to station and network performance, a decision was made to continue with the evaluation of the reference design as described since station performance results were not yet available and a system expansion could easily make up for the reduction. 2030 demand was considered exclusively in the reference design performance estimate. Demand in terms of vehicles given an average load factor of 1.4 passengers per vehicle is listed in Table 3.10-2.

Table 3.10-1. Revised O/D Matrix - 2030 Noon Hour Passenger Traffic

From/To	Terminal A	Terminal B/ ConRAC	Economy Lot	Lot 4	VTA LRT
Terminal A		505	85	30	30
Terminal B/ConRAC	225		50	15	15
Economy Lot	35	45		n/a	n/a
Lot 4	10	15	n/a		n/a
VTA LRT	10	15	n/a	n/a	

Table 3.10-2. Revised O/D Matrix - 2030 Noon Hour Vehicle Traffic

From/To	Terminal A	Terminal B/ ConRAC	Economy Lot	Lot 4	VTA LRT
Terminal A		361	61	21	21
Terminal B/ConRAC	161		36	11	11
Economy Lot	25	32		n/a	n/a
Lot 4	7	11	n/a		n/a
VTA LRT	7	11	n/a	n/a	

3.10.6.1 Multi-Mode Traffic Split and Density

As mentioned earlier, the terminal station layout was envisioned as providing reconfigurable, multi-mode flexibility so that it can adapt to changing demand profiles throughout the day, especially with respect to surges. The performance estimate discussed here is illustrative. As shown in Figure 3.10-19, for the peak hour considered, all of the outer bank blocks are assigned to service the highest of the asymmetric demand between Terminal A and Terminal B/ConRAC. The lowest portion of this demand is assigned to the inboard blocks of the two inner banks. In this particular hour, the high demand is traveling right to left from Terminal B/ConRAC to Terminal A, the low demand flowing in the opposite direction. The outboard blocks of the inner banks (uppermost in the figure) are designated to service demand between the terminals and all of the outlying stations. These assignments will be indicated on the changeable signage in the station concourses. Thus, during surges with many passengers having a common destination, the six blocks serving demand between Terminal A and Terminal B/ConRAC will operate in a virtual APM mode, with vehicles traveling in scheduled platoons.

Note that these assignments can be discretized down to the individual-berth level. Individual berths and associated vehicle stacks can be operated completely independently, providing a very high level of operational flexibility and responsiveness to demand surges. For instance, using a single turnstile or other type of "registration portal"—similar to the device that stops a grocery store checkout conveyor belt—a running count of total passengers destined for Terminal B/ConRAC, say, can be provided to the concourse management system. The management system can use that data to shut down entire queues to help ensure that the minimum number of vehicles depart unoccupied.

This can be taken a step further. In periods of low demand, a smaller number of berths in all four blocks can be assigned to service general destinations. With proper signage, or perhaps a more sophisticated, token-based concourse management system, it may be possible to distribute passengers uniformly among the blocks. Taken as a whole, this would result in yet another variation of the nonblocking station. One can see that such an arrangement is extremely flexible operationally.

Due to the guideway layout, the outer banks can operate completely independently using Loop 5. In order to avoid triple guideway the entire length of the Airport, however, the remaining service is shared among the terminal loops and the central portion of Loop 2 in the main Airport corridor. The coordination of service to outlying stations with that for Terminal A/B low demand is accomplished by taking advantage of the scheduling inherent in the virtual-APM mode. Thus traffic outbound to outlying stations from TA IB NB must wait a short amount of time until the outbound platoon to Terminal B/ConRAC from TA IB SB begins to move within the Terminal A station. Similarly, outlying traffic inbound to TB IB SB would need to have its arrival coordinated with the clearance of empty vehicles in TB IB NB.

In the scenario just described, traffic is flowing with general counterclockwise circulation patterns. If the angled-berth stations were operated in reverse, general circulation could be reversed when the low- and high-demand Terminal A/B traffic reverses flow. Alternately, the low-demand Terminal A/B traffic could be directed into the network at the expense of trip times or its flow can be reversed against general circulation. In the stations, this is equivalent to normal ATN operations as long as the movements are coordinated and vehicles present in the station remain stationary. Reverse flow on Loop 2 is more problematic. It is conceivable that with low demand to/from outlying stations, these movements can be coordinated. If, however, system expansions are realized and pass-through traffic on Loop 2 increases, this approach would be much less tenable.

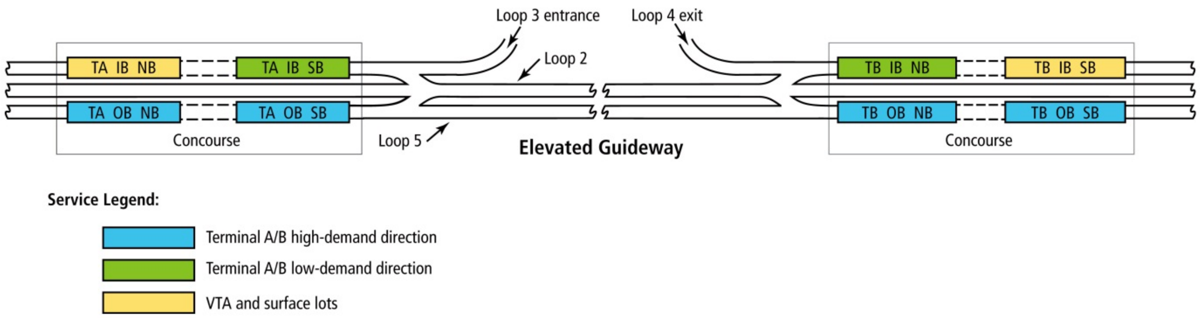


Figure 3.10-19. Peak hour station block assignments.

Nevertheless, to examine the effect of the latter method of handling the low-demand portion of Terminal A/B traffic in the scenario described, two cases were analyzed by the methods outlined in Section 3.3. In the first case, titled No Magic Link Low, the low-demand portion of peak Terminal A/B traffic is directed onto the network. In the case titled Magic Link Low, this traffic is directed in reverse flow northbound from Terminal B to Terminal A. The hourly traffic split for these scenarios are shown in Figure 3.10-20 and Figure 3.10-21, respectively. As one would expect, network traffic flow is considerably reduced and a potential congestion issue is eliminated. Further interesting results are noted in the discussion of energy usage.

This serves as an additional demonstration of the ability of the analytical technique to provide quick assessments of the performance of network layouts for given demand patterns, a useful capability for preliminary layout purposes. Problem areas might not seem so obvious except to a trained eye. Here, upon reflection, it can be seen that given a counterclockwise traffic flow and a majority percentage (excluding Terminal A to Terminal B traffic) of total traffic that is departing from the terminals to the Economy Lot, the guideway segment east of the Terminal A parking structure is a potential choke point.

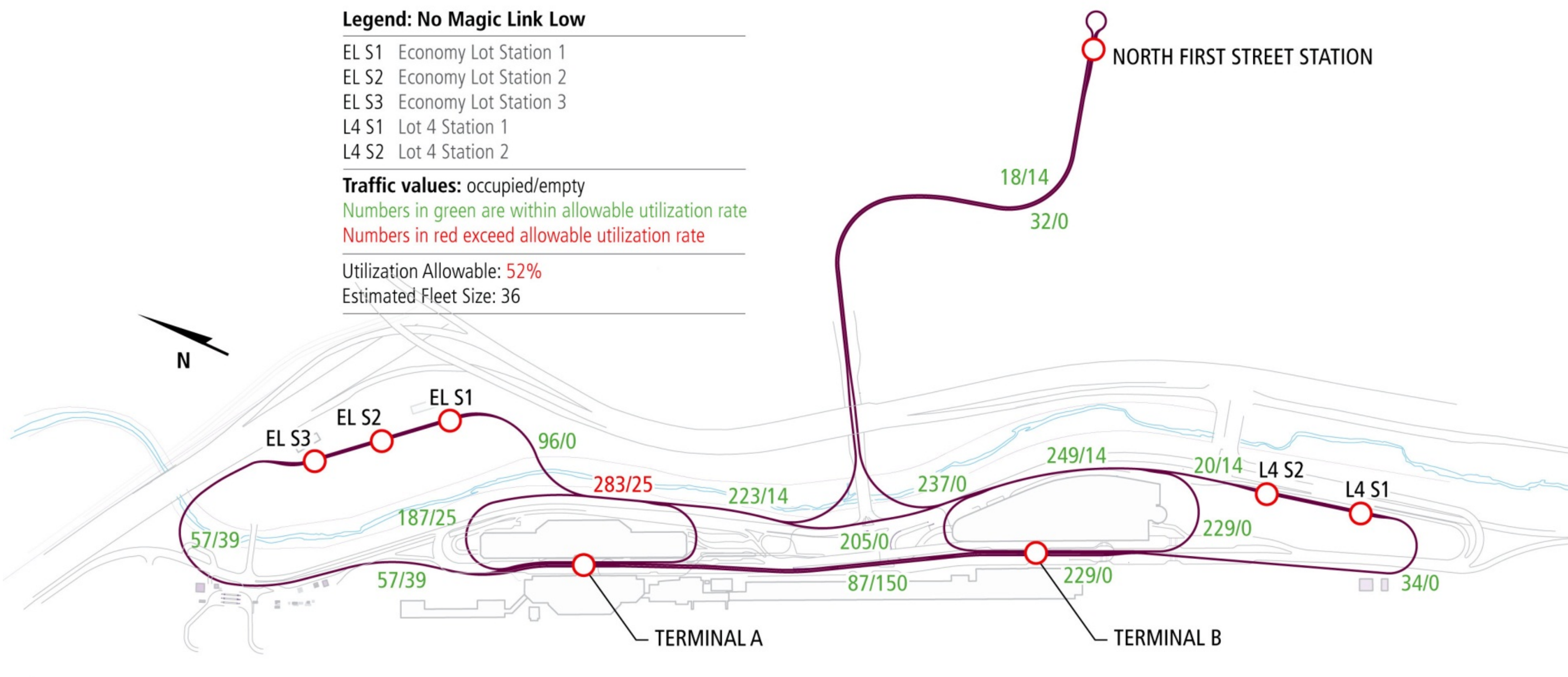


Figure 3.10-20. Network traffic split—No Magic Link Low.

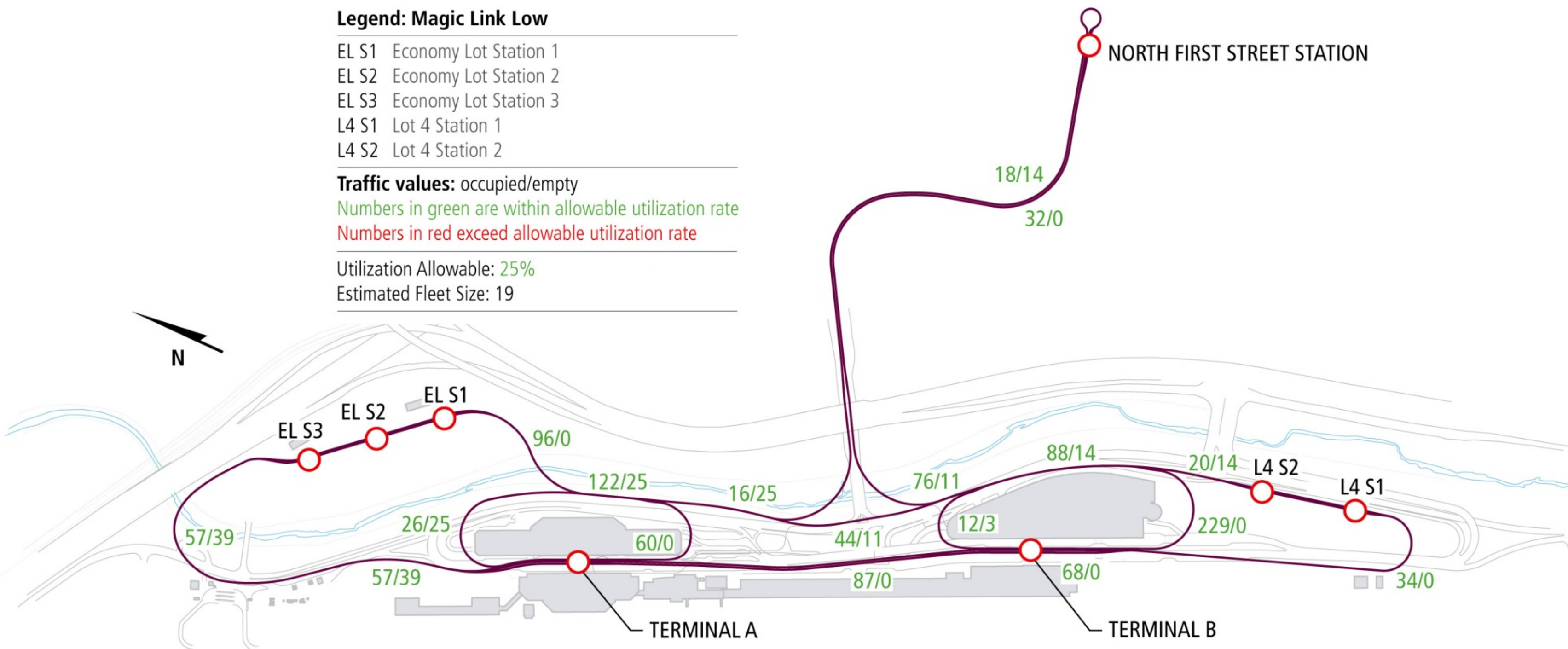


Figure 3.10-21. Network traffic split—Magic Link Low.

3.10.6.2 Main Network Trip and Wait Times

To further estimate system performance, three performance levels were established. These levels are not intended as representative of an actual specification, but rather to illustrate a range of performance based on a number of eventualities. Low, mid, and high performance levels were defined as in Table 3.10-3.

Table 3.10-3. Estimation Performance Levels

Performance Level	Low	Longitudinal Acceleration Allowable	0.06	g	2.01	ft/sec^2
		Longitudinal Jerk Allowable	0.06	g/sec	2.01	ft/sec^3
		Lateral Acceleration Allowable	0.06	g	2.01	ft/sec^2
	Mid	Longitudinal Acceleration Allowable	0.13	g	4.02	ft/sec^2
		Longitudinal Jerk Allowable	0.13	g/sec	4.02	ft/sec^3
		Lateral Acceleration Allowable	0.13	g	4.02	ft/sec^2
	High	Longitudinal Acceleration Allowable	0.25	g	8.04	ft/sec^2
		Longitudinal Jerk Allowable	0.25	g/sec	8.04	ft/sec^3
		Lateral Acceleration Allowable	0.25	g	8.04	ft/sec^2
		Lateral Jerk Allowable	0.13	g/sec	4.02	ft/sec^3
		Max System Design Speed	35.0	mi/hr	51.33	ft/sec
		Max Station Speed	5.0	mi/hr	7.33	ft/sec

The lateral acceleration allowables determine the maximum permissible speed in each curve, resulting in the speed limits for each loop or portions thereof.

A principal measure of performance is, of course, trip times. As previously mentioned, numerous trips are possible; a partial listing is given in Appendix D. The shortest trips between the presumed most popular O/D pairs[55] were extracted from the appendix for calculation. Trip times for alternate routes are not included. However, given the generally low demand outside of the Terminal A/B corridor, little congestion can be expected even at the very high six-second headways of current designs[56]. The trip times of single vehicles traveling in isolation are therefore fairly representative of the trip times that would occur when the network is managing full demand. This is confirmed by the traffic density analysis, where it is noted that, except at the choke point, densities nowhere exceed a very reasonable utilization rate. Thus, as discussed in Section 3.5.7.3, there is no need for merge denials; vehicles are all able to travel to their destination via the shortest routes.

The trip time values result from a straightforward time/speed/distance calculation, but they account for all speed changes when traversing the various loops as well as all acceleration and deceleration maneuvers. They also include in-station maneuvering to the extent that the single vehicles move from the most downstream input buffer location after deceleration to a stop, to a midpoint berth, and then

[55] It is conceivable, for instance, that some small amount of demand might exist from travelers using VTA light rail and the Airport ATN to access surface parking to meet friends for a subsequent trip by automobile or as a stopgap means to return home late at night after finding one's car battery dead. This also suggests a perhaps greater measure of value for ATNs in general—providing access to strategically located occasional-use automobile rental facilities. Convenient access to such facilities via light rail and a more extensive ATN deployment, rather than daily rental costs, might be the determining factor for many people who might be willing to give up automobile ownership altogether.

[56] Recall that congestion is not defined in everyday terms as the density of vehicles; it is defined as the density of vehicles plus the separation distance as defined by operational headway and line speed.

to the most downstream output buffer before accelerating upon departure. All acceleration and deceleration within stations are accounted for per this formulation, including vehicles backing out of angled berths and reversing direction. A compilation of the resulting trip times for the principal trips, excluding direct Terminal A/B traffic, is given in Table 3.10-4. The latter is discussed separately below.

Table 3.10-4. Representative Single-Vehicle Trip Times

			Low Performance			Mid Performance			High Performance		
			Trip Time		Avg Speed	Trip Time		Avg Speed	Trip Time		Avg Speed
Trip ID	Origin	Destination	(sec)	(min)	(mi/hr)	(sec)	(min)	(mi/hr)	(sec)	(min)	(mi/hr)
01	VTA	TA IB NB	333	5.5	13.4	243	4.0	18.4	180	3.0	24.7
04	TA IB NB	VTA	389	6.5	14.8	286	4.8	20.2	213	3.5	27.1
05	VTA	TB IB SB	453	7.6	13.9	331	5.5	19.1	245	4.1	25.8
07	TB IB SB	VTA	279	4.6	14.3	205	3.4	19.5	152	2.5	26.1
09	EL S1	TA IB NB	200	3.3	13.3	149	2.5	17.8	114	1.9	23.3
10	EL S2	TA IB NB	186	3.1	12.9	139	2.3	17.3	107	1.8	22.5
11	EL S3	TA IB NB	172	2.9	12.6	129	2.2	16.7	100	1.7	21.7
12	TA IB NB	EL S1	150	2.5	10.3	117	2.0	13.2	95	1.6	16.2
13	TA IB NB	EL S2	164	2.7	10.9	127	2.1	14.1	102	1.7	17.5
14	TA IB NB	EL S3	178	3.0	11.4	137	2.3	14.8	109	1.8	18.6
21	EL S1	TB IB SB	320	5.3	14.1	237	3.9	19.1	178	3.0	25.3
22	EL S2	TB IB SB	306	5.1	14.0	227	3.8	18.8	171	2.9	24.9
23	EL S3	TB IB SB	292	4.9	13.8	217	3.6	18.6	164	2.7	24.5
24	TB IB SB	EL S1	242	4.0	13.9	179	3.0	18.9	135	2.2	25.0
25	TB IB SB	EL S2	256	4.3	14.1	188	3.1	19.2	142	2.4	25.5
26	TB IB SB	EL S3	270	4.5	14.3	198	3.3	19.4	149	2.5	25.9
27	L4 S1	TA IB NB	264	4.4	13.8	194	3.2	18.7	146	2.4	24.9
28	L4 S2	TA IB NB	250	4.2	13.5	184	3.1	18.4	139	2.3	24.4
29	TA IB NB	L4 S1	252	4.2	13.3	190	3.2	17.7	146	2.4	23.0
30	TA IB NB	L4 S2	265	4.4	13.6	199	3.3	18.1	153	2.5	23.6
31	L4 S1	TB IB SB	190	3.2	10.8	144	2.4	14.2	114	1.9	18.0
32	L4 S2	TB IB SB	176	2.9	10.2	134	2.2	13.5	107	1.8	16.9
33	TB IB SB	L4 S1	141	2.3	11.1	107	1.8	14.5	84	1.4	18.5
34	TB IB SB	L4 S2	154	2.6	11.7	117	1.9	15.5	91	1.5	19.8

Wait times are affected by numerous variables and design choices. In particular, they are affected a great deal by fleet size and the availability of empty vehicles, a common-sense supposition. As discussed earlier in this report, a fully realized ATN system will require sophisticated algorithms in an attempt to direct vehicles to where they are needed not only in terms of geographic location but also at just the proper time. For the service to/from the outlying areas of the Airport network, a simpler near-term option may be to incorporate some form of the oft-suggested concept of staging empty vehicles in reserve at various locations. This was done here in the form of a staging berth at each of the outlying stations.

At first glance, this may seem indistinguishable from normal operations in which empty vehicles simply wait in all station berths until needed or required to depart to make way for an incoming occupied vehicle, and the analysis described here is, indeed, a bit nuanced. The difference here is that the stations are deliberately oversized by one berth, and when a reserve vehicle is used, it is immediately replaced by a call to a central depot—in this case from the Magic Link subnetwork. This may help to minimize empty vehicle circulation; i.e., vehicles are not stored in transit. Yet another way to conceive of this is as a multilayered empty vehicle logistics architecture consisting of large and small storage areas. Note that for this analysis, the number of empty vehicles designated as ready-reserve in the accumulator stacks for servicing outlying demand was taken as two.

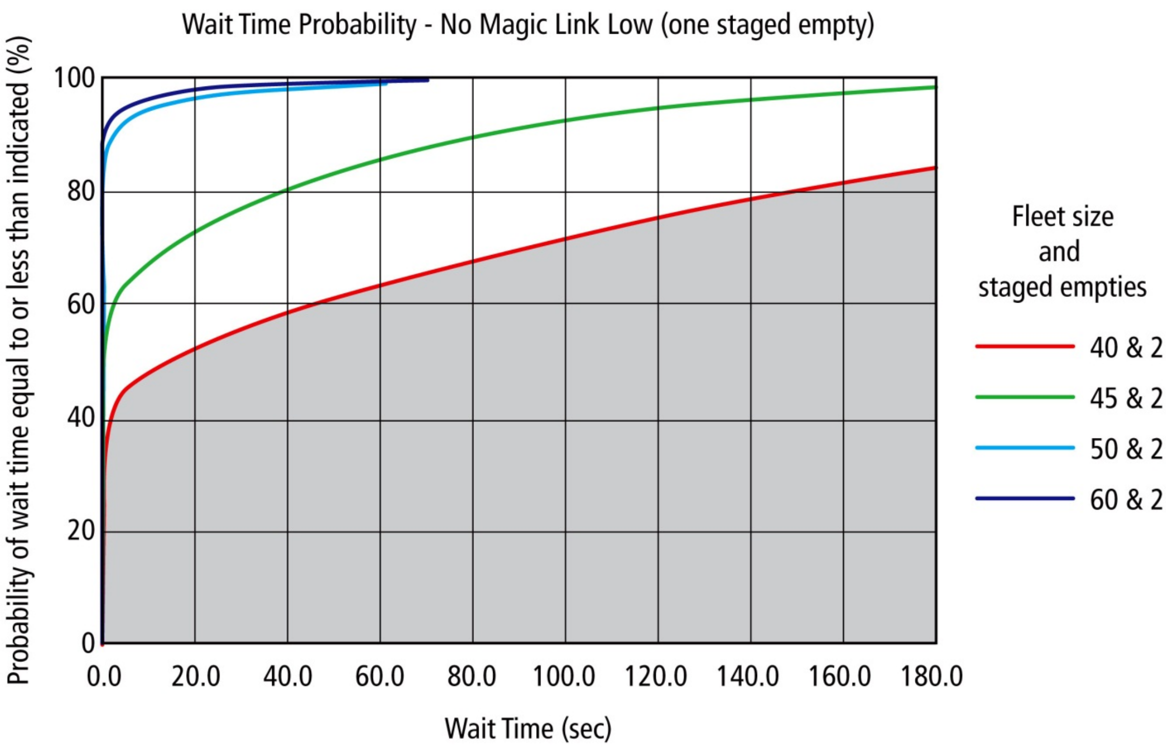
Taking advantage again of the very low demand to/from the outlying stations, the performance of such an arrangement and concept of operations can be simply modeled. The results are shown in Figure 3.10-22 and Figure 3.10-23. The analysis accounted for the two now-familiar Magic Link Low cases, excluding in each case only that portion of traffic associated with the high-demand direction of Terminal A/B demand. As opposed to scheduled-service transportation systems, wait times for a demand-responsive system must be given in terms of probabilities. Thus, each curve in the figures is to be read as the probability of average wait time *equal to or less than* the corresponding value of time on the horizontal axis. Note that the shaded areas in each figure represent fleet sizes that are insufficient for servicing the demand.

The results indicate wait times that are quite favorable for a modest operational fleet size of approximately 45 vehicles. Larger fleet sizes provide no additional benefit, excluding energy/storage/limited range considerations. The case in which the Magic Link subsystem is used to service the lower traffic portion of Terminal A/B demand results in an additional 10% to 20% improvement with a smaller fleet size, as one would expect. Additional vehicles would still be necessary, of course, to service this demand, operating instead primarily on the subnetwork. The shaded areas below the bottommost curves indicate a fleet-size limit, below which some passengers are *never* served.

A single caveat is in order for these results: They were calculated for the high performance case having the shortest trip times. Unless additional resources are provided, perhaps in terms of circulating empty vehicles, wait times will increase from those presented here.

A result that one would not intuitively expect, and a very interesting one, is revealed by comparing the sets of curves for the same operational case but differing in the number of staged empty vehicles. Counterintuitively, certain cases in which two vehicles are staged perform significantly worse than if only a single vehicle is staged. Close inspection reveals that this is a function of the centrality of the storage depot, the number of staging locations relative to station size, and fleet size.

Consider the case of a 45-vehicle fleet size. System performance based on two vehicles staged at outlying stations is considerably worse than that if one vehicle was staged. However, if a fleet size of 50 vehicles is specified, the comparison reverses, and the staging of two vehicles results in superior performance, because the larger number of vehicles at the central depot can more effectively service demand surges.



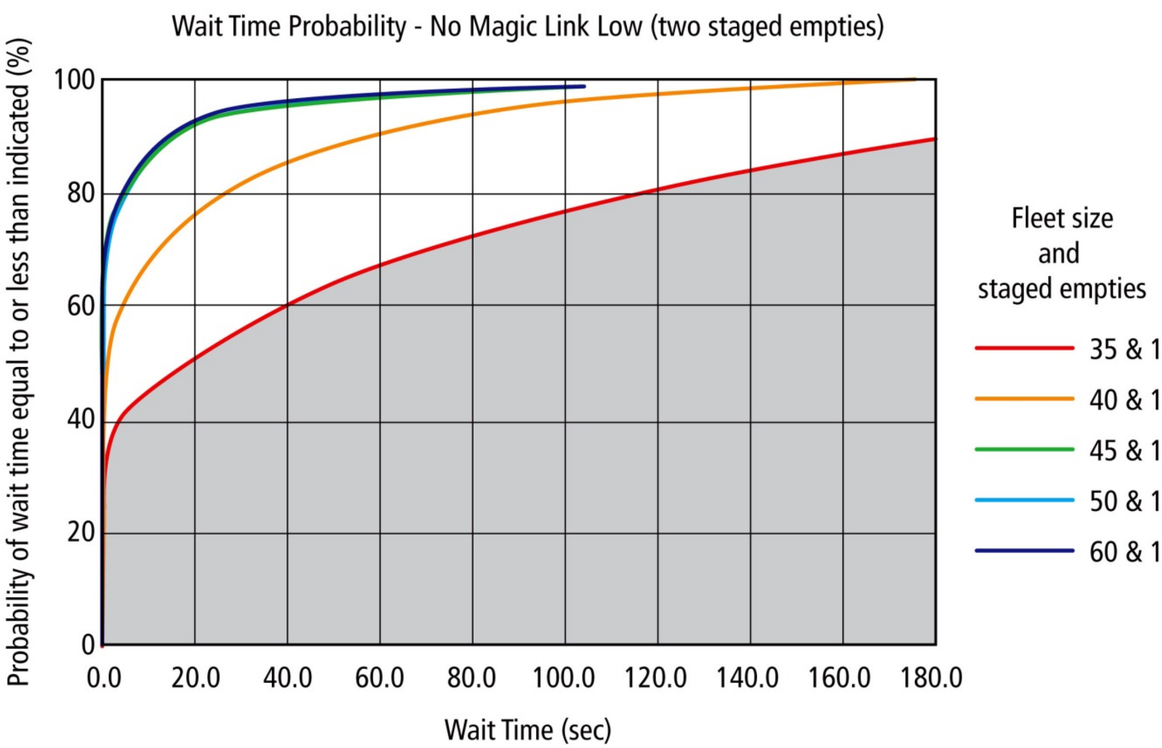


Figure 3.10-22. Outlying station wait time (No Magic Link Low).

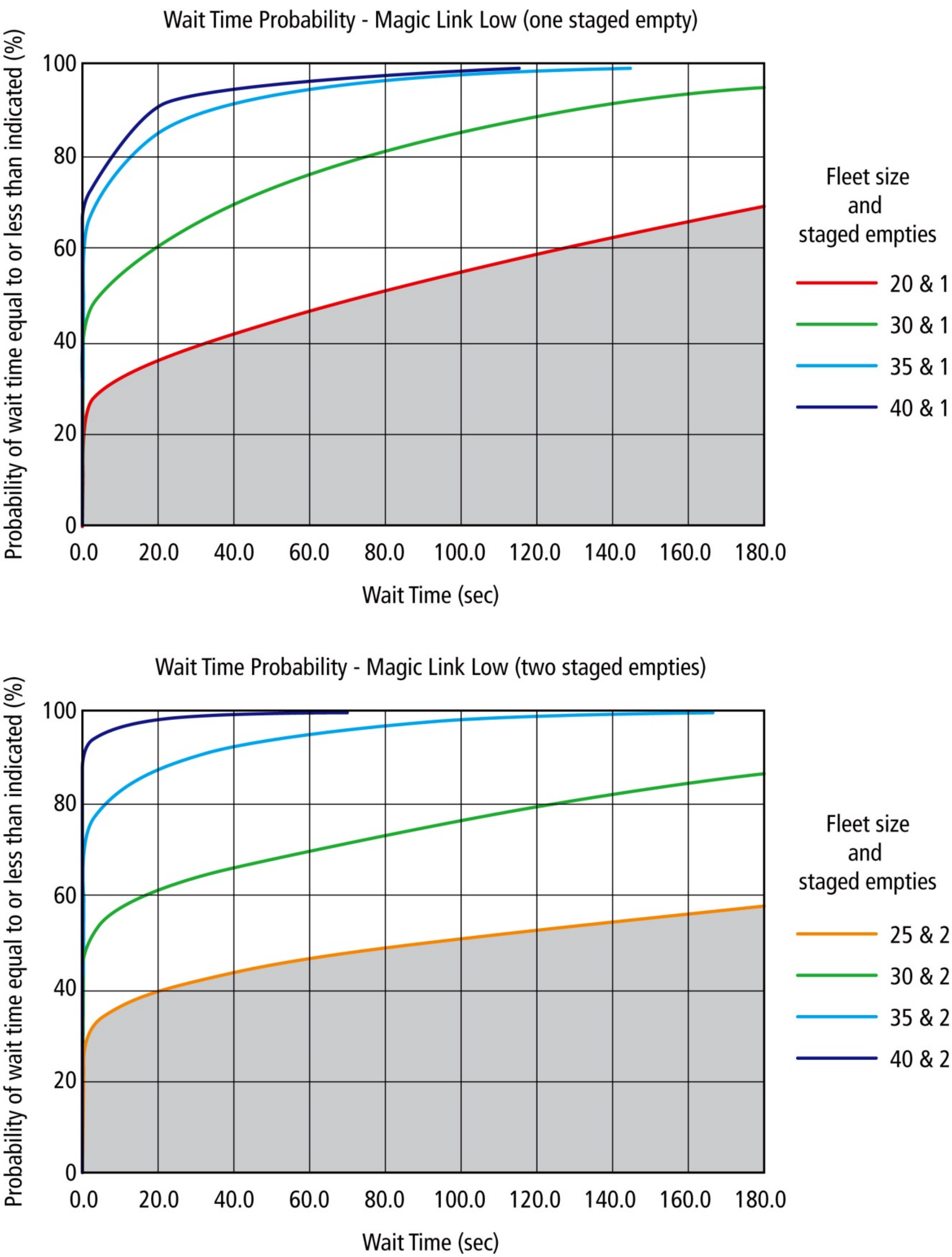


Figure 3.10-23. Outlying station wait time (Magic Link Low).

A final item of interest is shown in Figure 3.10-24. This figure consists of a bar graph for each combination of fleet size and staged vehicles for the No Magic Link Low case (i.e., all except Terminal A/B high demand vehicle traffic is circulating on the network) showing the average percentages of total times vehicles spend in different states. Results like this help illuminate and quantify, for example, the relationship between fleet size and the amount of time available for the opportunity charging of battery-powered vehicles.

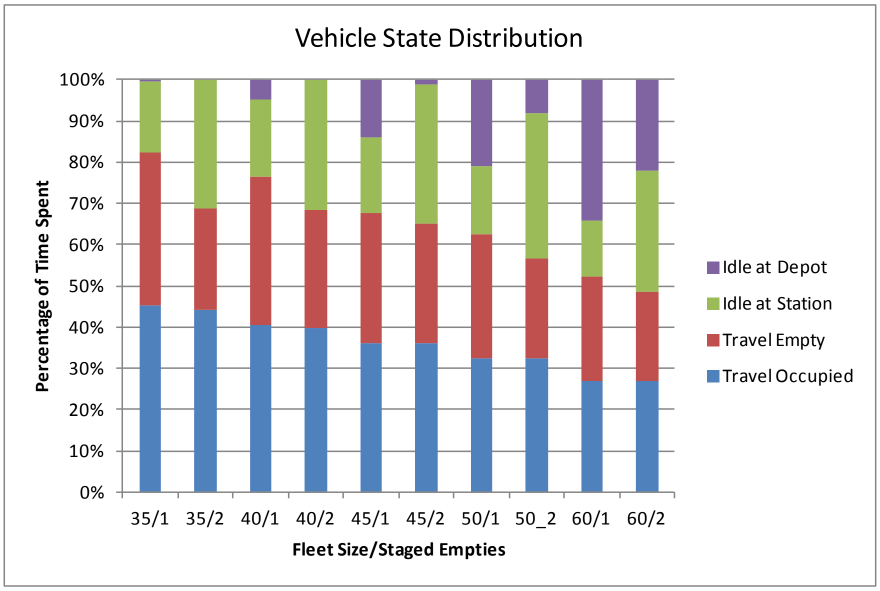


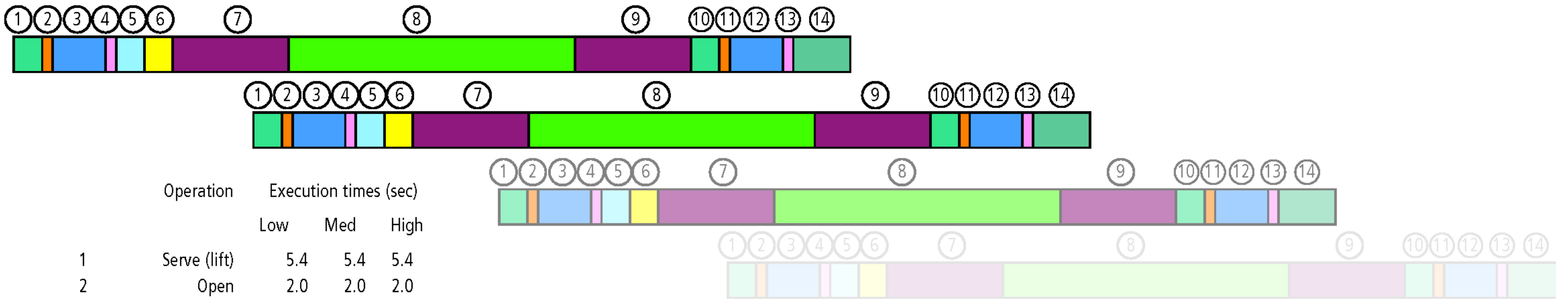
Figure 3.10-24. Vehicle state distributions.

The analysis and a comprehensive discussion of this topic are considerably more detailed than possible to describe here. Suffice it to say that, given the low outlying area demand at the Airport, it is possible for an ATN system to deliver an attractive level of performance in terms of passenger wait times at outlying stations. The next subsection will discuss these performance measures for the Magic Link subnetwork.

3.10.6.3 Magic Link Subnetwork Trip and Wait Times

The Magic Link subnetwork depends on the ability of developers to provide satisfactory assurances to regulatory authorities and the riding public that it could be safely operated. Unlike for general network maneuvering, however, the Magic Link instantiation of vehicle platooning does not need to account for relative speeds between vehicles. Other than a brief moment at the station speed limit in which a platoon from the upstream departure station block closes a 20-foot gap with the platoon in the downstream departure block before they both depart as a single, larger platoon, there are no instances of nominal closing speed. Once the gap is closed, all vehicles execute identical maneuvers in unison. Although satisfactorily safe performance is highly dependent on the precision with which this can be controlled, this is a considerably less complex problem than that of general maneuvering and merging. It is therefore, perhaps, a bit more conceivable that the necessary design, qualification testing, and establishment of the necessary regulatory allowances can be accomplished in a shorter term.

Assuming a successful effort, the Magic Link subnetwork could perform very favorably. Its performance is easily understood by reference to Figure 3.10-25. In this case, the Airport ATN changes its operational mode along the main terminal corridor to behave like a scheduled-service "virtual APM." The figure's legend lists the times of the various steps in a complete cycle, beginning with serving up a platoon of vehicles from the stacks to concourse level and ending with that same platoon, now empty at the destination station, being placed back into reserve, clearing the way for the next arriving platoon.



	Operation	Execution times (sec) Low	Med	High
1	Serve (lift)	5.4	5.4	5.4
2	Open	2.0	2.0	2.0
3	Board	10.0	10.0	10.0
4	Close	2.0	2.0	2.0
5	Serve (drop)	5.4	5.4	5.4
6	Station hold	5.4	5.4	5.4
7	Station clear	23.0	22.0	22.0
8	Guideway transit	75.7	53.9	47.5
9	Station entry	23.0	22.0	21.7
10	Serve (lift)	5.4	5.4	5.4
11	Open	2.0	2.0	2.0
12	Deboard	10.0	10.0	10.0
13	Close	2.0	2.0	2.0
14	Serve (drop)	10.8	10.8	10.8
	Headway (1 through 7)	53.0	52.0	52.0
	Total single platoon service time (1 through 14)	182.0	158.0	151.0

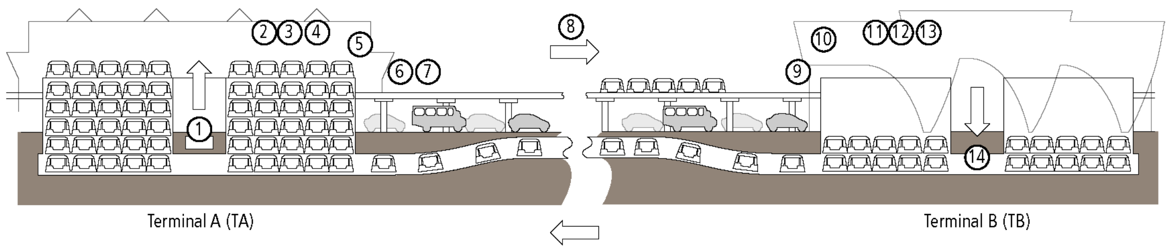


Figure 3.10-25. Magic Link subnetwork trip times and headway.

The sum of times for each of these steps is lengthy, but successive cycles can be safely put in parallel. Thus, while a platoon is in transit, another is being prepared for departure. And since the first few steps of the cycle are independent of network performance level, the headway between platoons is largely invariant, even though trip times vary. The trip times would vary between 2½ minutes and 3 minutes. The headway, or time interval, between departures (and between arrivals) would all be under one minute.

Operations are completely deterministic; there are no probabilities involved. The amount of time passengers spend waiting in the terminal stations concourse depends, as with conventional transit systems, on the relationship between the interarrival times of passengers, the number of berths per block in operation, and departure headways. Departure headways, in turn, depend on vehicle seating capacity. For scheduled service to a common destination and for short trip lengths, social preferences may allow one to expect fuller occupancy even for larger ATN vehicles having more seats. However, as discussed earlier in the report, the converse will also likely be true. For general operations that are configured to service less uniform (i.e., more random) demand for trips to each of the various stations and for longer trip lengths, travel requirements and preferences are likely to result in lower average occupancy rates. There is a price to pay for this in terms of the non-essential mass each and every vehicle has to carry and the consequently greater amount of energy consumption per passenger this would require—and the heftier and possibly costlier infrastructure required as well.

For these reasons, a decision was made to investigate the performance of the Magic Link subnetwork as a function of vehicle seating capacity both within and outside the range of currently available designs and, if found to be feasible, carry all variants through to energy consumption and other calculations.

Note in Figure 3.10-25 above, the times listed for step 3 (boarding) and step 12 (deboarding) are all identical. Everyday experience advises that these times will vary according to vehicle size and occupancy. Assuming the same distribution of per-passenger boarding times as in the Section 3.6.3 discussion of angled-berth station performance, but assuming here full occupancy, a simple queuing analysis was performed to estimate not only passenger wait times but also the required fleet size for the Magic Link subnetwork. The analysis was performed first for the high-traffic direction of Terminal A/B demand using the downwardly revised estimate of 505 passengers per hour. An exponential interarrival time distribution having a mean of 7.1 seconds was assumed. Also, since the demand was revised downward, only four berths in each block was assumed to operate, resulting in eight- rather than 10-vehicle platoons.

Seventy-six separate combinations of vehicle capacity, fleet size, and performance levels were considered, far too many to report on here. Representative results are shown in the following series of charts (see Figure 3.10-26), each based on the same infrastructure configuration and for the higher of the Terminal A/B demand. It is a bit difficult to trace the curves, but upon close inspection some very interesting results can be discerned:

The cost/performance ratio of using single-seat vehicles is clearly inferior using fleet size as a cost proxy. It would be possible to match the wait time performance of four-seat vehicles, but only with a fleet size roughly three times greater. In fact, as one would expect, larger fleet sizes are required as vehicle size is made smaller. However, the best performance is obtained with two-passenger vehicles, followed by four- and six-passenger vehicles. This is due to the increased boarding and deboarding times associated with the larger vehicles. Furthermore, this superior performance can be realized at the expense of a modest increase in fleet size.

To understand this, observe that the sets of curves for two-, four-, and six-passenger vehicles are each segregated into a grouping of “S” curves accentuated on the upper end, and a grouping that appears nearly as a straight line. This latter grouping consists of the curves for low, mid, and high performance and for the higher of the two fleet sizes. Focusing on this grouping for two- and four-passenger vehicles where they intersect the 100 percent line, it is seen that a value must be assigned to the approximately 30 percent reduction in wait times (52 seconds vs. 74 seconds) achievable from using two-passenger vehicles to offset the cost of an additional 45 vehicles (108 minus 63).

Alternately, if one instead compares the straight-line grouping (high fleet size) of the four-passenger vehicles to the alternate grouping (lower fleet size) of the two-passenger vehicles, one will see that the latter outperforms the former up to a value of approximately 87 percent probability of average wait times less than or equal to 65 seconds. This would cost fewer additional vehicles—34 (86 minus 52) in this case.

Note that each vehicle is not necessarily fully occupied. Occupancy depends on the balance between departure headways, vehicle size, and passenger interarrival time (passenger headway, if you will). This is true for any scheduled-service transportation system, and it is true for ATNs. However, if the right balance is struck and, as discussed earlier, the system is capable of seamlessly adding and subtracting resources by means of operating a greater or lesser number of queues and vehicles stacks in each block, it is possible to minimize the long-term cost of transporting empty seats.

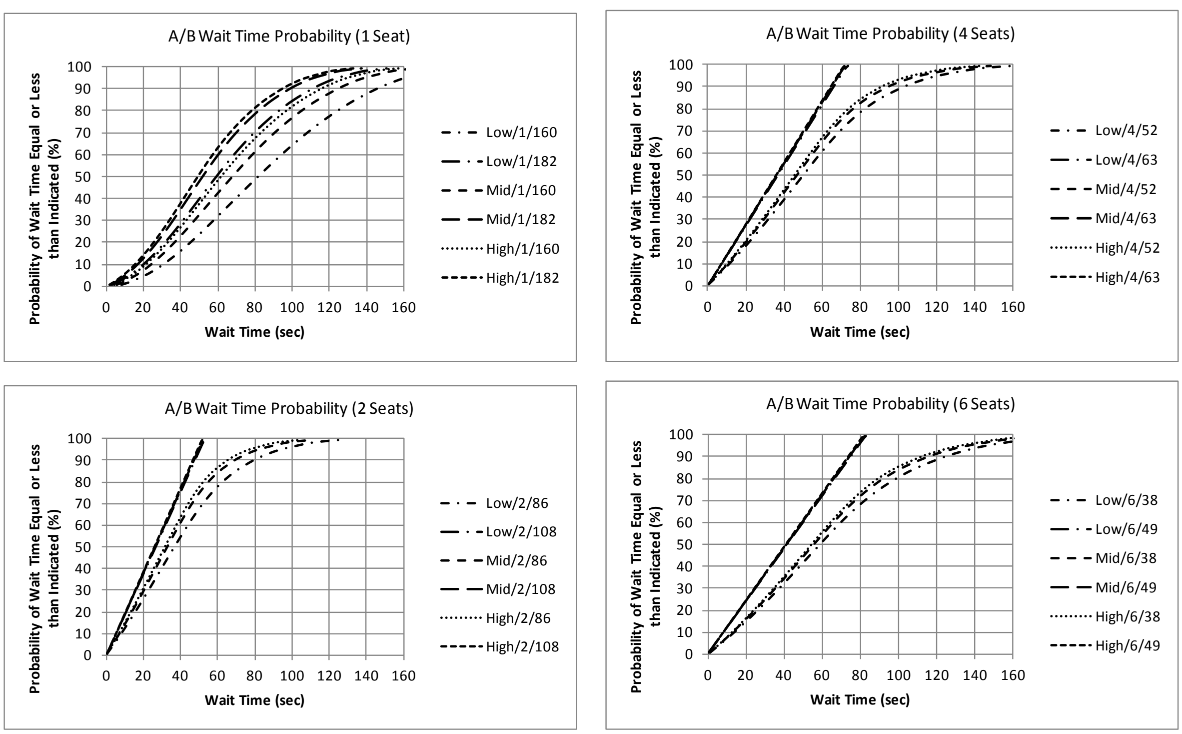


Figure 3.10-26. Magic Link wait times.

An identical analysis was performed for the low traffic direction of Terminal A/B demand if it were to be served via reverse flow using the easternmost portion of the dual Magic Link guideway (i.e., the Magic Link Low case). Similar results occur with an incremental fleet size of approximately one-half of the above values. This increment can be traded off against the incremental fleet size that would be required to service this demand over the network and against the superior trip times delivered by using the shorter Magic Link.

These cases serve as another illustration that ATNs must be seen and evaluated from an entirely new perspective as compared to conventional ground transportation systems. There are simply too many variables and too much interplay between them to draw sweeping and simple conclusions relative to cost/performance tradeoffs. The City must demand that these tradeoffs be made and understood prior to moving forward. As these trades are not obvious, this represents a significant challenge as well as a potential opportunity.

This particular vehicle size trade continues in the following sections in which the Airport reference design energy consumption estimates and renewable power source alternatives are discussed.

3.10.7 System Power and Energy Consumption Estimates

In Section 3.7, estimates were made of the required peak HVAC power for the purpose of sizing vehicle and/or vehicle/station HVAC systems. This was done for a single vehicle having a variety of characteristics and under a variety of circumstances. In this section, systemwide estimates of overall power consumption during combined traffic/thermal load peaks and on an annual basis is discussed.

In an attempt to tease out potential opportunities for minimizing propulsion power and energy requirements in an application requiring high-demand surge service in a generally low-demand, highly asymmetric environment, vehicle size becomes an important factor. To ignore it would be like ignoring one of the most common complaints about automobile rush-hour traffic—all those resources wasted and all that congestion because almost every vehicle is carrying but a single passenger.

Definitive estimates of ATN vehicle occupancy rates will require a significant undertaking integrating human and social science factors into a broader system architecting effort. For now, the best that can be done is to produce "what if" estimates, which, at a minimum, can illuminate the costs associated with inefficiencies resulting from estimate inaccuracies and, conversely, optimization opportunities that may exist.

Here, three of the four vehicle sizes considered above were carried through into power and energy consumption estimates[57]—two, four, and six passengers. Estimates were made for every possible[58] average integer occupancy level for each vehicle size. For instance, a separate estimate was made for a four-passenger vehicle with average occupancies of one, two, three, and four passengers.

Noting the wide range of construction techniques and consequent curb weights among current designs of identical vehicle size, and recognizing the potential for even greater vehicle mass reduction, a range of vehicle masses greater than those encompassing current designs was also considered for each vehicle size. The ranges considered begin lower and end higher than current designs and were taken in 500-pound increments. Finally, a coefficient of rolling resistance was used as a proxy for propulsion type—0.010 for rubber-tired vehicles and 0.005 for linear motor drives in which bogie guidewheels are made of solid materials having less hysteresis loss[59].

Each combination of vehicle size, weight, average occupancy, and propulsion type constitutes a vehicle definition. The range and increments of the variables considered results in a complete set of 62 vehicle definitions. These are listed in Appendix E.

[57] Single-passenger vehicles were eliminated due to their relatively poor performance and for convenience. However, they should not be entirely ruled out. They may, in fact, be optimal for certain applications such as business campuses or even in widespread subsystems understood to service commuter traffic exclusively.
[58] The single exception is a six-passenger vehicle with an average occupancy of five passengers.
[59] Energy losses due to the continuous distortion and relaxation of the portion of pneumatic or solid tires near the contact patch with a road or guiderail surface.

The estimation method described throughout this report was applied using each of these 62 definitions, resulting in a differing number of trips as a function of average occupancy and differing energy consumption as a function of both the number of trips as well as average gross weight (i.e., including both passengers and vehicle weight) and propulsion type. In addition to the coefficient of rolling resistance proxy, detailed estimates of the two predominant forms of electric propulsion—rotary synchronous alternating current (SA/C) and linear induction motors—were made by NREL using a verified electric power train and drive-cycle modeling tool.

In addition to the power and energy consumption required for propulsion, an estimated 0.33 kW of auxiliary power was included to account for control electronics, lighting, and information displays. The power required to operate vehicle HVAC systems during the peak hour of passenger demand on the summer design day was presented earlier in Section 3.7 and taken here as 1.45 kW.

Separate calculations were performed for a baseline case in which only the power required for propulsion and auxiliary loads were included, a second case in which baseline (i.e., no thermal management) HVAC loads were added, and a third case including thermal management (vehicle insulation and guideway sunshade)[60]. These sets of analyses were performed for the two operational scenarios described earlier: Magic Link Low and No Magic Link Low. Lastly, each of these cases was studied for each of the three performance levels listed in Table 3.10-3.

3.10.7.1 Peak Hour Estimates

The results of the peak traffic hour summer design day calculations is presented in the following series of charts, grouped together in various combinations to highlight certain notable aspects. In the first set of charts, Figure 3.10-27, results are presented for rubber-tired vehicles having a 10 kW SA/C motor for the case in which the Magic Link is employed to provide direct service to the low-demand direction between Terminal A and Terminal B/ConRAC. The upper chart of the set is the estimate for the baseline propulsion/auxiliary load case, the center chart for the case including HVAC loads, and the bottom chart for the case including HVAC loads and thermal management (TM).

There is a lot going on in these charts; the reader must follow closely.

[60] Metabolic and air exchange thermal loads were not included in the calculations but would need to be in a more thorough analysis.

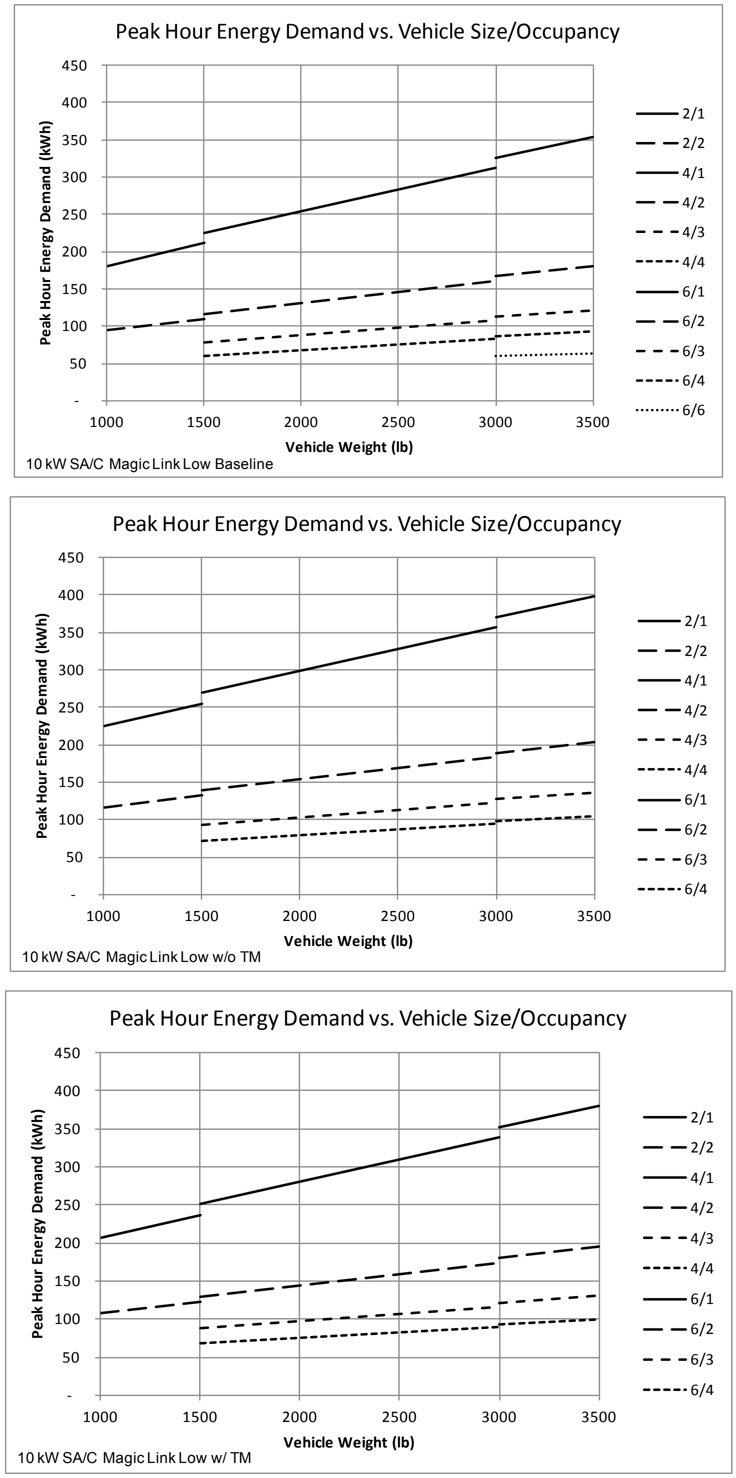


Figure 3.10-27. Peak hour energy demand vs. vehicle size/occupancy and thermal management.

The first item to note is the nature of each individual chart: The set of straight lines correspond to, with exceptions, 31 of the 62 vehicle definitions described earlier; that is, the subset defining rubber-tired vehicles using SA/C motors for propulsion. The set of vehicle sizes (in terms of seats) and presumed occupancy levels are indicated in the legend separated by a slash. The occupancy level is to be viewed as the average occupancy over the peak hour for only the vehicles using the network;

vehicles using both legs of the Magic Link are taken as fully occupied. As before, the system is unable to meet Magic Link demand using one-passenger vehicles; these have therefore been omitted.

The second principal dimension of the vehicle definitions—vehicle mass—is shown along the horizontal axis. Identical line styles are used for the same average occupancy across all vehicle sizes and weights. The three remaining vehicle sizes—two-, four-, and six-passenger—are easy to identify from the breaks in each occupancy line: two-passenger vehicles on the leftmost segment, four-passenger in the center, and six-passenger on the right.

The estimated peak hour energy is shown along the vertical axis. In each grouping of lines related to vehicle size—left, center, and right—the results for the lowest occupancy are at the top, each successively lower line corresponding to a higher average occupancy.

Now that the reader is oriented, one can see some very interesting results[61]. First, as one would expect, the required power increases as vehicle mass is increased; each line slopes up and to the right. Also as one might expect, power requirements become reduced with increased levels of average occupancy; as above, the lower a line's position in its grouping of lines, the higher its corresponding occupancy level. In the last of the less interesting results, one can also easily see that smaller vehicles carrying a specified average number of passengers require less energy than larger vehicles carrying the same number.

Although expected, these results clearly show the energy penalty that must be paid if ATN systems are designed around larger vehicles in an attempt to handle peak demand. In general, such vehicles will spend the majority of their time operating at lower efficiencies. This arises from two sources: a) During periods of low occupancy, vehicles are transporting unused seats and all the structure and componentry required to transport a larger number of passengers, and b) the electric motor is "oversized" relative to the lower passenger weight and therefore operates at lower efficiencies.

A more interesting result can be seen when comparing charts. The first comparison to make is between the upper and center charts. Here it can be seen that incorporating HVAC requirements into the estimate accounts for approximately 10 kWh to 50 kWh of peak power consumption, the higher value corresponding to lower occupancy levels. This occurs because more trips are required in order to service demand, and therefore vehicles spend more time exposed to solar and ambient air thermal loading. The percentage difference can be considerable, ranging from 15 percent to 24 percent.

It is notable that these percentages are less than what one would expect if, as stated previously, HVAC power requirements are of approximately the same magnitude as those for propulsion. The answer to the discrepancy lies in part to the fact that the propulsion requirements used in this comparison were based on constant vehicle speed. ATN systems, by contrast, may involve quite a number of instances of nominal and maneuvering accelerations and decelerations other than that occurring at stations. The reference design is a good example of the former; recall the different "speed limits" associated with the various "loops." The energy required to accelerate to a given speed is considerably higher than that to travel uniformly at that speed[62]. When this is accounted for, which these calculations do, it is seen that the HVAC power requirements are being compared to a higher baseline including this component[63]. The nature of this effect is shown in Figure 3.10-28.

[61] Note that results such as these are consistent with typical electric-vehicle power vs. weight curves.
[62] A portion of this may be recaptured via regenerative braking, but only up to the physical limits of the regenerative system (i.e., the energy recapture from decelerating a vehicle can overwhelm system components). Friction brakes are needed to make up for this difference.
[63] Although not exclusively; this to be discussed shortly.

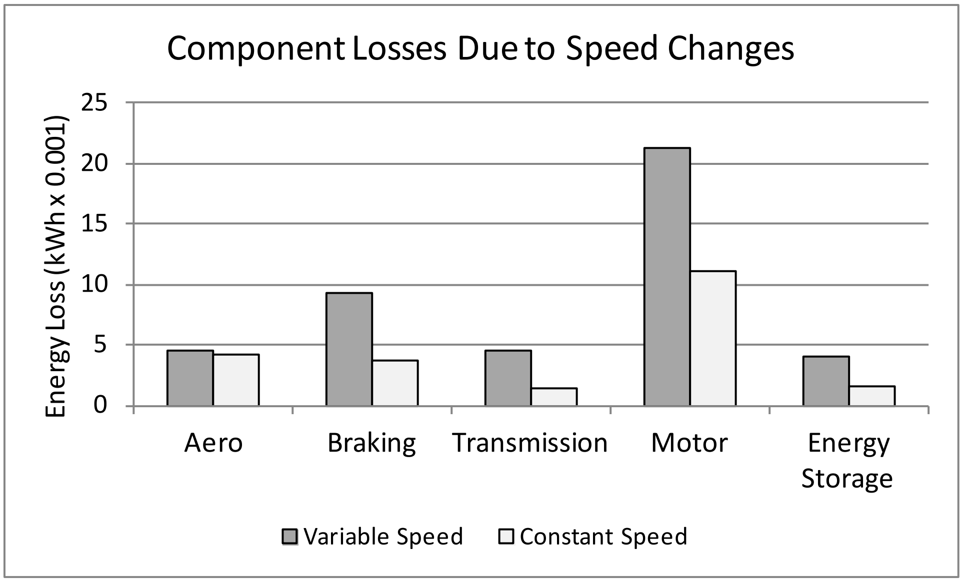
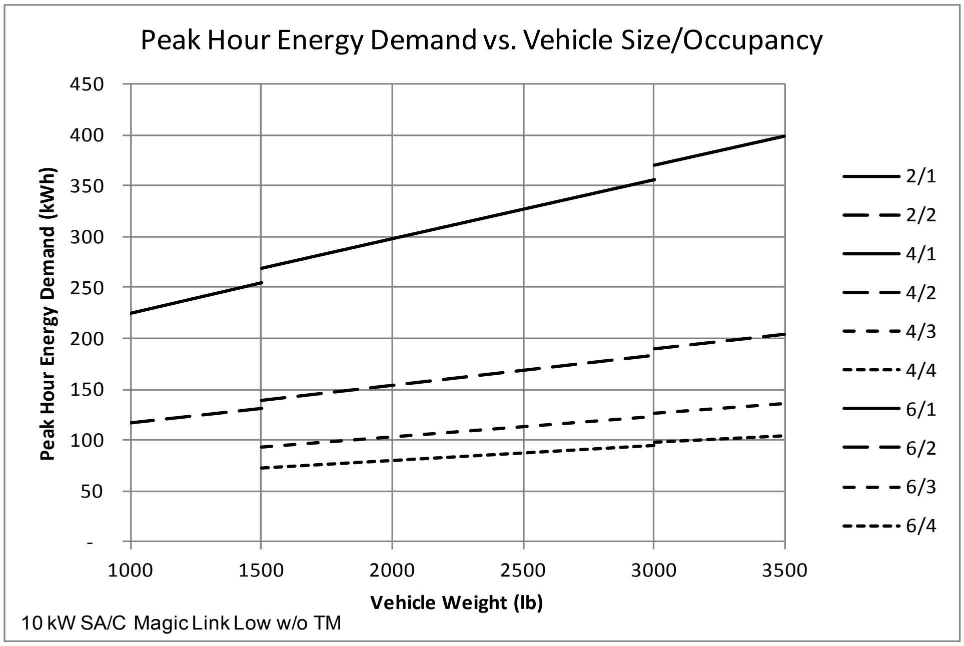


Figure 3.10-28. Effects of speed changes on power requirements.

The figure shows the losses associated with various subsystems and operation for both variable and constant speed vehicle motion. The figure is based on a select vehicle definition in the one case assuming a constant speed of 15 mi/hr and in the second case four acceleration/deceleration cycles between 10 mi/hr and 20 mi/hr, each case thus having the same average speed. As can be seen, losses attributable to speed changes are substantially higher as compared to those attributable to constant speed operations. Project constraints prevented a detailed calculation of this effect for the reference design cases considered here, but the identical effect is expected and will differ only in magnitude.

The final notable effect comes from a comparison of the center and bottom charts in Figure 3.10-27. In this case, the effect of the two selected components of a potential thermal management (TM) system is apparent. Reductions in peak power requirements span a range of 5 percent to 9 percent across the vehicle definition. The larger value is associated with lowest occupancy level; in this case, lower average occupancy means a greater number of trips and more exposure to thermal loads. Again, this is in comparison to a variable-speed baseline.

A comparison of the effect of operating with and without the low demand leg of the Magic Link is shown in the two charts in Figure 3.10-29.



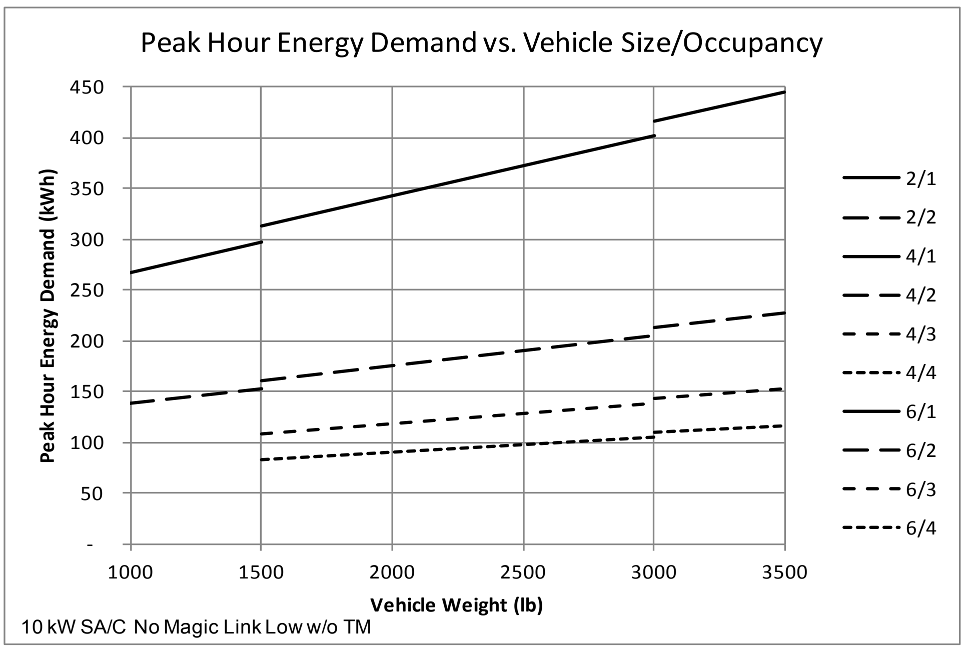


Figure 3.10-29. Peak hour energy demand: effect of Magic Link Low operation.

The upper chart shows peak hour power consumption for the case in which the Magic Link is used to service the low-demand leg of Terminal A/B traffic; the lower chart for the case in which this traffic is circulated around the network. What is interesting about this set of charts is that the Magic Link Low case results in a substantial energy savings, a reduction in the range of 11 percent to 17 percent. This is primarily attributable to HVAC loads as shown in Figure 3.10-30 and Figure 3.10-31. In this case, both more and longer trips between the two destinations expose vehicles to higher thermal loading for greater periods of time.

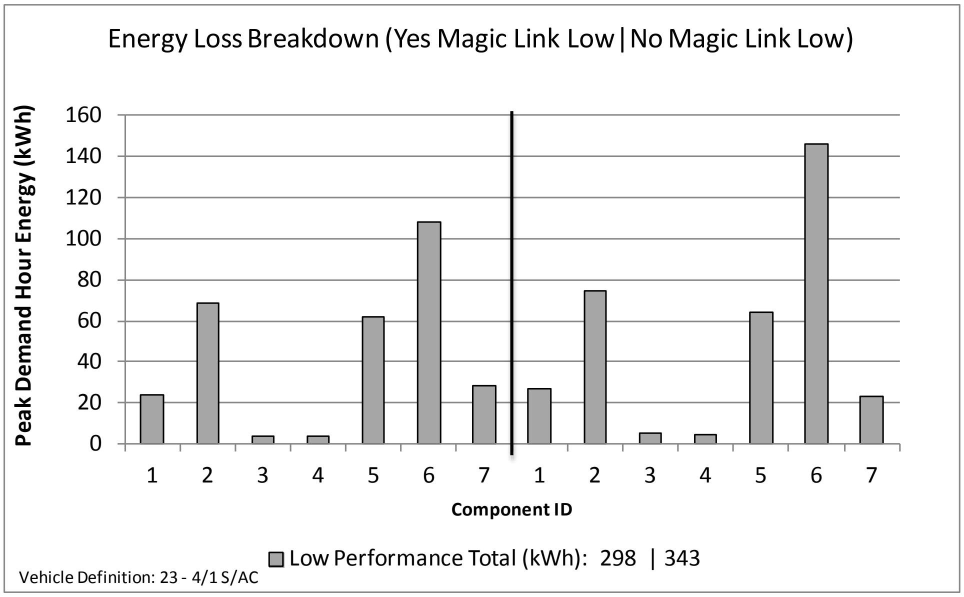


Figure 3.10-30. Energy loss breakdown.

Component	Component ID
Aerodynamic Drag	1
Rolling Friction	2
Braking	3
Transmission	4
Motor	5
Auxiliary & HVAC Loads	6
Accumulator	7

Figure 3.10-31. Breakdown component legend.

Not shown is the effect of thermal management in this comparison. If the vehicles are exposed more frequently to thermal loads, one would expect greater benefit from thermal management, and this is, in fact, indicated in the results. For the No Magic Link Low case, energy consumption is reduced by 9 percent to 14 percent as opposed to the 5 percent to 9 percent reduction noted earlier for the Magic Link Low case. In other words, if the Magic Link is not used to serve the low-demand leg of Terminal A/B traffic, thermal management can be used to recapture a portion of the energy consumption increase.

It is also interesting to note the energy requirements attributable to the operation of the accumulators. Assuming, as was done here, that "regenerative descent" can be incorporated into accumulator designs, the net power required for their operation is nearly the same as that required to overcome aerodynamic drag[64], less than 10 percent of the total required in this particular case.

[64] While on the topic of aerodynamic drag, it should be noted that prevailing winds and their net addition to drag, and therefore power requirements, were not included in this analysis. Because aerodynamic drag increases along with the square of the relative wind velocity, there is a net increase in required power over a closed loop in which a vehicle spends an equal amount of time traveling upwind as it does traveling downwind. This would amount to a 13 percent net increase for a vehicle traveling at 20 mi/hr with a prevailing wind of 5 mi/hr.

In a final comparison of peak hour power requirements, Figure 3.10-32 illustrates the results for a synchronous A/C design and a LIM[65]-based design assuming identical peak rated power and "worst case" design and operating conditions (i.e., No Magic Link Low, no thermal management). The much lower electromechanical efficiency of LIMs is the principal contributor to the near doubling of energy requirements.

Note, however, that a slight increase in average occupancy can recapture most of this deficit. Perhaps this is the reason why current-generation LIM-based systems involve the use of slightly larger vehicles. Still, this would only occur at the margin of full occupancy. In other words, if it were somehow possible to guarantee full occupancy, a fleet of larger, LIM-based vehicles would be able to service a given demand more efficiently. During slack periods, this advantage would disappear.

The perspective that LIM-based systems are more suitable for servicing heavier loads with larger vehicles is an important one. Relative to current designs, LIM-based systems have the additional advantage of avoiding battery recharging, an important consideration not analyzed in detail here. This can have a significant effect on fleet size; if the energy storage capability of a battery-powered fleet is exceeded, the deficit must be closed with additional vehicles. LIM-based systems also carry less propulsion subsystem mass on board vehicles, helping to offset electromechanical energy conversion inefficiency.

Collectively, these analyses drive home several very important points that have been mentioned throughout this report:

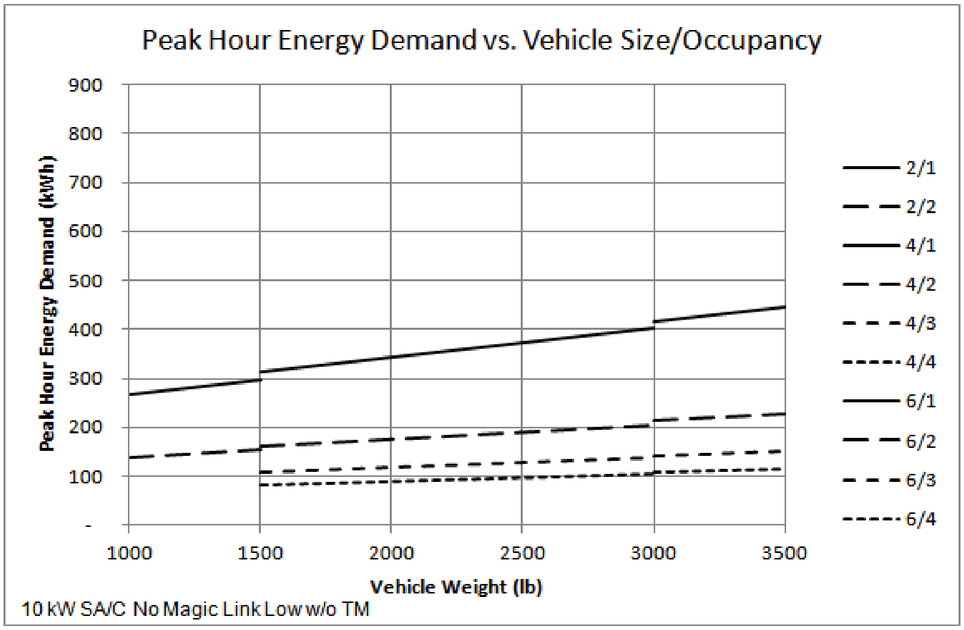
- There is not, or should not be, a one-size-fits-all conception of ATNs. The appropriateness of any particular design is completely dependent on the particular application for which it is intended.

- A mix of designs is appropriate to consider *even within the same local application* and, by extension, in broad-area applications. A single-minded conception of ATNs limits the concept, rendering it unsuitable for a wider range of applications. It is no wonder that ATNs draw criticism for simultaneously being inefficient (excess seat capacity) and incapable (insufficient seat capacity). Attractive service levels can be provided without needing to consider a single infrastructure design able to accommodate a range of vehicle sizes.

- Current ATN designs are based on conventional component and subsystem technology. Superior technologies, as in the case of propulsion, are conceivable and likely waiting in the wings. Via increased system integration, ATNs are uniquely positioned to take advantage of potential advances. A focus on technology first, and not the underlying value proposition and basic requirements of ATNs, is inhibiting their development.

- Thus, both the City and the development community should consider expanding the definition of ATNs and think in terms of a wide range of designs and their integration into a broader interoperable system.

[65] linear induction motor



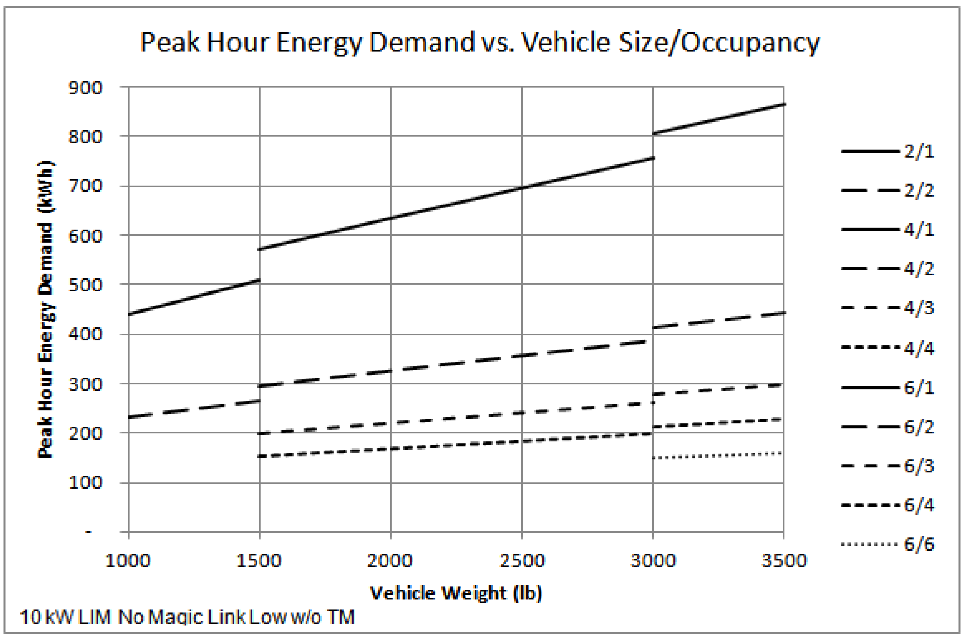


Figure 3.10-32. Peak hour energy demand: propulsion type comparison.

Lastly, note that these analyses are by no means definitive estimates of Airport ATN power and power consumption requirements. They are based on a host of assumptions made necessary by a lack of detailed information. They will require verification and revision once that information is made available. They also do not include other key sources of power requirements (i.e., outlying stations and terminal concourses, Magic Return lighting and ventilation, prevailing winds, and many others). Nevertheless, the analyses provide key insights into the many and complex tradeoffs associated with the Airport ATN. The last set of analyses pertinent to the topic, annual power consumption estimates, is discussed in the following section.

3.10.7.2 Annual Energy Estimates

Peak power estimates are required in order to properly size a power source and distribution system. It therefore most directly relates to capital expenditures. Average power consumption over an extended period of time more directly influences operational costs and is estimated here.

This is an enormously complicated calculation to accomplish in detail; only a very rough estimating approach was possible here. The first step in this process is to estimate component averages, i.e., average propulsion power requirements (based on daily and monthly demand distributions), average HVAC requirements (based on daily and monthly thermal load distribution time-correlated to transit demand), and others.

Beginning with a baseline per-vehicle average HVAC power estimate, an average vehicle occupancy of 1.3 passengers per vehicle was assumed along with an average relative wind speed of 15 mi/hr. All other parameter values used in estimating design day requirements were retained from Section 3.7.2 and held constant. A time-varying estimate similar to that described in Section 3.7.2 was then performed, resulting in a new per-vehicle baseline—in this case in terms of metabolic thermal loads and heat transfer based on the average occupancy and wind speed value, respectively. As before, calculations were performed using actual San José weather data from a Typical Meteorological Year.

In order to estimate energy consumption over the course of any particular day, required time-varying per-vehicle HVAC power must be time-correlated with daily variations in traffic levels. Transit demand data provided by Arup formed the basis of this correlation; this data is shown in Figure 3.10-33. Scaling the revised baseline per-vehicle HVAC power requirements by the variable daily transit demand results in a pseudo unit-power requirement relative to peak demand—essentially a per-vehicle power requirement normalized to peak demand. This scaling was applied to every day of the annual thermal simulation. Representative examples are shown in Figure 3.10-34 and Figure 3.10-35, respectively, for the select winter and summer design days used previously.

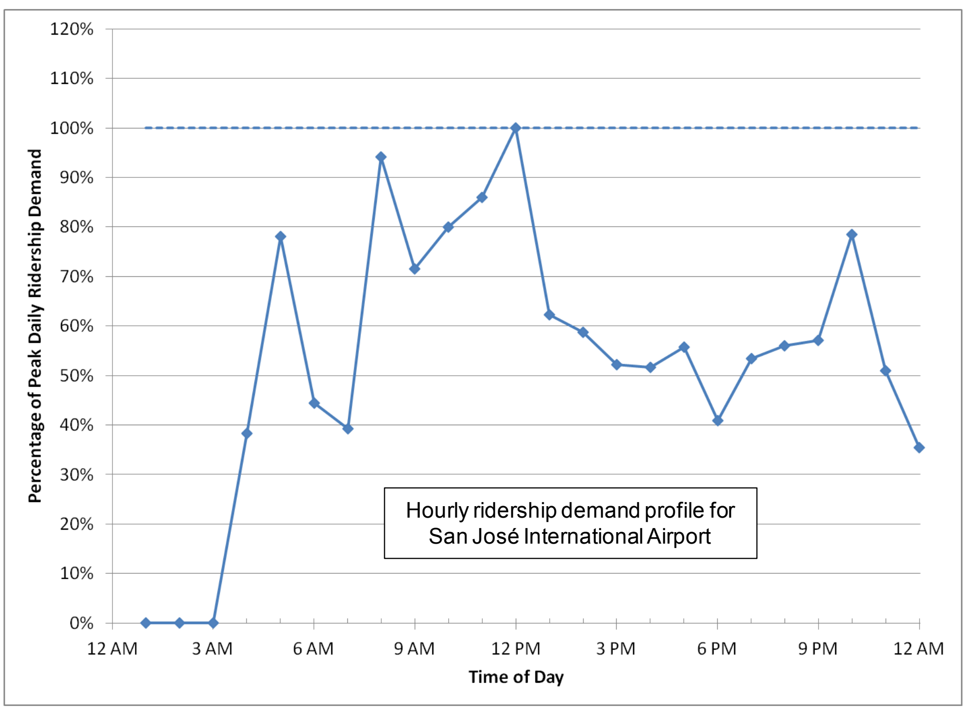


Figure 3.10-33. Daily transit demand profile.

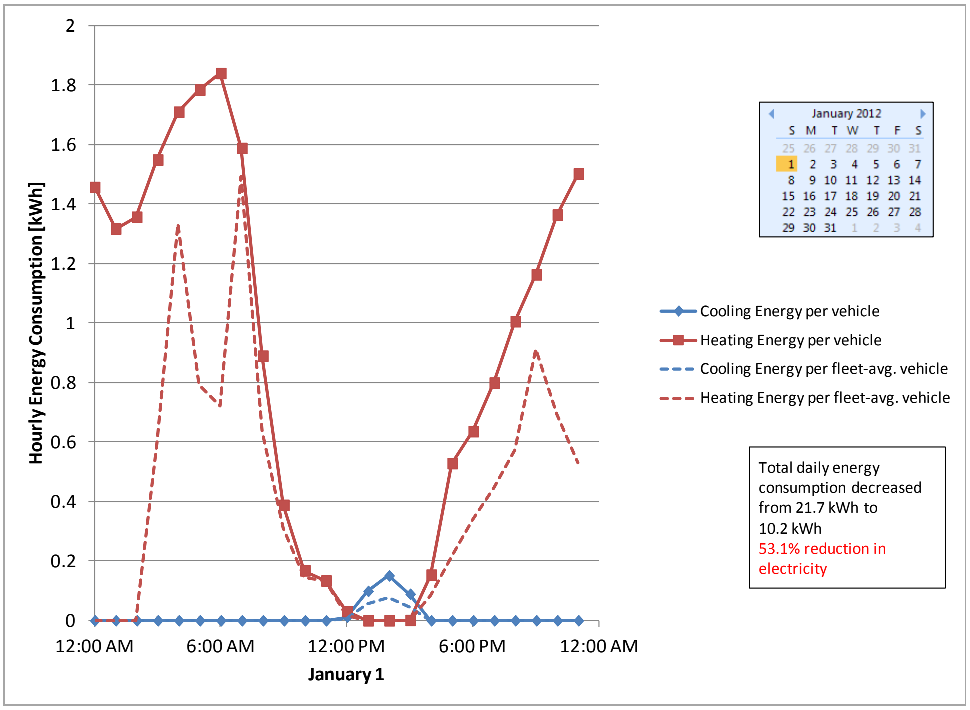


Figure 3.10-34. Demand-adjusted daily unit power requirements: winter design day.

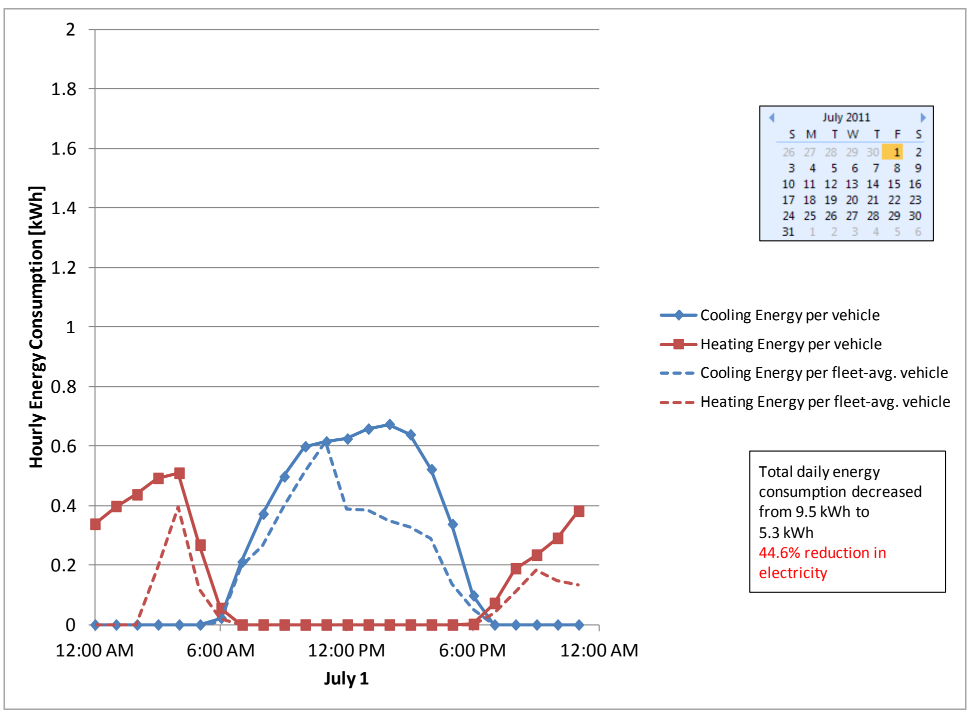


Figure 3.10-35. Demand-adjusted daily unit power requirements: summer design day.

This technique was used again on a monthly basis. The peak monthly energy consumption was scaled by a seasonal transit demand profile, also provided by Arup. This profile is shown in Figure 3.10-36.

This allows an adjusted monthly pseudo unit-energy usage profile to be constructed, as shown in Figure 3.10-37.

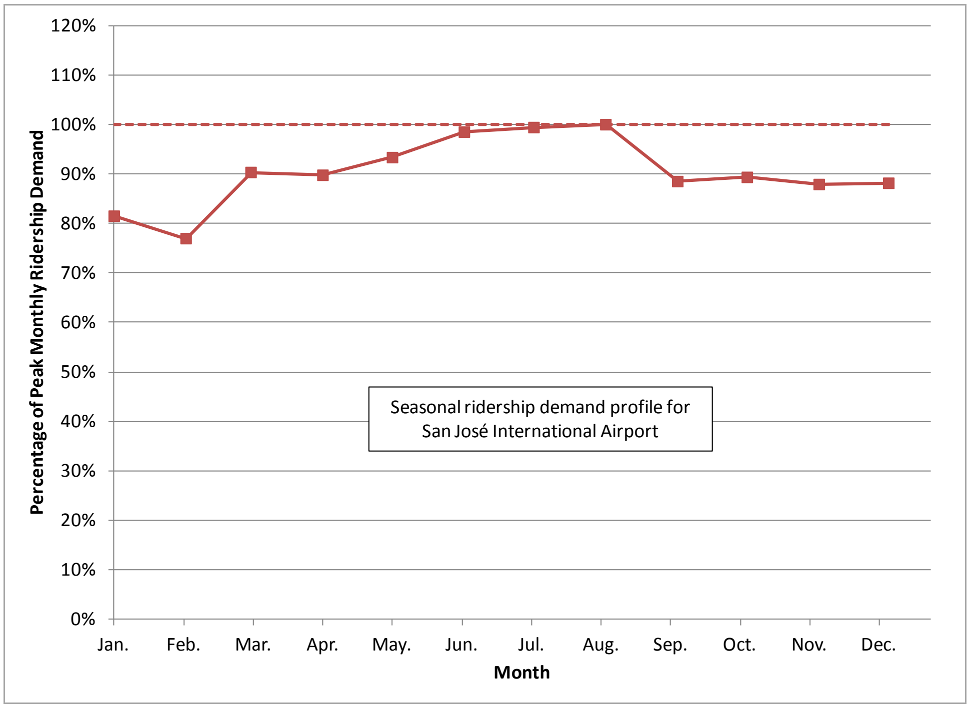


Figure 3.10-36. Seasonal transit demand profile.

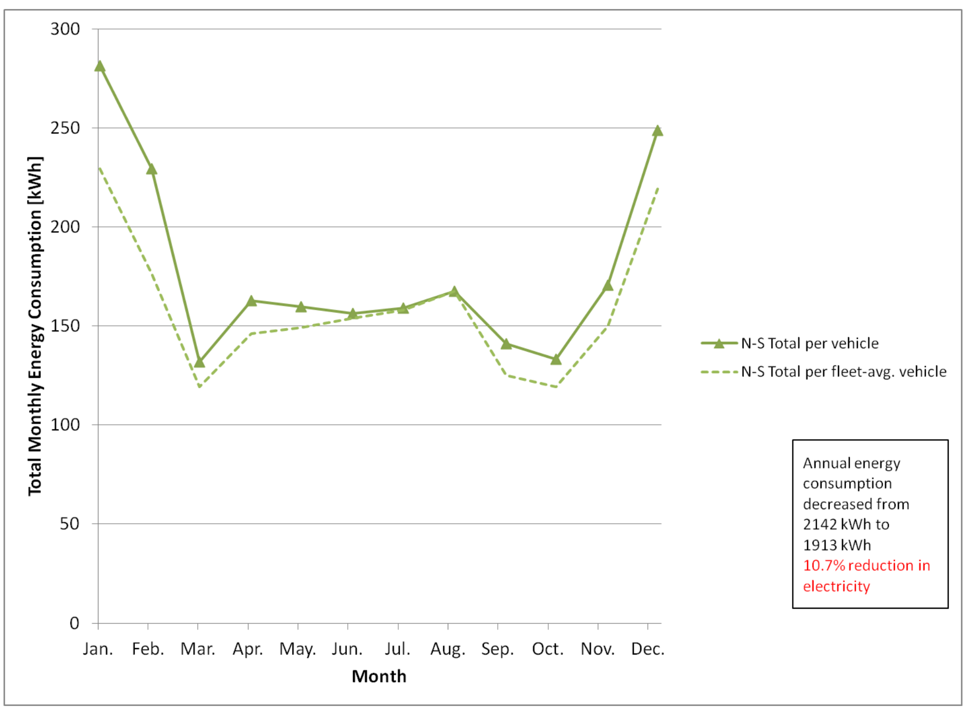


Figure 3.10-37. Demand-adjusted monthly unit power requirements.

The effects of the select thermal management items can also be estimated on a monthly basis. This is shown in Figure 3.10-38 for the north-south orientation and in Figure 3.10-39 for the east-west orientation.

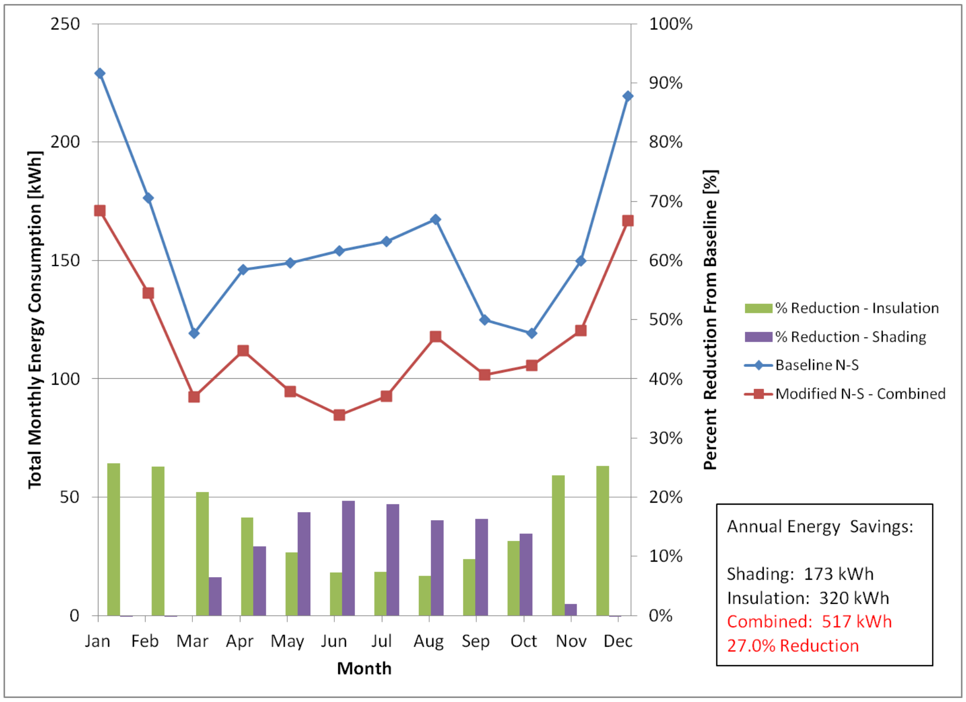


Figure 3.10-38. Monthly thermal management effects: north-south orientation.

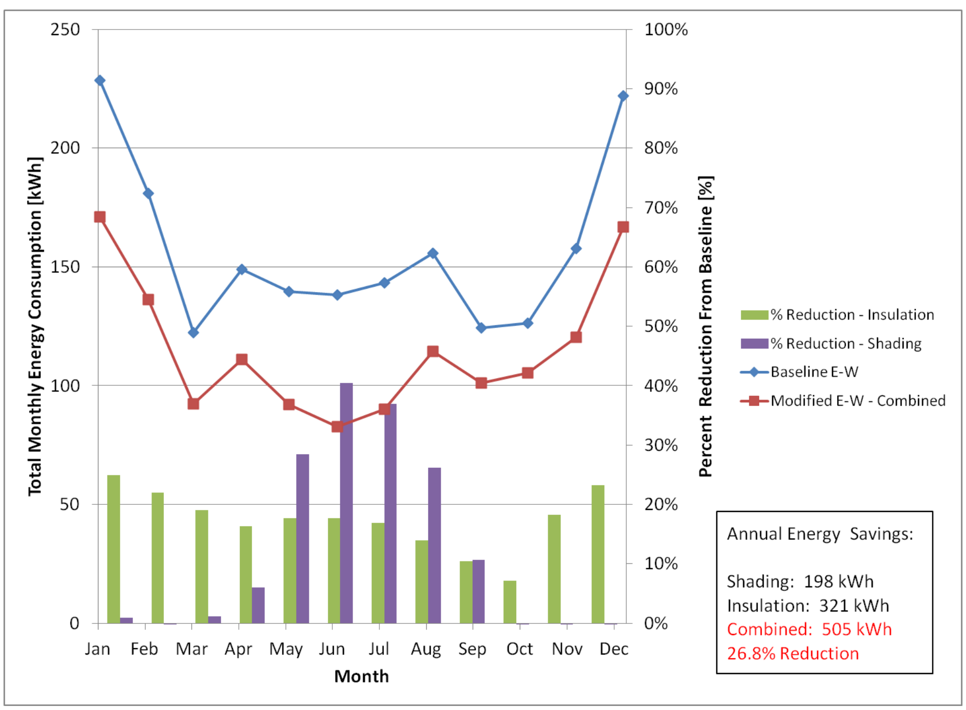
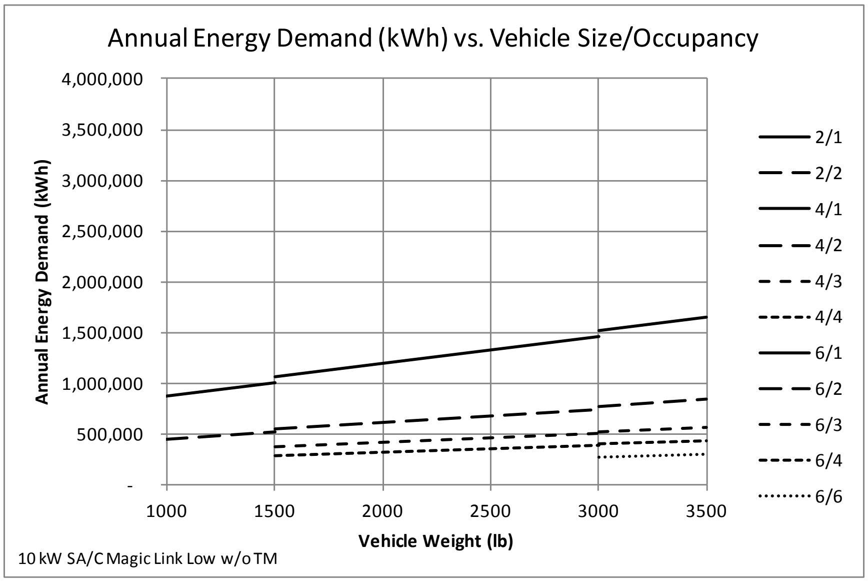


Figure 3.10-39. Monthly thermal management effects: east-west orientation.

Finally, from this recursive roll-up, average values of electrical power required for combined heating and cooling can be calculated. All of this results in two numbers: a) a value of 0.45 kW for the annual average HVAC power requirement assuming no thermal management, and b) a value of 0.33 kW assuming the use of vehicle insulation and guideway sunshades.

These values are then used in the combined network and electric vehicle drive-cycle model to calculate annual power consumption estimate for each of the vehicle definition and network operating modes. The results are shown in the following sets of figures corresponding to those given earlier for peak hour energy demand.



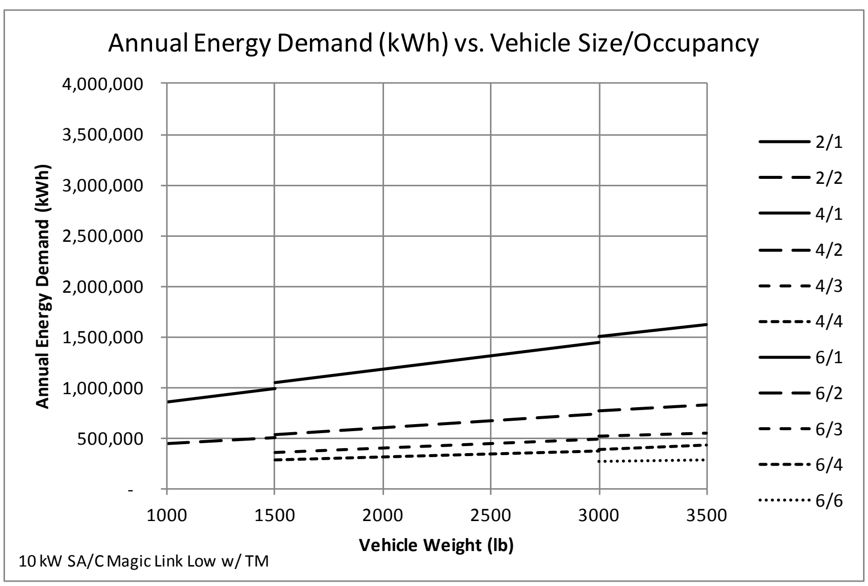
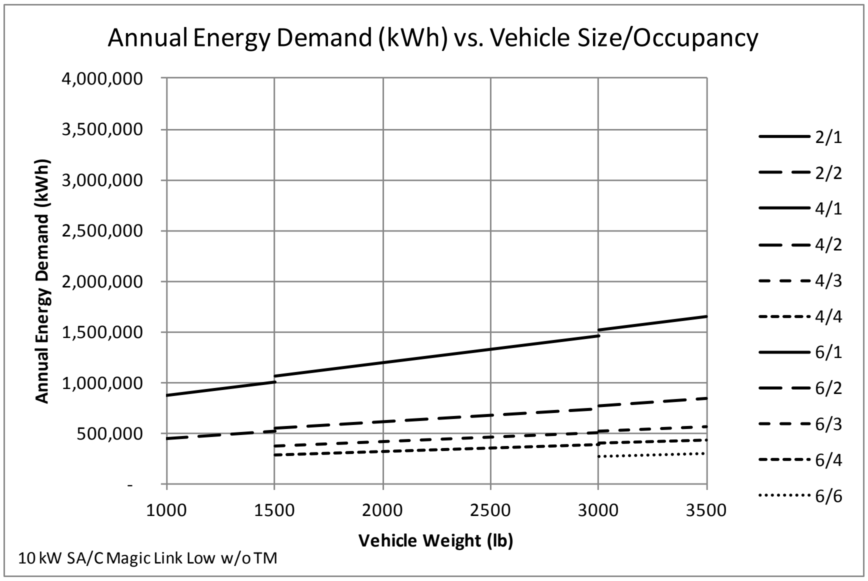


Figure 3.10-40. Annual energy demand vs. vehicle size/occupancy and thermal management.



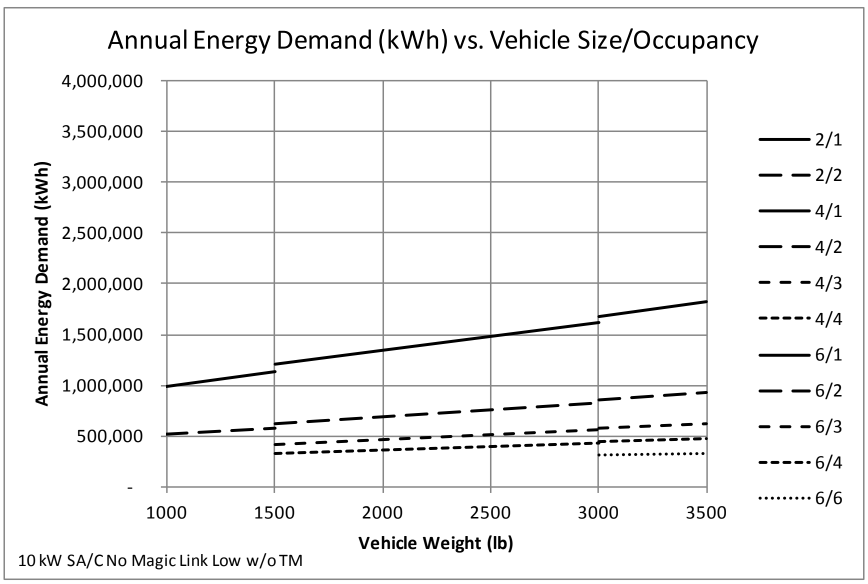
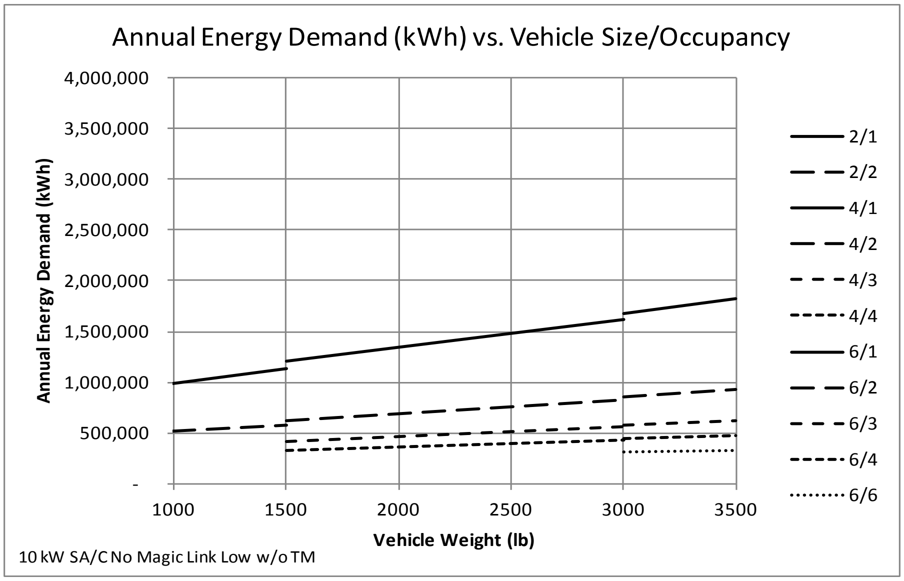


Figure 3.10-41. Annual energy demand: effect of Magic Link Low operation.



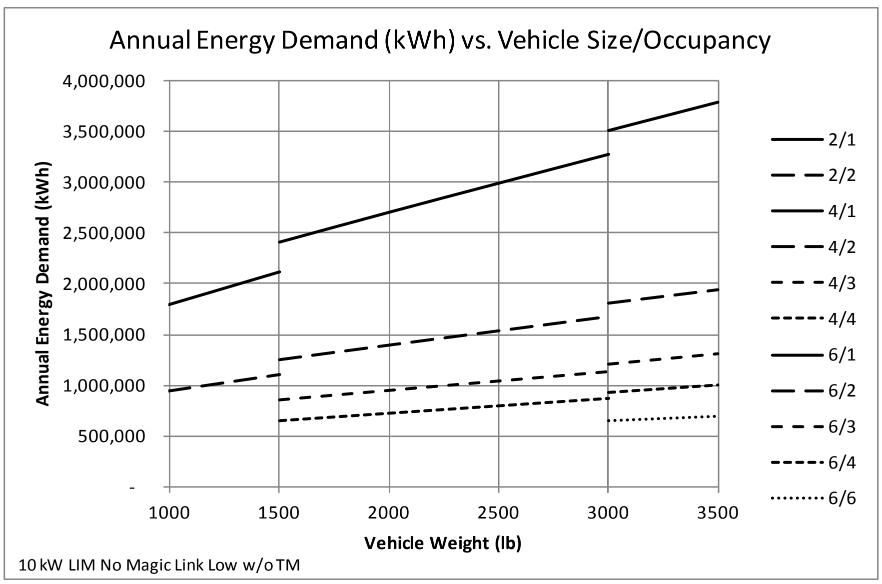


Figure 3.10-42. Annual energy demand: propulsion type comparison.

3.10.8 Reference Design Performance Summary

The reference design is capable of supporting a maximum speed of 35 mi/hr at slightly less than APM-standard performance levels, resulting in favorable trip times. The low demand to/from outlying stations coupled with a modest vehicle prepositioning strategy can delivery similarly favorable wait times and does not stress the angled-berth station design concept. Conversely, the high demand between the Terminal A and B is likely to require an innovative approach to supplying and managing empty vehicles.

4. Programmatic Issues and Options

It was originally intended that this section be entitled “Acquisition Strategy.” However, as the existence of key developmental issues became known, the focus shifted to producing a framework by which the City could continue to explore ATNs short of an acquisition and within the bounds of acceptable cost, risk, and its own capabilities. Thus, in a pivot that also produced the physical reference design, this section is devoted to a sort of reference design for a plan of next steps. It is necessarily abbreviated as a result of the redirection of resources and, most importantly, because “Development Strategy” is a much larger topic than “Acquisition Strategy” and requires a considerable effort of its own to develop. The information in this section can be considered a high-level discussion outlining for the City what might lie ahead and what it can do should it decide to continue its exploration of ATNs.

The resulting *programmatic* reference design is in response to the same set of uncertainties and unknowns as those that motivated its physical counterpart. Here, however, the goal is not to work around them but to address them head-on. The rather bland title of this section belies the significant challenges that will be associated with the likewise significant opportunities that might be had if the long-term viability of the ATN concept can be firmly established.

This section is organized into three principal subsections. The first is a discussion of several key factors regarding various approaches toward the development of complex systems such as ATNs. The second is a discussion of a key factor in this particular instance: that of the local regulatory effort that will be necessary, resulting in an outline of a potential “regulatory roadmap.” The third section will roll up these discussions along with those from earlier in the report into an outline of a possible approach for getting to the bottom of the ATN concept and exploiting whatever potential it may have.

The net effect, it will be seen, is the need to think in terms of the concept of a “value network” as presented in Section 3.4.3 as a means to work toward an understanding of the full potential of the ATN concept and the totality of the collective effort that will be required in order to realize whatever that potential might turn out to be.

4.1 ATN Systems Development in General and the City’s Role

The development community is generally aware of well-established methods for sizing up and managing the development of complex systems such as ATNs. Although the complexity makes it as much of an art as it is a science, such methods have been proven over many decades in many industries. This is not the place for a full discussion of these methods; suffice it to say that they are not a secret. Figure 4.1-1 shows a graphic representation of a high-level view of the overall process, reproduced from the U.S. Federal Highway Administration’s *Systems Engineering Guidebook for Intelligent Transportation Systems* [23].

This “Systems Engineering Vee” is a common representation of the process. It can be found in numerous guidebooks promulgated by professional engineering organizations and, as here, by government agencies. The practice of systems engineering in all of its aspects illustrated in the diagram is, in fact, a principal core focus of The Aerospace Corporation. It also serves as the basis for internal processes in many industrial concerns that engage in this type of work. It is not a paint-by-numbers method that admits no variation but, if well-implemented, is of proven usefulness. It is very simply a roadmap of how to define a system, break it up into parts that can be designed by engineers who may never meet or communicate directly, and assemble the physical/software pieces with reasonable assurance that the complete system will function well and do the job it was intended to do. It is very intuitive: *Define* the problem, *break up* the problem, *solve the parts* of the problem, and *integrate/verify the solution* in a piecewise, cumulative fashion, providing ample opportunity from beginning to end to catch and correct the inevitable errors and omissions—*before* the cost of their correction gobbles up budgets and schedules.

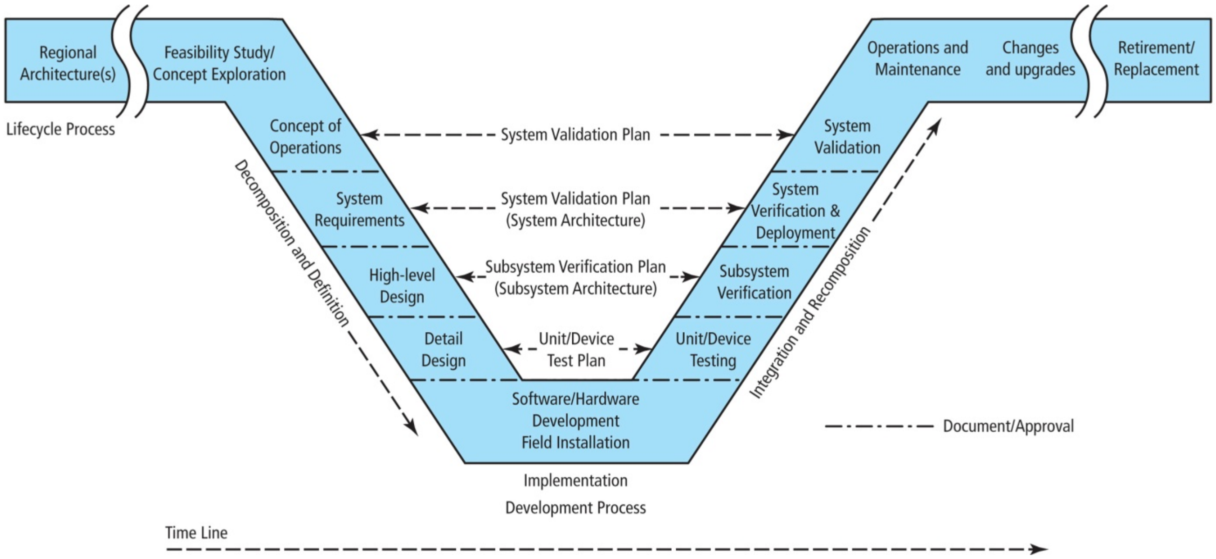


Figure 4.1-1. FHWA systems engineering process.

At its most fundamental level from the point of view of the *function or service* that a system is intended to provide for a user, this process serves as a roadmap guiding *all* participants in the value network from an *understanding* of user needs on the left to the *satisfaction* of those needs on the right. Between these two points and heavily engaged in the process stand the key participants in the value network, the agencies that represent users—the City and its companion stakeholders, regulatory authorities, etc.—and the teams of designers and financiers that can turn a concept into reality.

This process of defining and then translating a concept into a reality is a very risky one. After all, the intent is to solve a problem through invention, and invention is a process of discovery. One is by definition dealing with the unknown. Therein, of course, lies the principal difference between a conventional procurement and a development effort.

That this applies to ATNs is very clear: The development community is itself suggesting the use of this very same process in conjunction with providing a system for the Airport. It is doing so for a very good reason. If the process does, in fact, provide the opportunity to catch and correct problems early, it also represents a roadmap for managing and mitigating risks. Driving risks down to an acceptable level is beneficial for all parties. It is therefore in the City's interest to gain some familiarity with the process should it choose to continue its exploration of ATNs, despite what might at first seem a bit uncomfortable and foreign.

It can't be emphasized enough that the successful application of this process is crucially dependent upon the involvement of all parties. Organizations such as the SJDOT and its companion stakeholders *must* assume their role in the process. This principle and the critical efforts associated with this role occur in the upper left portion of the Vee and as such are *the most highly leveraged of an entire effort*. That is, errors made here amplify over the course of a project. In the worst case, this can and quite often does result in complete failure. The goal is obviously the converse, "getting it right" up front in order to maximize the probability of a successful outcome.

Very simply, the role of those representing the interests of end users and constituents is to understand and clearly articulate the goals, objectives, and constraints associated with the desired outcome. This is not an easy task when, by definition, solutions do not yet exist. It is one thing to articulate the need for a well-understood conventional system and quite another to do so when multiple options exist for innovative solutions, none of which are generally well understood—and perhaps not yet conceived. Nevertheless, both the development community and interested parties on the acquisition side have, in systems engineering parlance, been "guilty" of committing one of several "deadly sins" of systems engineering: starting at Step 5 – design. *Providing engineering teams with a set of well-considered requirements and end-revenue opportunities will do more to accelerate progress toward a final conclusion regarding ATNs than perhaps any other effort.* Only the City and its companion stakeholders can do this.

The second important component of the City's role is to understand, plan for, and participate in the remainder of the process. It is unlikely that the City will have the resources or know-how to assume the role of development project manager, but it and other key stakeholders will need to allocate some level of full-time, long-term resources as full participants.

For example, although not discussed in detail here, the Vee process is not the serial, step-by-step process it appears to be from inspection of its high-level diagram. Especially along its leftmost definition leg, numerous "feedback loops" arise in an *iterative* process of learning. Technical capabilities developed on "paper" are constantly checked against requirements and the two reconciled. Multiple revisions take place before cutting a single chip or ordering a single electronic component. The City will need to adjust its requirements in response to the technical, economic, and regulatory realities that are encountered along the way.

An exceedingly important role for the City throughout the process derives from its role representing its constituents. As mentioned, the ultimate construct of the systems engineering Vee is to serve as a bridge between users and other affected parties and designers. Users and other parties that may ultimately integrate ATN systems into their community must be as cognizant of this process as City officials, including its inherent unknowns as well as its exciting prospects. Especially if the developmental nature of ATNs is not made clear, the principal risk is that the concept can be entirely defined in the minds of many by best-effort precursor designs currently available and the confusing set of claims and counterclaims surrounding the topic. If expectations are not met in any particular application, disappointment with the concept can quickly outweigh enthusiasm. Engaging with constituents throughout the process is an essential role best assumed by the City.

This goes beyond a mere messaging issue—a fundamental characteristic of the Vee is that the needs and perspectives of users and other affected parties form the fundamental basis of development requirements. Without them, development efforts are forced to be purely speculative. This is an accurate characterization of current ATN designs. Thus far, contemporary ATN development has been forced to take place in a near vacuum. ATN developers have had to surmise the needs of users as they would be articulated by representative civil authorities and have designed systems that they have supposed would have the most appeal. In other words, judging from the RFI responses and other indicators from the development community, ATNs are currently being built largely *on* spec rather than *to* spec.

Lastly, the City must consider and prepare for its role on the rightmost verification leg of the Vee. As for the definition leg, the City's role here will be concentrated toward its upper reaches in a step known as validation. In this role, the City will gather data and analyze performance against expectations. This is the step during which it becomes known how well the new design, technically verified and placed in operation, meets the high-level goals and objectives established for it at the outset. Lessons will be learned, lessons that can then be applied to correct operational shortcomings and even for yet another cycle of development.

A natural question to ask here is, “Wait, you mean one won’t know until the very end if it works?” The answer is that the definition and verification steps accomplished prior to validation, if well-executed, will ensure with a high degree of certainty that the system works from both technical and functional standpoints and achieves its stated goals and objectives. The systems engineering catchphrase distinguishing definition, verification, and validation is that definition, verification, and validation, respectively, involves ensuring that the right system *is built*, that the system is *built right*, and that the right system *was built*.

A reasonable way to think about validation is as a systematic approach to measure success over time in a real-world environment. The things that are often of most interest at this stage are characteristics and outcomes that as a practical matter couldn’t have been fully tested in advance, such as overall public acceptance or true total lifecycle costs. Assessing factors of this nature typically involves long-term monitoring, data gathering, and the application of various analytical techniques in support of success measurement. Note that the validation stage is also a significant source of lessons learned that can be applied to future increments of development.

That the development community is suggesting the very same systems development approach discussed here is unambiguous recognition that ATNs are a work in progress and that civil-sector “partners” are needed in order to move the state of the inquiry, if not the state of the art, forward. Note that this project is a significant contribution toward this end. The City can expect a continuance of this effort should it decide to move forward in its ATN inquires. In the next section, the nature of the necessary systems development process is discussed in terms of the Airport project and beyond. After this and a discussion of the regulatory dimension of ATNs, the role of the City will be revisited in terms of tangible potential next steps.

4.2 ATN Development for the Airport and Beyond

Whether the City views the Airport as an isolated project or wishes to further explore ATNs for broader application, the required ATN designs will likely be an entirely different beast than current designs. While the method to develop these designs is sound, its application as it is being articulated by the development community—tying what is essentially a research-and-development effort to an infrastructure acquisition—is a highly risky undertaking. There are a number of manageable shortcomings that first require identification and discussion:

- The Airport is not a laboratory. Passengers and taxpayers are not likely to be interested in becoming inappropriate experimental subjects. Qualification-level[66] system verification and validation will need to be performed prior to final design and construction at the Airport. The Airport is appropriately used at first simply as a case-study application, defining system requirements in order to focus the necessary development and regulatory efforts.

- Establishing the boundaries of a development effort appropriate to the City's goals and objectives is a bit problematic. Currently, it appears that the Airport project is a reasonable objective supporting the City's long-term goals. As discussed, portions of the project may be technically well served by ATNs; challenging but plausible workarounds can be envisioned for other portions. However, it is far from clear if or when ATNs may achieve fully realized form, what that form may be, or how to design initial applications that are truly scalable.

  To the extent that near-term decisions regarding the Airport or any other application the City might find of interest is affected by the long-term outlook for ATNs, it will be difficult to know precisely where to establish project boundaries. In other words, just how far would the City go in its commitment to participate in the advancement of ATN art without knowledge of its ultimate extent? This is the perennial chicken-and-egg dilemma of ATN proponents and developers.

  Furthermore, it is hard to imagine any single organization or consortium risking the levels of capital that would be necessary to produce a broad enough product line of fully realized ATN components and subsystems from which to assemble a satisfactory system at the Airport in the near term and suitable for long-term expansion—or even to sort through the many conceivable options—merely in support of the Airport project. There will exist practical private-sector return-on-investment limits that will be difficult to establish in advance. If the assessment of this report is accurate, considerable pressure would exist for the City to adjust its requirements downward to a level corresponding to roughly current capabilities.

- The City would need to concern itself with the funding of both the recurring capital and operating/maintenance costs *and* the nonrecurring development costs. A private concern confident in its plans might be willing to cover nonrecurring costs without the promise of an immediate return on investment—as the development community has been doing to date—essentially viewing the Airport project a loss leader. However, nonrecurring costs and development schedules are very uncertain, given the unknowns associated with systems development in general and regulatory issues in particular. The City would be a party to this speculative approach, risking schedule delays or even failure of the project if the cost/risk calculus sours as the result of development difficulties. And there will be difficulties.

[66] This is discussed in Section 4.3.4.

- Assigning exclusive development rights to a single organization or consortium would limit the City to a correspondingly singular technical approach determined by the limited capital that would likely be made available. Furthermore, to the extent that the resulting design consists of proprietary elements, the City may find itself in a position of being "locked in" to a single entity for both a long-term development effort that could last a decade or more and additional years of operations necessary for the contractor to realize a return on investment[67].

  A decision must also be made early on as to whether the ATN business model should be based on the delivery of transportation services or of hardware/software/operational support for a government-owned system. As mentioned earlier, given that certain aspects of ATN design involve serious security and safety issues, a government-owned system may be necessary. Such a model is common in both the civil and defense sectors, e.g., the civilian air traffic control system, planetary exploration, and many national defense systems. Under this model, today's principal ATN developers would transition from "turnkey" system providers to the role of system integrator working in concert with government agencies to collectively develop ATN system architectures for numerous applications.

- Given the City's potentially highly leveraged role as pathfinder, the above approach might also carry with it the potential to inhibit innovation overall. A selection may be perceived as "the" "optimal" form of ATN design. If successful, it would certainly result in an attractive level of "proveness," but, as discussed, appropriate ATN designs are likely to be very application-dependent. At a minimum, an approach based on exclusivity would leave on the table the considerable talent of those having different but perhaps significantly meaningful perspectives, essentially short-circuiting the development process.

It follows from all of this that the City may be best served by adopting a broader, long-term view of ATN development. An outline of some potential, tangible, near-term tasks consistent with such a view is given in Section 4.3. In the remainder of this section, a very broad outline of an overall process is given for context.

Presuming that the value proposition(s) of ATNs can be substantiated, it is clear from the above and from earlier discussion that ATN development will require a rather large and involved collective effort spanning a good number of years. In order to "structure" such an effort and focus resources, it is natural to consider a series of successive efforts, each designed to incrementally add capability and assuredness and build on prior work. This would take on the character of a development roadmap, a series of intertwined developments and deployments that, if well-planned, could minimize exposure to potential cul-de-sacs and perhaps shorten the overall development lifecycle. Within this context, the Airport would only be an opening act.

How does this relate to the systems development process discussed above? In short, the City can anticipate a number of trips down and up *several* development Vees, each successive trip building on the last. Depending on how each successive trip references its predecessor, various terms such as waterfall development or spiral development are used to describe the overall process. For example, the earlier discussion of forward compatibility was an attempt to reuse as much as possible the actual physical infrastructure from an early deployment in a spiral development.

It may also be possible to rely on "planned obsolescence" in certain circumstances if the ultimate value of ATNs is found to be great enough to justify such an approach. For example, a stand-alone shopping mall application, even if not economically justifiable in its own right, could be of value as a

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[67] That is, if a design, build, operate, and maintain (DBOM) model were selected.

means of gaining operational experience in the context of an overall development roadmap. Whether such a system is actually preplanned for eventual replacement or retained as a member in a family of interoperable systems, its economics could be seen as secondary to its principal purpose as a steppingstone.

The various approaches have their pros and cons, the chief conceptual limiting factor being the improbability of actually planning a definitive course. After all, development is a largely unpredictable process of discovery. In general, though, each successive step builds on the knowledge gained in its predecessor.

The overall process of development in going from concept to conventionality can be represented by the ubiquitous thermometer of NASA Technology Readiness Level (TRL)[68] fame, which serves as the basis for Figure 4.2-1. This figure also delineates the differences between those items of principal concern in the development phase and those, above the line, when a technology can be considered conventional. In the grand scheme of things, the marker indicates where ATNs now stand in general.

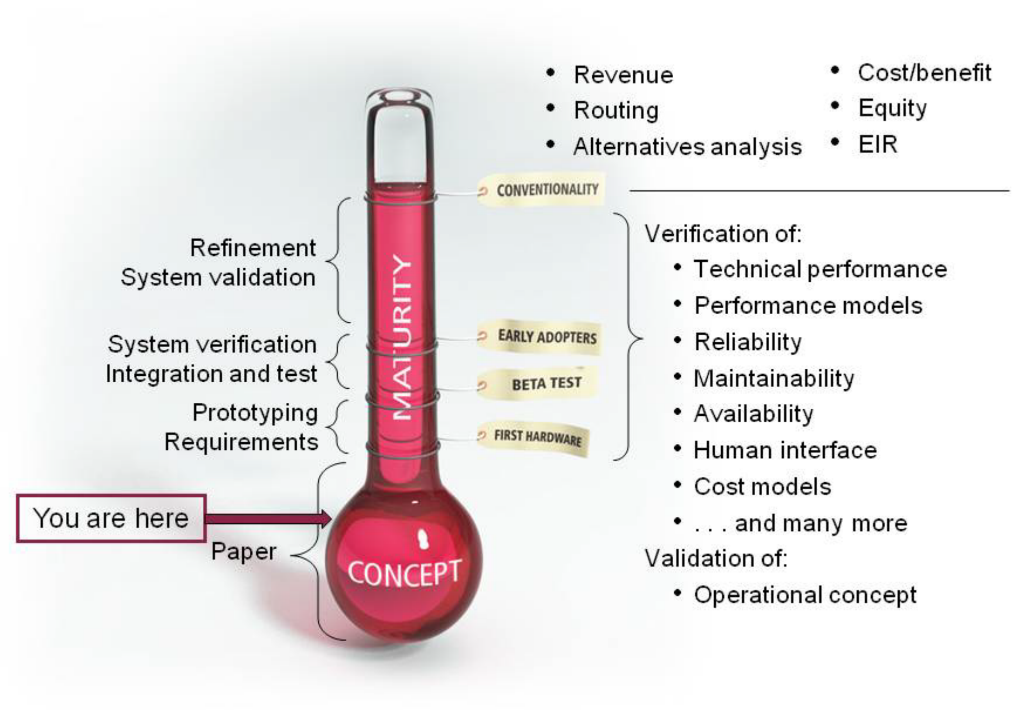

Figure 4.2-1. Conventionality thermometer.

The incremental acquisition of knowledge and operational experience can be represented by a series of these thermometers as shown in Figure 4.2-2, each associated with a particular steppingstone application and trip down and up its Vee.

[68] A rating of 1 to 9 used to describe the maturity of a "technology."

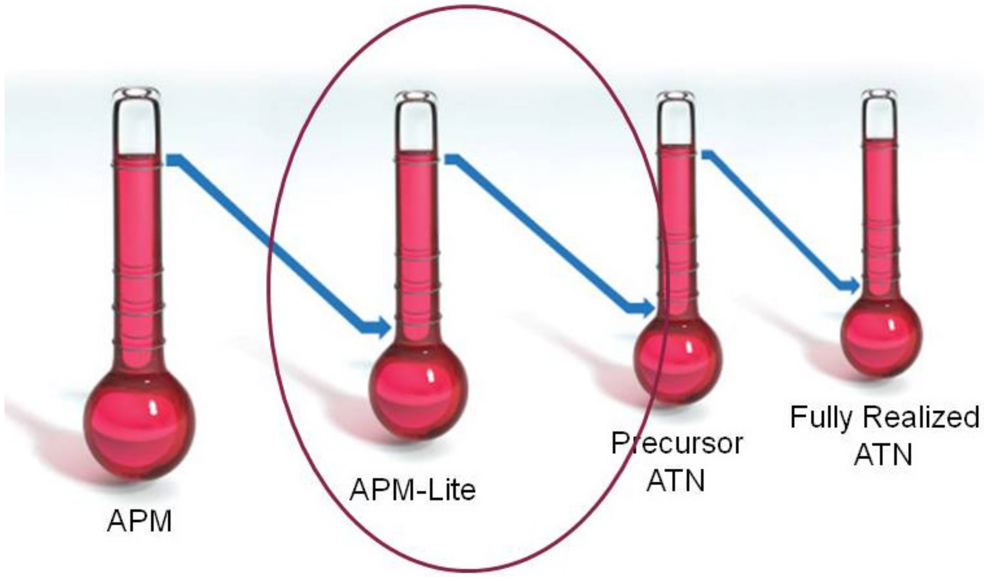

Figure 4.2-2. A progression of capabilities.

The oval in the figure is intended as a rough approximation of where in this particular cascade of development stages current operational designs are located. The low demand and headways result in operations similar to that of scheduled-service systems[69], but several system elements required for more advanced operations have also been developed and are in place. Many characterizations are possible. This one is by no means definitive but is generally in tune with the perspective and plans of the development community.

Note that an attempt to establish a TRL value has been avoided throughout this report. The use of a readiness level prompts the question "Ready for what?" Given the many possible applications conceivable for ATNs, even the "You are here" label in Figure 4.2-1 can simultaneously be a fair and unfair characterization of the TRL level of ATNs. In other words, common sense dictates that the maturity of a technology is only meaningful in the context of its intended use.

Finally, note once again that all of this is predicated on substantiation of the business case of not just the Airport project but of future instantiations of ATN technology. Prior to discussing this and outlining a few potential next steps the City might want to consider, attention is turned in the next section to the interrelated and highly significant issue of what the City can expect in regard to regulatory issues.

[69] The term APM-Lite is used to correlate operations to scheduled-service APMs and in regard to vehicle size.

4.3 Regulations, Codes, and Standards: A Roadmap

The California Public Utilities Commission (CPUC) oversees the safety and security of all rail transit systems operating within California. The CPUC's authority in this regard flows from USDOT Federal Transit Administration policy that allocates regulatory responsibilities for public transit systems to the states. This is referred to as the State Safety Oversight (SSO) Rule.

Although the language describing the systems regulated by the CPUC refers to Rail Fixed Guideway Systems (RFGSs), included in this definition is:

> *"…any light, heavy, or rapid rail system, monorail, inclined plane, funicular, trolley, cable car, automatic people mover, or* ***automated guideway transit system*** *used for public transit and not regulated by the FRA or not specifically exempted by statute from Commission oversight."* [70]

An ATN installation at the Airport will therefore rather unambiguously come under the purview of the CPUC. Furthermore, in preliminary discussions with CPUC staff, it became clear that that the regulatory effort may very well amount to the development of an entirely new General Order (GO), the term used for regulatory documents produced by the CPUC. Given the complexity associated with ATNs and the unprecedented regulatory allowances being sought, such an effort is likely to be greater than that undertaken to produce General Order 127, which was developed for BART in the 1960s.

Such an effort will initially be of a very different nature than that used to guide the establishment of a transit installation based on conventional technology. It will likely be similar to such efforts being pursued internationally[71]. Although these experiences are, in fact, useful for gauging an initial domestic effort relevant to the Airport project, it is simply not possible to accurately predict the level of effort or amount of time that will be required to achieve a satisfactory result for more fully realized ATN systems, as nowhere has such an effort yet run its course.

Although the steps for ensuring the performance and safety of innovative designs in many fields of endeavor are well known among technical professionals and authorities, the details of the actual work that will be required by the CPUC in order to establish the performance and safety envelope of ATNs under a wide range of conditions is unknown at present. This is as one would expect, as every innovation by definition has its unique characteristics that must be explored, understood, and thoroughly tested. Although not without limit, of course, such an effort begins as being largely open-ended, its ultimate extent determined by what is essentially a technical negotiation between regulatory authorities and industry.

Given the unprecedented nature of proposed ATN operations for a public conveyance, these negotiations will extend well beyond the confines of the typical regulatory process. Despite its transparency, regulatory proceedings are most often attended by those with inside-the-ballpark interest. Regulatory bodies ultimately represent the public. Therefore, prior public knowledge and acceptance of this unusual form of transit will be a major consideration; a significant additional component of effort supporting public discourse and understanding of the concept will likely need to be conducted in parallel with regulatory efforts.

This section discusses the sequence and nature of each of the regulatory processes, hopefully serving as a sort of regulatory roadmap useful to the City in its deliberations. It begins with an overview of

[70] CPUC General Order 164-D, Paragraph 2.15.
[71] Several are discussed in Appendix G.

the complete regulatory environment relevant to ATNs including the role of codes and standards. This is followed by a description of well-established CPUC regulations that apply to installations of conventional transit systems, including provisions to revise such regulations to accommodate new technological developments or application-specific peculiarities. It will be seen that current CPUC regulations and the revision process are not relevant for addressing such a radical departure in technology and operations as embodied in the ATN concept, underpinning the need to develop an entirely new General Order.

Finally, in an attempt to further characterize the process and quantify, at least to some extent, the required effort, two case studies involving CPUC regulations are described in Appendix F, and a discussion of several international efforts in this area is given in Appendix G. A much more extensive effort is required to provide a range of more detailed scope, cost, and schedule estimates of potential ATN regulatory paths and their likelihoods.

4.3.1 Overview of the Local Regulatory Environment

As one can imagine, a regulatory environment can be a complex, multiagency web representing sometimes conflicting underlying means, goals, and objectives. Perhaps it goes without saying that the technical and economic feasibility of the Airport project and any potential alternates or extensions is dependent to a very large extent on the requirements imposed by the collection of pertinent statutes, regulations, and codes. Each regulatory requirement represents a cost and/or a performance limitation that, given well-reasoned regulations representing underlying public interest goals, must be accounted for.

Certifying a current-generation ATN-based system for public transit operations in California will require approvals from a number of agencies at multiple levels of government, including at the federal level if federal funds are to be requested. While safety and security naturally rise to the top of the list of concerns in qualifying an ATN system for public revenue operations, a diverse set of regulations imposed by a similarly broad range of authorities will be applicable to the Airport project and potential extensions and/or alternates. A high-level representation of this regulatory environment is shown in Figure 4.3-1.

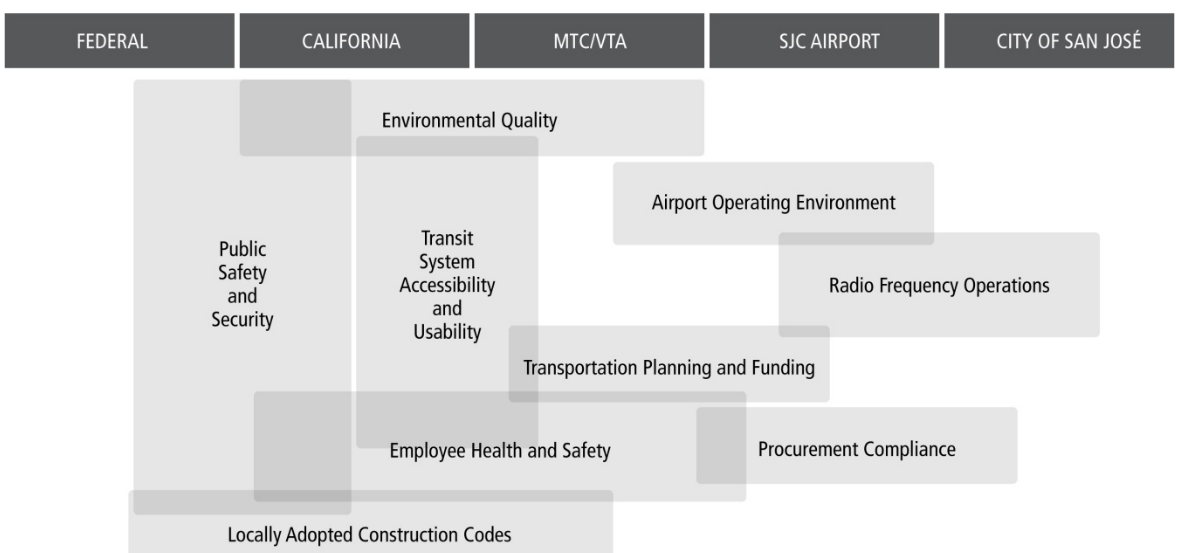

Figure 4.3-1. The local ATN regulatory environment.

Regulatory authorities, as a matter of course, refer as much as possible to well-established codes and standards. As discussed in Section 3.13.1, codes and standards can be seen as a sort of shorthand from a regulatory perspective, representing the distilled experience of countless efforts to improve product performance, safety, reliability, and a host of other measures of value. Beyond their benefits mentioned earlier, it is likely that the simultaneous development of independent codes and standards for the design, verification, and operation of all elements of ATN systems will be necessary in order to garner regulatory approval and certification.

The ATN development community is already a default beneficiary of such activities to a considerable extent. Most notably, the ANSI/ASCE/T&DI Automated People Mover Standards provide what is generally recognized as a solid initial foundation upon which to base ATN-specific standards. Safety standards developed by the American Public Transportation Association (APTA) are primarily oriented toward rail transit but may also have a degree of relevance to ATN systems.

Numerous other standards established in the automotive, construction, and computing/data communications fields can and are being leveraged in current ATN system designs. Through selective application of evolving standards, a strong potential exists to further their net positive effects on development of ATN technologies and the industry as a whole. However, the magnitude of the task to identify, understand, and compile pertinent codes and standards into a set comprehensive enough for reference by regulatory authorities to ensure public interest goals yet spare enough to avoid unwarranted costs is rather daunting. The development community has made significant progress in this regard as part of its design efforts, as discussed in a number of the RFI responses. The results of these efforts will form the basis for the aforementioned technical negotiations with regulatory authorities, but the effort on the part of authorities to understand and accept such a set of codes and standards will be significant. As an example, the result of a very preliminary effort to construct a list of potentially relevant and useful regulatory, code, and standards organizations is given in Appendix H.

Finally, as noted above, conflicting means sometimes exist between authorities. For example, and as noted in Section 3.1, the CPUC General Orders related to transit systems do not currently refer to ASCE APM Standards. However, the California Labor Code and provisions of Cal/OSHA regulations do explicitly impose compliance with the ASCE standards as a requirement for people mover systems.[72] While Cal/OSHA is primarily focused on the safety of employees and workers while on the job, there is an obvious attendant interest in passenger safety, analogous to the role Cal/OSHA plays in the inspection and certification of elevators in California commercial buildings. Note that this is a statutory requirement embodied in law, not a regulation established by a commission. Reconciling issues like this must also be included in an estimation of ATN regulatory efforts.

4.3.2 Existing CPUC Regulations

As the delegated System Safety Organization (SSO) authority for California, the CPUC has issued General Orders and associated rules specifying numerous aspects of safety and security involving the design, construction, operation, and maintenance of guideway-based public transit systems. Brief descriptions of the General Orders relevant to an ATN system for the Airport are given here. They include:

- General Order 164-D: Rules and Regulations Governing State Safety Oversight of Rail Fixed Guideway Systems

[72] Incidentally, Cal/OSHA references an older, noncurrent version of the ASCE APM Standard in its regulations.

- General Order 143-B: Safety Rules and Regulations Governing Light Rail Transit
- General Order 127: Regulations Governing Automated Train Control Systems
- General Order 26-D: Regulations Governing Clearances on Railroads and Street Railroads
- Related General Orders: 95, 110, 118

General Order 164-D: The thrust of GO 164-D is a description of the safety and security processes and documentation required for *certification* of a rail/fixed guideway system. The principal requirement is that a System Safety Program Plan (SSPP) and a Security Program Plan (SPP) must be developed by a Rail Transit Authority (RTA) formed or designated to have cognizance over the specific project. The minimum requirements for these plans are specified at the federal level in the Implementation Guidelines for 49 CFR[73] Part 659, and are detailed for California projects in Sections 3 and 4 of GO 164-D. The SSPP and SSP are reviewed and approved by the CPUC as a prerequisite for certification of the system for public use. Example SSPP and SSP checklists can be readily referenced on line.

General Order 164-D also requires that periodic safety and security audits be conducted and an ongoing process be established for hazard identification and analysis as well as accident reporting and investigation. It also specifies the features of a corrective action process and the content of a formal System Certification Plan and System Certification Verification Report, both based on federal guidelines.

General Order 143-B. GO 143-B specifies the technical capabilities that trains and light rail vehicles must provide to ensure operational safety. It covers a diverse set of topics including vehicle construction and safety equipment, operational performance limits, operational rules and procedures, and maintenance/inspection processes.

General Order 127. GO 127 represents the definitive set of California regulations governing automatic train control systems and associated restrictions on minimum train separation and speeds for rapid transit systems. It also provides specific requirements for route interlock management, right-of-way hazard protection, and related issues of system construction, operations, and associated procedures.

Specifically developed in the 1960s to address the advanced capabilities of the then-novel BART system,[74] there are elements of terminology and technological content which at first glance appear somewhat dated for a discussion of ATN systems. However, on closer examination, one finds much that is technology independent and is of fundamental relevance to ATNs. GO 127 is certainly viable as a point of departure for discussions of how regulations for current and future ATN technologies could be effectively tailored and augmented to ensure safe operations.

General Order 26-D: GO 26-D describes physical clearance requirements for “railroads and street railroads” relative to adjacent or overhead structures. While primarily targeted to full-scale rail systems, it serves as a foundation for consideration of clearance requirements for other types of conveyances and in fact contains an explicit provision for selectively modifying the requirements for specific cases upon the CPUC’s determination that to do so is in the public interest.

[73] Code of Federal Regulators
[74] The original 1967 release of GO 127 is apparently still in effect.

Related General Orders: Three additional General Orders deserve mention for potential relevance to the construction and operation of an ATN system in California:

- **General Order 95** provides a detailed description of design, construction, and safety verification requirements for systems powered by overhead electrical pickup mechanisms. Use of this type of power distribution technology is common in numerous transit systems in the state. Although overhead ("catenary") power distribution lines are not specifically relevant to most current-generation or proposed PRT designs, GO 95 could, at a minimum, serve as a reference for general issues of electrical distribution.

- **General Order 110** specifies rules for the use of radio frequency communications as part of rail system operations.

- **General Order 118** provides specifications for maintenance of "buffer zones" around public transit rights-of-way.

4.3.3 Waivers and Revisions

As is common practice among regulatory agencies, the CPUC possesses a degree of authority to grant waivers and exemptions to existing regulations if good cause is established and it can be shown that the essential intent of the original regulation will be met in some other fashion. In such cases, the regulations themselves are not formally changed but may be applied in a discretionary manner given adequate supporting analyses and demonstrations. More importantly for ATNs, a process is provided by which regulations can be formally supplemented or modified as necessary to address new technologies, system capabilities, and modes of operation. And, as previously mentioned, standards bodies employ in analogous fashion systematic processes for updating standards to accommodate new or unique technology applications. The updated standards, in turn, often feed back into the regulatory baseline, thus paving the way for certification of applications based on the new technologies.

The processes used by regulatory authorities to consider revisions to public transit system regulations possess a generally common set of features:

- Any person or organization can petition the regulatory agency for a hearing on a regulatory matter.

- The proceedings are designed to maximize public involvement

- Steps in such processes follow a sequence that typically includes:

  - Preliminary fact-finding

  - Gathering of inputs from interested and affected parties

  - Consultation with transportation planning, legal, economic, and technology experts

  - Developing draft rules, specifications, provisions, etc.

  - Soliciting public feedback

  - Developing revisions based on feedback

– Making final rulings

– Formulation and execution of a plan for instituting the new rules or standards, typically in accordance with a time-phased effectivity schedule

Appendix F includes a case study of a CPUC ruling as an example of this general approach as well as a case study in which a set of CPUC regulations were used as the basis for a national standard.

A key consideration for the City deriving from this discussion is that its planning regarding ATNs must account for the fact that such rulemaking typically involves extensive collaboration and negotiations among multiple parties and for considerable periods of time, especially when formal modifications or augmentations to regulations are required to accommodate new technology.

More important, however, is the extent to which existing regulations, codes, and standards are applicable to ATNs and what this means in terms of the combined time and effort that will be necessary to understand, demonstrate, and certify ATN systems for public use. This is discussed in the following section.

4.3.4 Regulations Development, Systems Design and Verification, and Innovation

Although regulatory authorities administer flexible and transparent processes to accommodate necessary design variations and technological updates, the extent of such changes in comparison to the design and operation of the systems addressed by the baseline regulations determines the approach to and extent of regulatory efforts. To make up an example or two for the sake of illustration, suppose a new breed of energy-efficient nano-glass were developed and proposed for use on light rail vehicles. The CPUC would likely demand a set of statistically meaningful test data to ensure that the glass also meets safety requirements already in place.

A more ambitious undertaking might be a proposal to retrofit the same light rail vehicles with a similarly new breed of propulsion/braking subsystem. The new subsystem would not affect established Automatic Train Control operations and control devices, but once again the CPUC would certainly demand adequate test data ensuring performance prior to "certification."

In both of these cases, however, the CPUC would almost certainly not require that the same set of test data be supplied prior to certification of every subsequent new application that used the technology. Once, if done properly, is enough.

Thus, there is a parsing that can be done on the meaning of the word "certify" and an important distinction to be made. Existing certification procedures are written to be as technology-agnostic as possible, regulating primarily how *any* capable technology must be operated in order to ensure the safety and security of passengers. Nevertheless, trains are trains, and their operation presumes a certain general design that is both implicitly and explicitly referred to in regulations. For example, the formal title of General Order 127, developed for BART, is:

> *"Regulations Governing the Construction, Reconstruction, Maintenance and Operation of Automatic Train Control Systems with Respect to Train Detection and Separation, Route Interlocking, Speed Enforcement and Right-of-Way Hazard Protection on Rapid Transit Systems."*

Beyond the brick-wall stop criterion already discussed, the route interlocking feature alone is antithetical to the ATN concept. So, beyond technological upgrades that relatively speaking are mere “tweaks,” there comes a point when a clean regulatory sheet must be used. As discussed in detail earlier in this report, ATNs would represent an unprecedented leap in transit system design and operations. The CPUC has therefore determined in a preliminary assessment that the consideration of ATNs would be a clean-sheet occasion requiring the development of a new General Order.

This brings the discussion back to the meaning of the word “certification.” There are two aspects to the discussion. The first, mentioned above, is the distinction between certifying a technology and certifying an application of that technology. It is the latter that is addressed by the SSPPs and SPPs and all the other guidance flowing down from 49 CFR Part 659. The former, being very distinct in nature and the effort required to accomplish it, deserves its own term and is referred to as “qualification” in technical circles. Thus, a *technology* is *qualified* for use, and an *application* is *accepted and certified* for use.

To give an easily understood example, one can imagine the rigorous flight “certification” process that new commercial aircraft must undergo, administered by the FAA and executed by private-sector manufacturers. However, only a few of the first aircraft to be manufactured are subject to the extremely demanding tests necessary to establish their performance and safety envelope. To subject every aircraft to such tests would be extremely costly and unnecessary. Once these tests are accomplished and the aircraft is certified for flight, each production aircraft is subject to a still substantial but less demanding battery of acceptance tests prior to customer delivery for flying particular routes. At an even finer level, pilots conduct preflight visual inspections “certifying” in their judgment the airworthiness of the aircraft.

It is the equivalent of the former, or qualification, tests that must be conducted to support the development of a new set of underlying regulations that would be the ATN equivalent of General Order 127. The latter tests are considered as “proof of workmanship” or operational readiness for particular aircraft outfitted to particular customer specifications (the number of seats, for example). This, coupled with requirements imposed on airline operators to ensure safe and secure operations, can be thought of as the equivalent of General Order 164-D.

As long as an aircraft is operated within the specified limits established during qualification, the collective network of regulatory authorities, manufacturers, and operators have done their utmost to ensure passenger safety and security. Thus, the qualification tests establish a *performance envelope* governing all subsequent operations. Thus it will be with ATNs.

So, certification comes after qualification and acceptance testing, each of which can be thought of as separate instances and levels of a general process called *verification*. Roughly speaking, qualification verifies the performance envelope and is done once; acceptance verifies workmanship and is done repeatedly, once for each application.

Verification is a well-understood process in technical circles. It is, in fact, what is illustrated by the right-hand side of the “Vee” diagram in Figure 4.1-1. The question is: How are the particular verification activities defined in order to qualify a technology? Obviously, this must be done well because they are generally very costly and directly affect both safety and return on investment. The definition therefore needs to be comprehensive and technically rigorous; not overdone, but, considering the consequences if done in an insufficient manner, philosophically erring on the side of safety. Note that there exists a range of acceptable verification methods that are used as appropriate to verify individual aspects of a complex system. The ASCE APM Standards – Part 4 provides a good example, listing nine separate verification methods, including qualification tests, and assigning them to various design aspects based on judgments with respect to characteristics such as design maturity and criticality.

For a completely new system architecture (i.e., technology) for which multiple design approaches are possible, conventional experience is useful but not necessarily entirely sufficient; by definition, the boundaries of knowledge are being expanded. The answer, then, to the question of how to qualify this new ATN animal is that a number of well-known analyses are conducted, beginning with the Failure Modes, Effects, and Criticality Analyses (FMECA) described in Section 3.4.2.3 (page 51) and including additional methods such as the development and analysis of fault trees and the performance of quantitative risk assessments. Such work helps to reveal safety faults in architectures and designs and forms the basis of safety and maintenance plans and procedures.

Most important from a development perspective, they help identify the nature and extent of the necessary verification effort, illuminating where and how much resources need to be allocated, forming the baseline against which actual system performance is verified by tests, demonstrations, and additional analyses and then iteratively fed back into the design process to mitigate any deficiencies.

Thus, as also noted in Section 3.4.2.3, these analyses are tools, not reality. They are used to help define the verification effort and serve as a baseline measure for verification results; they are not a substitute for verification. Especially for so complex a system as ATNs, only verification via rigorous physical testing under a wide range of conditions will suffice as a means of qualification.

The most important questions in this regard for the City are: Just how much of this effort has already been carried out by the development community and is it transferable to a CPUC regulatory effort? The answer to the first question is that it is simply not known for certain how extensive efforts have been to date, but it is reasonable to assume that they have been considerable. For unknown reasons, the development community highlighted its analytical efforts but did not include details of its verification efforts in their RFI responses, including the reports of independent peer review teams.

In answer to the second question, it is not known precisely what the CPUC's view of this will be, particularly with respect to the use of existing safety analyses and verification results carried out under similar but varied national regulatory approaches. It is possible that provisional allowances be made authorizing the operation of current low-performance ATN designs in a manner similar to other national efforts. However, based on the information available, it is very likely, to say the least, that whatever the extent of verification efforts to date, they do not encompass anything approaching a fully realized ATN. This is to be expected but must be accounted for in the City's planning. It is far too early to tell precisely what level of verification the CPUC will find acceptable for purposes of certifying ATN *technology,* as opposed to installations *using* the technology.

A final aspect of this issue of exercising the systems development Vee to further the ATN concept is to recognize that a premature drive to a "standard" ATN design can have the adverse effect of stifling innovation. As has hopefully been demonstrated to the City by the discussion in this report, a single one-size-fits-all instantiation of the ATN concept is far too limiting and, even if it were acceptable, far too early to establish. ATNs are too complex for relatively small engineering teams with similarly small research-and-development budgets to fully explore from either a technical or business case perspective. Recent developments have been useful for the purpose of popularizing this 40-year-old-plus concept, but the bulk of the collective effort that would be necessary to fully understand the concept and establish its ultimate value has not yet been estimated, much less planned.

4.4 State of the Art and Value Network Revisited: A Potential Framework for Next Steps

The SJDOT made its policy concerning ATNs known to the project team very succinctly: “We’re interested in giving the technology a chance, but will not buy a black box.” This is an eminently sensible policy. The work of this project has uncovered both promise and challenges associated with ATNs, yet neither is entirely clear, and much about ATNs remains a black box. Not enough is generally known about the details of current designs, the developments and investments required to produce the next generations of ATN designs, the ultimate regulatory, legal, and human factors constraints, and the value proposition(s) of ATNs.

Perhaps ATNs will encounter fundamental practical limitations that run counter to the business propositions being put forth. On the other hand, perhaps alternate ATN forms, applications, and measures of value can be conceived. For example, approached objectively, the ATN concept seems to be as deserving of attention as other proposals related to the future of transportation, perhaps having significant value that is not usually highlighted, even some that might at present seem far-fetched:

1. Unique combination of service and equity characteristics (i.e., broad-area, nonscheduled service not requiring private ownership of vehicles)

2. Potential member of a broader range of an interoperable family of systems of improved overall efficiency

3. Possible application of ATNs’ architectural features and technologies to the advantage of applications based on conventional transportation systems

4. Risk mitigation tool and evolutionary pathway for continuing automated highway research and development

5. Potential basis for a new generation of energy-efficient urban designs

In order to develop satisfactory answers to the many outstanding questions and drive risk down to levels acceptable for design/build efforts—or even for further development—a considerable collective effort requiring the establishment of an institutional framework, or value network, needs to take place.

Articulating what an institutional framework might look like and the specific steps that would need to be taken to accomplish these objectives were not within the scope of the effort reported on here; that would require a substantial effort of its own. However, a very-high level outline is discussed here regarding the nature of such a framework and some tangible near-term steps the City might wish to pursue should it decide to continue its exploration of ATNs.

The framework outlined is one possible approach to establishing a deeper understanding of the value and limitations of the ATN concept. In the best case (i.e., a substantiated value proposition justifying a significant, long-term collective effort), it would deliver a commonly understood and transparent *development pipeline*, incrementally leading to full-scale deployment. In the worst case, the same incremental approach would limit the downside exposure to all parties, providing off-ramps immediately upon discovery of unbridgeable flaws.

The general framework is shown in Figure 4.4-1. The figure illustrates the parties and transactions defining a collective effort. Although four corners are shown in a diamond shape, the outline defining a subgroup is a clue that the framework includes only three general classifications of participants: government-sector agencies; private-sector industry and finance; and private or quasi-governmental not-for-profit, independent, and objective planning and "peer review" organizations used collectively as a risk-mitigation component. The key to this framework is the simultaneous engagement of all levels of government and an allocation of investments, risks, and rewards appropriate to each individual participant.

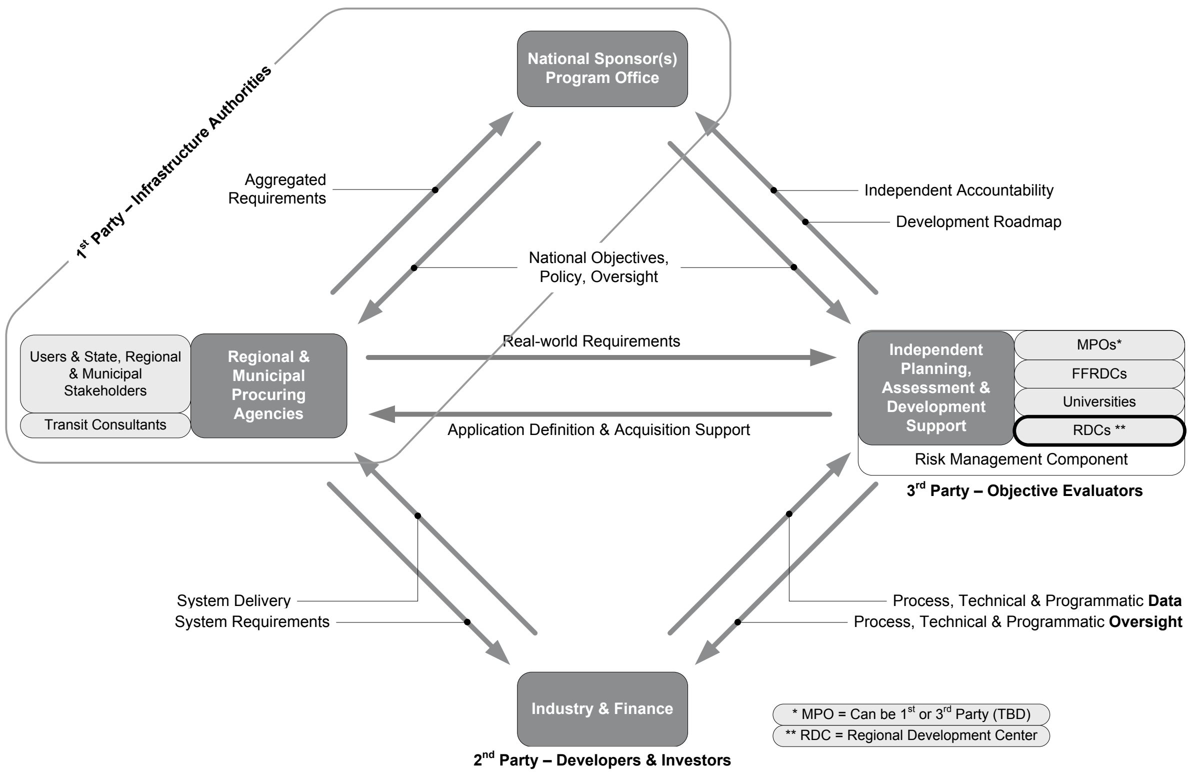

Figure 4.4-1. Potential development framework.[75]

For example, whatever the mechanism, the private sector requires a pathway to revenues in order for it to consider underwriting the technology development risk. Government agencies are the gatekeepers of this revenue, which must ultimately be provided by users and/or voters. Government agencies are therefore in the unique position of being able to influence the level of revenue risk by ensuring the value of systems to their constituents.

Organizations constituting the risk management component are, or can be if so structured, external to the risk/reward equation, enabling participation in the role of objective "customer rep." These organizations can also provide technical and other skills necessary to the role, avoiding the need for wholesale establishment of such skills within government agencies. It is this component that makes this model distinct from the design/build/funding model that is the current norm, allowing

[75] Figure legend:
MPO: Metropolitan Planning Organization, a quasi-governmental organization responsible for planning or planning/design/build across urban jurisdictions. Depending on individual charters, MPOs may be viewed as occupying either a government agency role or a risk management role or both.
FFRDC: Federally Funded Research and Development Center; Aerospace and NREL run FFRDCs. Not listed but also in the risk management category are national laboratories.
RDC: Regional Development Center, a concept being developed by Aerospace to support ATN development, including research and full-scale integration and test facilities for design issues unique to particular regions.

government decisionmakers to take on what would be a new role necessary for operating in a technology development environment.

Note that this model is scalable. This was the model employed in this evaluation and can be extended to the project and program level. The distinction between second- and third-party participants is the exclusion of third-party participants from *ex post facto* revenue streams and the planned retirement of the role at the end of the development lifecycle. That is, when conventionality is achieved, the framework shrinks back to a correspondingly more conventional infrastructure planning and acquisition model.

This model can essentially be viewed as a public-private partnership model adapted to technology development, a context in which the usual revenue and construction risks are joined by technological risk and newly defined revenue risk based on uncertain operational value. Its purpose is to manage the latter two risks, driving them down to acceptable levels for all parties so that innovations may be more easily considered and private capital more easily attracted to the development of civil system solutions.

As previously mentioned, a detailed articulation of a consensus version of this model is far beyond the scope of this evaluation, not to mention the effort that will be required to put it in place. However, a number of next steps can be imagined that would help illustrate its characteristics and operation, and these are discussed below. The City might wish to encourage these steps if it concurs with the approach. The general goals of these next steps may be as follows:

Given all that has been discussed in this report, *the most essential near-term goal is to develop a comprehensive consensus viewpoint regarding the basic value proposition(s) of ATNs*. To maximize the chance of a successful outcome, decisions guiding ATN development must be informed ones. The uncertainties and unknowns uncovered in this effort must be answered, the chicken-and-egg question overcome.

An important companion goal is to encourage innovation and to engage industry in helping to define an overall development strategy. Because a design/build decision would be a risky one given the present state of knowledge, alternate near-term revenue opportunities should be considered to "prime the pump." This can take the form of both public and private investment.

Although no ultimate guarantees can be given, an *incremental, yet forward-moving approach* can encourage investment by limiting financial exposure and demonstrating progress toward a commonly understood long-term goal. It would serve as the first steps in the establishment of the value network and the design of the institutions essential to innovation. In the broadest terms, such an incremental approach can be viewed in the form of the following five steps:

1. Concept Verification & Validation and Development Roadmapping

2. Subsystem R&D and Pilot Project(s) Definition

3. Physical Verification: Full-scale Pilot(s) Integration and Test

4. Physical Validation: Pilot Project(s) Execution

5. Mainstreaming: Repeat Steps 2–5 per the validated development roadmap until conventionality is achieved

Concept Verification & Validation and Development Roadmapping: While this evaluation has (hopefully) put the topic of ATNs in somewhat better perspective, much more needs to be understood about ATNs in order to make informed development, no less design/build decisions. The concept verification and validation step defined here is suggested to fulfill the stated SJDOT policy of looking inside the black box, reach a consensus viewpoint regarding ATN value, and size up the required nonrecurring development effort. Note that a consensus opinion as to the most appropriate business model for both development and operations is the single most important factor in determining how and how quickly the state of the ATN art can be pursued. Some near-term tasks come immediately to mind:

1. Solicit and document feedback to the City's findings of this evaluation.

2. Plan and execute a second-round effort, redirecting focus from acquisition planning to development planning.

    a. Establish the legal environment enabling appropriate and agreed-upon access to and protection of trade-secret information.

    b. Arrange for the issuance of competitive study contracts for the Airport and/or other applications as case studies for the simultaneous definition of development and business models.

    c. In conjunction with the study contracts and using trade-secret agreements, seek definitive knowledge of existing verification and validation (i.e., maturity) levels. This is required to establish a development baseline.

    d. Engage regulatory authorities and standards organizations to estimate scope of required efforts.

    e. Perform independent performance, reliability, cost modeling, etc.

    f. Fully research and characterize the significant ATN development efforts undertaken in the past to serve as a lessons-learned basis for contemporary efforts.

3. Prepare a Development Roadmap

    a. Establish defensible long-term system architectural options based on the work accomplished in Item 2.

    b. Establish a defensible and consensus business case/system ownership model. It is in this and the previous step that revenue from whatever source necessary to cover costs is linked to system performance, i.e., a comprehensive articulation of value and affordability.

    c. Similarly, develop a consensus agreement on a public/private R&D (i.e., nonrecurring) cost-sharing model.

    d. Define subsystem technology and human-factors R&D. Presuming that future ATNs will be more fully integrated systems acquired from a wide array of sources, this activity and its subsequent execution will serve as the first step in bringing a broader set of innovators into the market and establishing the various roles such as system integrator and subsystem specialist.

e. Develop an institutional plan. Define the government agency side of the value network, its role, and scope its efforts.

f. Prepare a Pilot Project(s) Plan. Identify a series of applications requiring incremental increases in ATN capabilities as part of a managed development/deployment plan.

g. Prepare development lifecycle cost and schedule estimates. This is perhaps the single most important task. Throughout this evaluation, no estimate of the overall investment required to bring the ATN concept to fruition has been uncovered. This is a crucial item for long-range public and private planners and investors to have in support of near-term decisions.

Subsystem R&D and Pilot Project(s) Definition: This phase would be devoted to competitively awarded subsystem development contracts and government-sponsored independent research. The purpose of this phase is fourfold: a) to continue the provision of “pump-priming” revenue to the private sector, b) continue to attract private capital to corporate R&D efforts, c) begin the development of a robust industrial base, and d) advance the ATN state of the art and focus efforts in areas consistent with the overall development roadmap. This phase will include the all-important human factors research.

Physical Verification: Full-scale Pilot(s) Integration and Test: In this phase, the various components and subsystems developed in the prior phase are subject to full-scale integration and test in either private- or public-sector purpose-built facilities or both in configurations consistent with the pilot application(s). This is an essential step to mitigate risks prior to pilot design/build procurements.

Physical Validation: Pilot Project(s) Execution: In this phase, pilot systems having well-characterized performance and costs are acquired on a competitive basis. As a result of initial and ongoing roadmapping work, these applications will be chosen to validate the technical and business cases on an incremental basis. Applications will have known operational lifecycles: systems intended for later expansion, stand-alone durable systems or semi-durable systems, intended for replacement. These validation efforts provide operational experience used in subsequent development activities.

Mainstreaming: As increasingly capable systems are pursued as part of an ongoing incremental development cycle, systems proven for the type of applications represented by the pilot projects may be pursued at acceptable levels of risk by interested parties having similar applications in mind. The work done in the earlier stages of the overall development lifecycle has established the beginnings of an industry—the suppliers, consultants, and knowledge (i.e., a value network) needed to plan and acquire systems.

Note again that an incremental approach provides ample opportunities at each stage to mothball the overall effort in light of any negative findings. However, a transparent effort could at the very least provide an opportunity to settle many of the issues at the root of the numerous claims and counterclaims associated with the ATN concept. Downstream development activities of increasing complexity and expense are, in fact, predicated on many of these issues being resolved up front, thereby limiting overall investment exposure.

A number of recent ATN feasibility studies have called attention to the obvious fact discussed here that the ATN concept is at present an uncertain one requiring substantial investments in research and development to fully understand its value proposition(s). The outline given here is by no means a detailed plan for undertaking such an effort and is subject to the perspectives of the numerous stakeholders it will involve. The development of a detailed, defensible, and consensus plan is a significant effort in and of itself. It is hoped that this outline perhaps articulates a few basic principles that could guide the development of such a plan.

5. Concluding Remarks

ATNs are at present at a very early stage in their development from both technical and nontechnical perspectives. The concept itself has not been fully substantiated despite decades of effort. However, neither has it been proven to have no value at all. ATNs have a clean-slate opportunity to define a range of designs consisting of various vehicles sizes, system architectures, and operating characteristics in order to more closley match capacity to demand within or across applications. In many cases, this will mean striving for minimalist systems composed of small vehicles of absolutely minimum mass and cost. In others, it will mean filling in the range of transportation options with ATN systems based on larger vehicles in targeted applications for which conventional systems would be prohibitively expensive and/or oversized. For the Airport, these issues come into play, necessitating the conclusion that ATNs may be feasible if the City is willing to engage in a technology development effort to more fully understand the future state of the art.

Decisionmakers at the municipal levels do not normally need to concern themselves with the level of technical detail presented here. In this case, they do. Should the City decide to engage in an effort like this, it would need to adopt a new role for itself in support of development efforts and take a long view. The information and discussion given in this report represent a sliver of the tip of the ATN iceberg. Perhaps the most important perspective deriving from this effort is to not underestimate the scope and difficulty of fully understanding and developing the ATN concept. If one steps back from focusing on individual technologies and associated claims and counterclaims, one can see that what is actually being proposed is a revolutionary and unprecedented approach to transportation system design.

Existing systems, which are neither heavily integrated in and of themselves nor integrated into a complex built environment, are more amenable to evolutionary improvements. The ATN concept is in essence a synthesis of centuries of transportation know-how into complete system designs that are envisioned for development over the span of mere decades. Such compression of the development lifecycle would be unprecedented in the world of ground transportation and would require a substantial collective effort to achieve. The development community is making initial and welcome moves in expanding the definition of ATNs and articulating their promise, but there is a long way to go.

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Appendix A. Preliminary Requirements

The San José Airport ATN System Project requirements generated as a result of the Feasibility Evaluation are presented in this appendix. Per accepted systems engineering practice, each requirement is expressed as single, discrete statement describing a specific need, function, performance level, quality, or constraint relevant to the system, with a unique identification number for unambiguous reference. The following definitions are applicable to the language of the stated requirements:

- *shall* is used to indicate a requirement that the system must verifiably satisfy, through analysis, demonstration, inspection, instrumented testing, operational validation, or related method
- *will* is used to indicate a statement of intent to be pursued for the project, representing one or more important objectives but not subject to formal verification
- *should* is used to indicate a desirable feature, characteristic or action that could benefit the interests of the Project and is recommended for adoption
- *may* is used to indicate a feature, characteristic or action that is currently being taken under advisement

Notes are selectively appended to the text of the requirements in italic font. The purpose of *Notes* information is to provide additional definition and context related to the stated requirement. (The *Notes* information itself is not intended to be formally verified.)

The acronym *TBR* ("to be resolved") is used in the requirements and *Notes* text to indicate initial decisions or values that are subject to additional analysis and potential revision. In a similar fashion, the acronym *TBD* ("to be defined") is used to indicate a concept or value that has yet to be decided or initially determined.

The following material is excerpted from Section 4 of a separate Project Requirements document, initially delivered to the City earlier in the study and more recently updated in response to comments from the City, VTA, and the SJC Airport Administration. Section 4.1 presents the set of top-level "Tier 0" goals and objectives for the Airport ATN System Project, from which all lower-tier requirements are derived. In section 4.2, the more detailed sub-tier requirements that have been developed as a result of Task 2 data collection and analysis activities are listed. Section 4.3 provides detailed metadata and traceability link information for each of the Project requirements.

4.1 San José Airport ATN System Project: Goals and Objectives

The top-level goals and objectives of the Airport ATN System Project are specified in this section as Tier 0 requirements. These requirements address the basic transit service interconnections enumerated in the 2000 Measure A language, along with additional goals of interest to the City and SJC Airport staff for the project. All lower-level requirements for the ATN system implementation are ultimately derived from these top-level goals and objectives.

[4.1-001] The San José Airport ATN System Project shall fulfill the 2000 Measure A ballot provision to provide a people mover connecting the Norman Y. Mineta San José International Airport terminals directly with the Bay Area Rapid Transit (BART), Caltrain, and Santa Clara Valley Transportation Authority (VTA) Light Rail Transit systems. [Tier 0]

Note: The specific purpose of Phase 1 of the Project is to evaluate the technical and economic feasibility of "Personal Rapid Transit" (PRT) technology, also referred to as Automated Transit Networks (ATNs), to implement the transit service connectivity specified in Measure A.

[4.1-002] The San José Airport ATN System Project shall be designed and implemented with the goal of improving local public transit service in and around the San José International Airport. [Tier 0]
Note: Service improvements could include increased convenience, connectivity, safety and security, and related factors.

[4.1-003] The San José Airport ATN System Project shall be designed and implemented with the goal of improving the convenience of access to and from the airport. [Tier 0]
Note: Increased airport usage helps reduce cost per emplaned passenger (CPE).

[4.1-004] The San José Airport ATN System Project shall be designed and implemented with the goal of reducing the operational costs of airport transit services relative to the currently deployed public transit systems. [Tier 0]
Note: Lower transit costs help reduce cost per emplaned passenger (CPE).

[4.1-005] The San José Airport ATN System Project shall be designed and implemented with the goal of facilitating increased utilization of other area public transit systems, including VTA Light Rail, Caltrain and BART. [Tier 0]
Note: The goal is to design the ATN system to be a well-integrated and effective complement to existing public transit services, further advancing their environmental and economic benefits.

[4.1-006] The San José Airport ATN System Project shall be designed and implemented with the goal of providing an environmentally sound and energy-efficient means of transportation across the system's route structure. [Tier 0]
Note: This is directly intended to advance the San José "Green Vision" goals.

[4.1-007] The San José Airport ATN System Project shall, as a goal, leverage the strength of the local technology industry base to promote innovation in advanced transportation systems technology. [Tier 0]
Note: The intent is to 1) contribute to the advancement of the state of the practice in automated transit systems and 2) increase economic development opportunities for San José and the surrounding area.

[4.1-008] The San José Airport ATN System Project shall, as a goal, facilitate the development of "clean-tech" employment opportunities in San José. [Tier 0]
Note: The intent is to increase high technology employment opportunities in San José and the surrounding area.

[4.1-009] The San José Airport ATN System Project shall, as a goal, provide a foundation for sustainable development in San José. [Tier 0]
Note: "Sustainable development" includes increased land-use efficiency, improved accessibility to airport-area activity centers, improved "quality of life" (cleaner environment, reduced noise and traffic, increased public mobility), increased use of renewable energy, and related factors.

[4.1-010] The San José Airport ATN System Project shall be designed and implemented so as to address the needs, objectives and constraints of all key stakeholders in the Project. [Tier 0]

Note: Key stakeholders in the Project include, but are not necessarily limited to, the City of San José, the Valley Transportation Authority, the SJC International Airport Administration, and the San José area public transit ridership community.

4.2 San José Airport ATN System Project Sub-Tier Requirements

This section presents the requirements for the San José Airport ATN system, organized into the nine topical categories described in section 3 above. A unique reference number ("requirement identifier") appears in brackets at the beginning of the text of each requirement. The tier level of each requirement is included in brackets following the requirement text, and can also be determined from the indentation of the requirement paragraph.

4.2.1 Airport ATN System Transit Service Needs

In this section, the transportation needs of the San José Airport ATN System are characterized in terms of the airport-area points to be connected, the service transit times between the connection points, the service capacity required to meet the projected demand, and the key service features to be provided.

4.2.1.1 Airport ATN System Connectivity

[4.2.1.1-001] The San José Airport ATN System shall provide public transit service between the San José International Airport terminals, the Valley Transportation Authority (VTA) Light Rail system, the Caltrain system, and a future Bay Area Rapid Transit (BART) terminal in the San José area. [Tier 1]
Note: These points represent the minimum set of terminal locations for the Airport ATN System Project, as reflected in the 2000 Measure A statutory language.

> [4.2.1.1-002] The San José Airport ATN System shall provide bidirectional point-to-point service between Terminals A and B of the San José International Airport. [Tier 2]

> [4.2.1.1-003] The San José Airport ATN System shall provide a connection to, at a minimum, a single terminal of the VTA LRT system. [Tier 2]
> *Note: The optimum LRT terminal(s) for ATN system connection is TBD.*

>> [4.2.1.1-004] The San José Airport ATN System shall provide point-to-point connection between any station of the ATN system and the Metro-Airport Station [TBR] of the VTA LRT system. [Tier 3]

> [4.2.1.1-005] The San José Airport ATN System shall provide a connection to, at a minimum, a single terminal of the Caltrain system. [Tier 2]
> *Note: The optimum Caltrain terminal(s) for ATN system connection is TBD.*

>> [4.2.1.1-006] The San José Airport ATN System shall provide point-to-point connection between any station of the ATN system and the Santa Clara [TBR] Caltrain terminal. [Tier 3]

> [4.2.1.1-007] The San José Airport ATN System shall provide a connection to, at a minimum, a single terminal of the BART system. [Tier 2]
> *Notes: 1) The optimum BART terminal for connection to the ATN system is TBD. 2) The initial design of the ATN system should accommodate this connection even though the Airport ATN System service may begin before the BART terminal is completed.*

[4.2.1.1-008] The San José Airport ATN System shall provide the capability for point-to-point connection between any station of the ATN system and the future Santa Clara [TBR] BART station. [Tier 3]

[4.2.1.1-009] The San José Airport ATN System shall be designed to accommodate the capability for bidirectional public transit service between existing SJC Terminals and future terminal facilities located south of Terminal B. [Tier 2]

[4.2.1.1-010] The San José Airport ATN System shall serve the SJC Airport terminals and hosted airlines equitably; i.e. any ATN passenger facilities must be generally replicated at or equidistant from the existing/future terminals. [Tier 2]

[4.2.1.1-011] The connection between SJC Airport Terminals A and B provided by the San José Airport ATN System shall be symmetrical. [Tier 3]
Note: By "symmetrical," it is meant that the transit time from Terminal A to Terminal B should be substantially the same as in the inverse direction.

[4.2.1.1-012] The San José Airport ATN System shall provide for future connection to an additional terminal south of Terminal B, such that a symmetrical connection between each of the current terminals and the new terminal facilities is implemented. [Tier 3]
Note: By "symmetrical," it is meant that the transit time between either of the existing terminals and the new facility should be substantially the same in either direction.

[4.2.1.1-013] The San José Airport ATN System shall provide public transit service between the points enumerated in requirement [4.2.1.1-001] and potentially additional station locations between those points in the immediate SJC Airport area. [Tier 1]
Note: These points represent additional ATN system stations intended to increase the utility and cost-effectiveness of the ATN system, while maintaining consistency with the scope and intent of Measure A.

[4.2.1.1-014] As a goal, the San José Airport ATN System station locations shall be selected so as to keep walking distances between transit stops and primary airport facilities (e.g., terminals, parking structures and lots, rental car center, etc.) within a maximum of 500 [TBR] feet. [Tier 2]

[4.2.1.1-015] The San José Airport ATN System shall provide the capability to extend public transit service from the points enumerated in requirement [4.2.1.1-001] to additional station locations in the City of San José area. [Tier 1]
Note: These points represent additional terminal locations intended to increase the utility and cost-effectiveness of the San José Airport ATN System, funded separately so as to maintain independence from the Measure A mandate.

4.2.1.2 ATN Service Transit Times

[4.2.1.2-001] The San José Airport ATN System shall provide public transit service between the station locations, defined in the requirements of section 4.2.1.1, with better passenger-experienced transit times, on average, than those provided by current airport-area transit modes. [Tier 1]

Notes: 1) For the purposes of this requirement, "transit time" means the time between the passenger's entry to the departure station and exit from the arrival station, including time spent waiting for an available vehicle, boarding the vehicle, traversing the inter-station guideway, queuing for arrival, and de-boarding and exiting the arrival station. 2) To warrant the significant potential investment needed to realize the Airport ATN System, the requirements for transit service times need to be substantially faster – a minimum of a 50% improvement with a goal of 100% improvement - than the average of the point-to-point service times currently provided by airport-area transit modes. 3) The current transit modes include the Airport shuttle, Line 10 buses, and local taxi service.

[4.2.1.2-002] The San José Airport ATN System shall provide the capability to achieve the average transit times between the system origin-destination pairs comprising the reference ATN system route structure as listed in Figure 3. [Tier 2]
Notes: 1) "Average transit time" is defined as the mean time between the passenger's entry to the departure station and exit from the arrival station, including time spent waiting for an available vehicle, boarding the vehicle, traversing the inter-station guideway, queuing for arrival, and de-boarding and exiting the arrival station. 2) The values listed in Figure 3 are initial estimates and subject to further resolution.

From/To	Terminal A	Terminal B	ConRAC	Term. A LT Parking	Term. B LT Parking	VTA LRT	Sta. Clara Caltrain
Terminal A		2560' 4.21 min	2640' 4.25 min	2865' 4.36 min	N/A	6420' 6.04 min	13065' 9.19 min
Terminal B	2560' 4.21 min		N/A	N/A	650' 3.3 min	3860' 4.83 min	15625' 10.40 min
ConRAC	2640' 4.25 min	N/A		N/A	N/A	N/A	N/A
Term A LT Parking	2865' 4.36 min	N/A	N/A		N/A	N/A	N/A
Term B LT Parking	N/A	650' 3.3 min	N/A	N/A		N/A	N/A
VTA LRT	6420' 6.04 min	3860' 4.83 min	N/A	N/A	N/A		19485' 12.23 min
Sta. Clara Caltrain	13065' 9.19 min	15625' 10.40 min	N/A	N/A	N/A	19485' 12.23 min	

Distance in feet
Total Transit Time, assuming 1 minute average boarding station entry time, 1 minute average vehicle wait time, 40 kph (24 mph) line speed, and 1 minute average destination station exit time

Figure 2. Target Origin-Destination Transit Times for ATN System Connections

4.2.1.3 System Capacity

[4.2.1.3-001] The San José Airport ATN System shall provide the overall capacity to support projected peak service demand levels on a system-wide basis. [Tier 1]

[4.2.1.3-002] The San José Airport ATN System shall provide the capacity to support system-wide "peak hour" demand of up to 1,280 [TBR] vehicle trips per hour across the system. [Tier 2]

Notes: 1) This represents "peak-hour" demand on a system-wide basis, defined as the highest number of vehicle trips expected to be served on the ATN system during any one-hour period during the course of a 24-hour operational day. For the San José ATN system, peak hour demand is defined as 15% of the projected total daily demand, including anticipated growth through the year 2030. 2) The system capacity needed to serve this demand should be sufficient that the mean passenger wait time for an available vehicle is no longer than 1 [TBR] minute. 3) The projected demand for the San José ATN system is a preliminary estimate[x] which is subject to additional analysis and refinement.

[4.2.1.3-003] The San José Airport ATN System shall provide and distribute sufficient operational vehicles throughout the system route structure to serve the system-wide "peak hour" passenger demand defined in requirement [4.2.1.3-002]. [Tier 3]

[4.2.1.3-004] The San José Airport ATN System shall provide the capacity to serve passenger demand at each ATN station in accordance with expected usage on each of the origin-destination pairs comprising the system route structure. [Tier 1]
Notes: 1) "Expected usage" is defined as a) "peak hour" demand, representing the highest number of vehicle trips to be served on the system during any one-hour period during the course of a 24-hour operational day, with a mean passenger wait time for an available vehicle no longer than 1 [TBR] minute, and b) "instantaneous peak" demand, representing the highest passenger arrival rate experienced over any 5 [TBR] minute period that can be served with a mean passenger wait time no longer than 3 [TBR] minutes. 2) An estimated demand growth factor for the next 20-30 years should be considered in computing the required ATN system size and capacity.

[4.2.1.3-005] The San José Airport ATN System shall provide the capacity to serve the peak-hour passenger demand between all system origin-destination pairs comprising the reference ATN system route structure as listed in Figure 4. [Tier 2]
Notes: 1) "Peak hour" demand is defined as the highest hourly vehicle trip rate, experienced over a 24-hour period, that can be served with a mean passenger wait time for an available vehicle no longer than 1 [TBR] minute. 2) The values provided in Figure 4 include current usage levels as well as a projection of year 2030 demand to account for long-range growth. 3) The values provided in Figure 4 assume symmetrical demand over the course of an operational day. Additional capacity requirements to meet asymmetrical demand patterns are defined separately. 4) The values listed in Figure 4 are preliminary estimates[x] and are subject to additional analysis and refinement.

[4.2.1.3-006] The San José Airport ATN System shall provide the capacity to support asymmetrical peak hour demand loads between the origin-destination pairs listed in Figure 4, up to an 80/20 proportion. [Tier 2]
Notes: 1) It is anticipated that asymmetry in the demand pattern may increase the level of line utilization and number of vehicles required to ensure responsive service, and therefore should be accounted for in system capacity planning. 2) "Peak-hour" demand is defined as the highest number of vehicle trips expected to be served on the ATN system during any one-hour period during the course of a 24-hour operational day. For the San José Airport ATN System, it is defined as 15% of the projected total daily demand, including anticipated growth through the year 2030. 3) The system capacity needed to serve this demand should be sufficient that the mean passenger wait time for an available vehicle is no longer than 1 [TBR] minute.

From/To	Terminal A	Terminal B	ConRAC	Term. A LT Parking	Term. B LT Parking	VTA LRT	Sta. Clara Caltrain
Terminal A		60 128	203 443	38 83	N/A	13 28	13 28
Terminal B	60 128		N/A	N/A	56 120	19 42	19 42
ConRAC	203 443	N/A		N/A	N/A	N/A	N/A
Term A LT Parking	38 83	N/A	N/A		N/A	N/A	N/A
Term B LT Parking	N/A	56 120	N/A	N/A		N/A	N/A
VTA LRT	13 28	19 42	N/A	N/A	N/A		23 49
Sta. Clara Caltrain	13 28	19 42	N/A	N/A	N/A	23 49	

2011 peak hour demand
2030 peak hour demand

Figure 3. Estimated Peak Hour Demand Levels for ATN System Origin-Destination Pairs

[4.2.1.3-007] The San José Airport ATN System shall provide the capacity to serve the instantaneous peak passenger demand at each of the origin points of the system route structure as listed in Figure 5. [Tier 2]
*Notes: 1) "Instantaneous peak" demand is calculated as a number of passengers equal to 2.0% of the total daily movements from the origin station, entering the station intending to board an ATN vehicle within a 5 minute period. 2) As an example, this equals 95 passengers (0.02 * (850+2950+550+185+185)) coming into the Terminal A station within a 5 minute period, for the 2030 projected demand. 3) The system capacity provided to serve this demand should be sufficient that the mean passenger wait time for an available vehicle is no longer than 3 [TBR] minutes during these surge conditions. 4) Ability to service these instantaneous peak levels would be expected to factor into station sizing decisions.*

	Demand within 5 min
Terminal A	43 95
Terminal B	21 44
ConRAC	27 59
Term A LT Parking	5 11
Term B LT Parking	8 16
VTA LRT	7 16
Sta. Clara Caltrain	7 16

2011 instantaneous peak demand (5 minute interval)
2030 instantaneous peak demand (5 minute interval)

Figure 4. Instantaneous Peak Demand Levels for ATN System Origin Stations

4.2.1.4 Service Features

[4.2.1.4-001] The San José Airport ATN System shall provide around-the-clock transit service between the stations enumerated in section 4.2.1.1. [Tier 1]

> [4.2.1.4-002] The San José Airport ATN System shall be capable of operating on a 24/7/365 service basis. [Tier 2]
>
> [4.2.1.4-003] The San José Airport ATN System shall support transit service access from any ATN system station at any time of day. [Tier 2]
>
> [4.2.1.4-004] The San José Airport ATN System shall provide service without the need for advance request or reservation of a vehicle. [Tier 2]
>
> [4.2.1.4-005] The San José Airport ATN System shall provide the capability for a passenger to request a vehicle from the boarding station if one is not readily available. [Tier 2]
>
> [4.2.1.4-006] The San José Airport ATN System shall take action to provide an empty vehicle to a given station upon request of a waiting passenger. [Tier 2]
> *Note: Such action could take the form of locating and routing an empty vehicle to the station, or determining that, within a short a time, a loaded vehicle destined for that station will be available for service upon de-boarding of the existing passengers.*

[4.2.1.4-007] The San José Airport ATN System shall be capable of providing freely accessible transit service between the stations enumerated in requirement [4.2.1.1-001]. [Tier 1]
Note: The intent is to provide airport-area transit service free of charge to SJC Airport passengers, employees, and other patrons.

> [4.2.1.4-008] The San José Airport ATN System shall accept passengers at the stations enumerated in requirement [4.2.1.1-001] without requiring prior action to purchase or obtain a credential (e.g., a physical ticket or authorization code). [Tier 2]
>
> [4.2.1.4-009] The San José Airport ATN System shall accept passengers at the stations enumerated in requirement [4.2.1.1-001] without requiring passengers to produce identification or provide personally identifiable information. [Tier 2]
>
> [4.2.1.4-010] The San José Airport ATN System shall provide the capability for passengers to select their desired destination using an in-vehicle data entry interface. [Tier 2]
>
> [4.2.1.4-011] The San José Airport ATN System shall provide the capability for passengers to change their desired destination while in route using the in-vehicle data entry interface. [Tier 2]
>
> [4.2.1.4-012] The San José Airport ATN System shall provide the capability for passengers to immediately request re-routing to a manned emergency station using the in-vehicle data entry interface. [Tier 2]
> *Note: Please see section 4.2.3.6 for additional requirements related to safety and emergency operations.*

[4.2.1.4-013] The San José Airport ATN System design shall provide for the ability to collect fares for use of the ATN service. [Tier 1]
Note: This is intended as a potential future capability which should be considered in the initial system design. Detailed operations concepts for ticketing, point-of-sale fare collection, user subscription options (e.g., monthly passes), affinity programs, transfers to other local transit services, etc. are TBD.

> [4.2.1.4-014] The San José Airport ATN System shall provide the capability to manage ticketing and fare collection for a subset of the ATN system's origin-destination pairs. [Tier 2]
> *Note: This implies that some connections could be provided free of charge while others would require some form of payment.*
>
> [4.2.1.4-015] The San José Airport ATN System design shall consider capabilities to offer and manage transfers to the other transit services to which the ATN connects. [Tier 2 Objective]
>
> [4.2.1.4-016] The San José Airport ATN System service shall implement and maintain industry-standard safeguards for protection of any personally identifiable information obtained as part of the fare purchase process for use of the ATN system. [Tier 2]
>
> [4.2.1.4-017] The San José Airport ATN System shall provide the capability for automatic vehicle destination selection based on information associated with the credential (e.g., ticket or authorization code) at the time the credential is obtained. [Tier 2]
> *Note: This could be accomplished via a ticket reader or code entry capability in the vehicle.*

[4.2.1.4-018] The ability for passengers to initiate an emergency destination override shall be provided even with automatic route selection (e.g., via encoding on a ticket). [Tier 2]
Note: Non-emergency destination change selection need not be provided for routes requiring prior ticket purchase or authorization.

[4.2.1.4-019] The San José Airport ATN System design shall provide for the ability for passengers to reserve a vehicle in advance of their arrival at an ATN station. [Tier 1]
Note: This is intended as a potential future capability which should be considered in the initial system design. Detailed operations concepts for how service can be pre-requested are TBD.

4.2.2 San José Airport ATN System Design Requirements

This section specifies the criteria, standards, and constraints applicable to the design, implementation and operation of the San José Airport ATN System. These are addressed for the ATN as an overall system, as well as for primary subsystem-level elements.
Note that this section's focus is on compliance of the ATN system design with applicable standards and codes and to known constraints related to the San José International Airport environment. Requirements for the functional capabilities, performance specifications, and operational activities of the ATN system are specified separately in sections 4.2.3 and 4.2.4.

4.2.2.1 ATN System Design Constraints

[4.2.2.1-001] The San José Airport ATN System design shall generally conform to the features and characteristics commonly associated with Automated Transit Network (ATN) systems, also known as Personal Rapid Transit (PRT) systems. [Tier 1]
Notes: 1) A ground rule of the Phase 1 Feasibility Study that Group Rapid Transit systems, Automated People Movers, and other alternative transportation concepts (e.g., dual mode vehicle systems) are not within the scope of interest of the City. 2) The terms PRT and ATN are synonymous for purposes of this document and the overall Phase 1 Feasibility Study.

[4.2.2.1-002] The San José Airport ATN System design shall utilize small vehicles (nominally in the range of 2 to 6 passenger capacity). [Tier 2]
Notes: 1) "Small" is by comparison to Group Rapid Transit systems, in which the vehicle capacity is typically 12 to 20 passengers or more. 2) This requirement is not intended to preclude consideration of design alternatives that utilize multiple vehicle sizes on a compatible guideway structure, or implement methods for linking multiple small vehicles into a single operating unit, as possible options for handling surge loads within the ATN system.

[4.2.2.1-003] The San José Airport ATN System shall provide "on-demand" service. [Tier 2]
Note: On-demand service means that there are no predefined timetables or service schedules; a vehicle is provided immediately (or as soon as possible) upon passenger arrival for boarding.

[4.2.2.1-004] The San José Airport ATN System shall provide direct routing of vehicles from the point of boarding to a single destination selected by the passenger(s) in that vehicle. [Tier 2]

Notes: 1) In the ATN concept, "direct" routing means that a) vehicles do not stop at intermediate stations, as is common with light rail, bus, and other public transit systems, and b) passengers do not transfer to another vehicle to complete their trip on the ATN. 2) While an ATN system will in general seek to send vehicles along the shortest path from origin to destination, for load balancing purposes this may not always be the case in actual operations. Routing decisions are generally made in near-real time under automated control based on existing service loads across the system.

[4.2.2.1-005] The San José Airport ATN System shall provide for automated vehicle operation. [Tier 2]
Note: ATN vehicles are driverless and, under normal circumstances, not under direct control of passengers or human operators.

[4.2.2.1-006] The San José Airport ATN System shall accommodate location and operation of passenger boarding/deboarding stations off of the main guideway. [Tier 2]
Notes: 1) The "guideway" of an ATN system refers to the track or dedicated structure along which the vehicles are routed. 2) "Off-line" stations ensure that vehicles which wish to bypass a particular station are not held up by other vehicles which do stop at that station. 3) It is not a hard requirement that the San José ATN must categorically have only off-line stations; in certain low-capacity applications, on-line stations can be the most cost-efficient approach and may be considered.

[4.2.2.1-007] The San José Airport ATN System design shall, as a goal, accommodate the physical constraints (e.g., curvature, grade, horizontal and vertical clearances) of current, generally available ATN technology. [Tier 1]
Note: Some degree of enhancement to the current ATN design capabilities, if necessary to meet physical routing constraints, may be considered within reasonable levels of added complexity, cost and risk.

[4.2.2.1-008] The San José Airport ATN System design shall allow for a minimum of 1.0 [TBR] meter clearances between each side of the guideway and laterally-adjacent structures or obstructions. [Tier 2]

[4.2.2.1-009] The San José Airport ATN System design shall allow for a minimum of 1.0 [TBR] meter clearance between the top of the vehicle and overhead structures or obstructions. [Tier 2]
Note: This requirement is applicable only for systems with guideway-supported vehicles.

[4.2.2.1-010] The San José Airport ATN System design shall allow for a minimum of 1.5 [TBR] meter clearance between the bottom of the vehicle and the underlying grade level during nominal vehicle operation in a restricted right-of-way. [Tier 2]
Notes: 1) A restricted right-of-way means that the vehicle operates over an area that is fenced off and/or otherwise made inaccessible to pedestrians or other vehicle traffic. 2) This requirement is applicable only for systems with guideway-suspended vehicles.

[4.2.2.1-011] The San José Airport ATN System design shall allow for a minimum of 5.1 [TBR] meter clearance between the bottom of the guideway structure for guideway-supported vehicles, or the bottom of a guideway-suspended vehicle, and the underlying grade level during nominal vehicle operation in an unrestricted right-of-way. [Tier 2]
Notes: 1) An unrestricted right-of-way means that the vehicle operates over an area that pedestrians and/or other vehicle traffic may traverse. 2) Depending on the nature of grade-

level road activity (e.g., roadways with no trucks allowed), the City may consider the possibility of relaxing this requirement to 4.5 meters of overhead clearance.

[4.2.2.1-012] The San José Airport ATN System design shall accommodate uniform guideway curves having a centerline radius of 16 [TBR] meters or greater. [Tier 2]
Notes: 1) This specification recognizes the distinction between ATN technology and larger APM systems, which typically have larger minimum turning radii of 20 – 40 meters. 2) Centerline turning radii of 16 meters can generally be accommodated by all ATN system designs; vendor-specific limitations may come into play for tighter turns. 3) Exceptions to this 16-meter design target may be accommodated in instances where tighter curves, having centerline radii of 3 [TBR] to 15 [TBR] meters, are needed to meet other constraints, though this will likely entail reduced system performance (e.g., limiting line speed through the turn).

[4.2.2.1-013] The San José Airport ATN System design shall, as a goal, accommodate ascending grades up to +10 [TBR]% (+5.7 [TBR] degrees). [Tier 2]
Note: Exceptions to this target may be accommodated in instances where steeper ascending grades are needed to meet other constraints, possibly with restrictions on grade length and/or reduced ability to maintain normal operational line speed.

[4.2.2.1-014] The San José Airport ATN System design shall, as a goal, accommodate descending grades up to -6.25 [TBR]% (-3.6 [TBR] degrees). [Tier 2]
Note: Exceptions to this target may be accommodated in instances where steeper descending grades are needed to meet other constraints, possibly with restrictions on operational line speed to ensure controlled braking action on the grade.

[4.2.2.1-015] The San José Airport ATN System design shall, as a goal, incorporate bank angles no more than 5 [TBR] degrees from the horizontal. [Tier 2]

[4.2.2.1-016] The San José Airport ATN System design shall accommodate the limits of minimum turning radius and maximum ascending/descending grade, as specified in other requirements, for guideway sections having simultaneous elevation and directional differentials (compound curvature). [Tier 2]

[4.2.2.1-017] The San José Airport ATN System design shall accommodate vehicle convergence at intersections consisting of no more than two merging guideways. [Tier 2]

[4.2.2.1-018] The San José Airport ATN System design shall provide the capability for vehicles to follow a selected route at intersections consisting of no more than two diverging guideways. [Tier 2]

[4.2.2.1-019] The San José Airport ATN System design shall provide for staging area(s) for empty vehicles to wait until needed for operational use. [Tier 2]
Note: Specific empty vehicle staging areas located near high-capacity stations may be needed to meet system performance requirements.

[4.2.2.1-020] The San José Airport ATN System design shall provide for vehicle access to maintenance, repair, and cleaning facilities from the system's primary guideway routes. [Tier 2]

[4.2.2.1-021] The San José Airport ATN System shall be designed so as to make the San José International Airport more appealing, attractive and desirable to use. [Tier 1]

[4.2.2.1-022] The San José Airport ATN System shall be designed to provide increased convenience for SJC Airport customers by reducing maximum walk distances to no greater than 500 feet.. [Tier 2]
Note: An ATN that could shorten the walk from Terminal A to the Rental Car Center (and thus help equalize this factor between the two Terminals) would be desirable.

[4.2.2.1-023] The San José Airport ATN System shall be designed to provide increased convenience for SJC Airport customers by reducing passengers' time from the beginning of their journey to the gate. [Tier 2]

[4.2.2.1-024] The San José Airport ATN System shall be designed to provide increased convenience for SJC Airport customers by improving the predictability of transit time for their airport travel experience. [Tier 2]
Note: Having on-demand transit service with predictable and minimal wait times, rather than random waits for scheduled service, is seen as a desirable characteristic to facilitate this improvement.

[4.2.2.1-025] The San José Airport ATN System shall be aesthetically designed to be compatible with the architectural and design themes of SJC Airport facilities and surrounding infrastructure elements. [Tier 2]

[4.2.2.1-026] The San José Airport ATN System design shall be technically compatible with the SJC Airport operating environment. [Tier 1]

[4.2.2.1-027] The San José Airport ATN System alignment shall respect all horizontal and vertical clearance requirements related to the SJC Airport runways and associated airport structures. [Tier 2]

[4.2.2.1-028] The San José Airport ATN System shall be operationally compatible with the Radio Frequency (RF) environment of the airport's control and communication facilities. [Tier 2]
Notes: 1) The intent of this requirement is that the ATN introduce no interference with communications or other functions related to airport operations. 2) Rules governing RF communications in and around the airport are specified by the Federal Communications Commission.

[4.2.2.1-029] All San José Airport ATN System transmission and receiving equipment shall be in compliance with the licensing requirements of CFR Title 47, Chapter I, Part 90, *Private Land Mobile Radio Services*, Subparts S and T, and the interference restrictions codified in Title 47, Chapter I, Part 15, *Radio Frequency Devices.* [Tier 3]

[4.2.2.1-030] The San José Airport ATN System shall be operationally robust relative to electromagnetic emissions generated in and around the airport and surrounding areas in which the ATN route is aligned. [Tier 2]
Note: Detailed guidance on the types of electromagnetic interference to be guarded against in the ATN system design are listed in the ASCE APM standard, Part 1, Section 2.1.8.

[4.2.2.1-031] The San José Airport ATN System shall not utilize laser equipment that operates externally to the vehicle. [Tier 2]

Note: use of lasers for guidance or related operational purposes is acceptable as long as the beam is fully shielded and contained within the vehicle body or other covering.

[4.2.2.1-032] The San José Airport ATN System design shall accommodate the locations and layout of existing civil and utility infrastructures, with the goal of imposing minimal or no need for reconfiguration/relocation of existing structures and utilities. [Tier 2]

[4.2.2.1-033] The San José Airport ATN System design shall accommodate environmental and safety factors associated with SJC Airport operations. [Tier 1]

[4.2.2.1-034] The San José Airport ATN System design shall provide for avoidance of jet blast effects in the vicinity of the airport runway ends. [Tier 2]

[4.2.2.1-035] The San José Airport ATN System design shall provide for avoidance of jet fume accumulation in the system vehicles. [Tier 2]

[4.2.2.1-036] The San José Airport ATN System design shall be designed in close coordination with the local utility infrastructure for electrical power distribution, water supply and waste water removal. [Tier 1]
Note: It is especially important that the design of the ATN be developed in conjunction with the local electrical utility provider.

4.2.2.2 ATN System Route Selection Constraints

[4.2.2.2-001] The San José Airport ATN System infrastructure shall align within existing or acquirable rights-of-way along airport thoroughfares and surrounding metropolitan streets and properties. [Tier 1]
Note: The ATN system infrastructure includes the guideways, stations and support facilities, e.g., vehicle storage areas and a maintenance and repair facility.

[4.2.2.2-002] The San José Airport ATN System route alignment shall provide exclusive rights-of-way for the system's vehicles. [Tier 2]
Note: This means that the ATN vehicles will not share right-of-way with, or impose constraints on, the operation of other traffic modes, including pedestrian traffic.

[4.2.2.2-010] The San José Airport ATN System route alignment shall be designed for maximum passenger convenience. [Tier 1]
Note: Stops must be located as close as possible to passenger destinations such as stops/stations for other public transit systems and airline baggage check-in counters.

[4.2.2.2-003] The San José Airport ATN System routes shall conform to right-of-way restrictions and clearance requirements relative to the SJC Airport infrastructure and the built environment in the surrounding properties. [Tier 1]

[4.2.2.2-004] The San José Airport ATN System route alignment shall accommodate required buffer zones around the end(s) of the airport runways. [Tier 2]
Note: This means that the ATN vehicles will not share right-of-way with, or impose constraints on, the operation of other traffic modes, including pedestrian traffic.

[4.2.2.2-005] The San José Airport ATN System route alignment shall accommodate required vertical encroachment limitations around the end(s) of the airport runways. [Tier 2]

[4.2.2.2-006] The San José Airport ATN System route alignment should be selected for maximum compatibility with the built infrastructure on and adjacent to SJC Airport property. [Tier 2]

[4.2.2.2-007] The San José Airport ATN System route alignment should be selected for maximum compatibility with the installed utility infrastructure on and adjacent to SJC Airport property. [Tier 2]

[4.2.2.2-008] The selected routes for the San José Airport ATN System shall, as a goal, accommodate the physical constraints (e.g., curvature, grade, horizontal and vertical clearances) of current, generally available ATN technology. [Tier 1]
Notes: 1) Some degree of enhancement to the current ATN design capabilities, if necessary to meet other physical layout constraints, may be considered within reasonable levels of added complexity, cost and risk. 2) Recommended clearance restrictions are specified in section 4.2.2.1.

[4.2.2.2-009] The San José Airport ATN System routes and station locations shall be selected such that current Airport revenue streams from Airport parking facilities, rental car services, and other airport services are not negatively impacted. [Tier 1]

4.2.2.3 San José Airport ATN System Design Standards

[4.2.2.3-001] The San José Airport ATN System shall be designed and implemented in compliance with applicable design criteria, standards and practices for automated guideway transit systems. [Tier 1]

[4.2.2.3-002] The design and operation of the San José Airport ATN System shall be in general compliance with the American Society of Civil Engineers (ASCE) Automated People Mover (APM) Standards, Parts 1, 2, 3 and 4 [b., d., e., f.] [Tier 2]
Notes: 1) While the ASCE APM standards are specifically targeted to APM systems which generally use larger vehicles and potentially different operational modes as compared with ATN technology, a large proportion of the general principles and requirements specified in the APM standards are applicable to both APMs and ATN-based systems. 2) The APM standards have been generally recognized as the most relevant and comprehensive compendium of ATN design guidance currently in existence. It is noteworthy that the applicable regulations of the California Public Utilities Commission, which has authority over design and operation of public transit systems in the state, have significant parallel with the ASCE APM standards. 3) The APM standards recognize the notion of "communications-based train control" as a viable technological foundation for fixed-guideway systems, and provide reference to external standards for vehicle operation and hazard protection under that scenario. Parallels to this concept may be appropriate for consideration relative to the San José Airport ATN design.

[4.2.2.3-003] The design and operational procedures of the San José Airport ATN System shall take into account the guidance provided in, at a minimum, the following standards: [Tier 2]

a. ANSI 117.1-2003, Guidelines for Accessible and Usable Buildings and Facilities
b. ASME B15.1-2000, Safety Standard for Mechanical Power Transmission

c. MIL-E-6051D, Electromagnetic Compatibility Requirements, Systems
d. NFPA 556, Guide on Methods for Evaluating Fire Hazards to Occupants of Passenger Road Vehicles
e. Society of Automotive Engineers (SAE) Technical Standards
f. Institute of Electrical and Electronics Engineers (IEEE) 493-2007, Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems
g. American Association of State Highway & Transportation Officials (AASHTO) Technical Standards
h. American Society of Civil Engineers: Construction and related standards as listed on p. iii of each of the four Parts of the ASCE Automated People Mover Standards referenced above
i. American Association of State Highway & Transportation Officials (AASHTO) LRFD Bridge Design Specifications, 4th edition, 2007 (guidance for seismic force computations for elevated structures)
j. Institute of Electrical and Electronics Engineers (IEEE) P1474.1-2004, IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements
k. International Standards Organization, ISO 2631, Mechanical Vibration and Shock -- Evaluation of Human Exposure to Whole-Body Vibration, Parts 1 through 5

[4.2.2.3-004] The San José Airport ATN System design shall be a directly traceable derivation from a proven technology base. [Tier 1]
Notes: 1) The intent is that the system technology comprising the Airport ATN system, including all major subsystems, has successfully been demonstrated in actual public service operations or comparable full-scale long-term test environments prior to implementation for public transit operations in San José. 2) Given that the City of San José requires that the ATN enter service as a fully operational public transit system, the Airport ATN System Project should not be considered as a technology development platform or be expected to evolve through a pilot/demonstration trial phase.

> [4.2.2.3-005] The design of all primary subsystems of the San José Airport ATN System, including the vehicle structure, propulsion and braking subsystems, guidance, control, switching and communications functions, power storage/distribution systems, automated station functions, and operational management capabilities shall be based on proven capabilities. [Tier 2]
> *Note: The intent is for these subsystems to have been successfully demonstrated in actual public service operations or comparable full-scale long-term test environments prior to implementation in San José.*

4.2.2.3.1 Design for Longevity

[4.2.2.3-006] The San José Airport ATN System shall be designed to subsystem-specific design life targets. [Tier 1]
Note: The intent is to maximize the overall life cycle cost effectiveness of the system while allowing for orderly upgrade of particular subsystems to reflect natural technology evolution.

> [4.2.2.3-007] The San José Airport ATN System guideway and station infrastructure shall be designed for a 50 year operational life. [Tier 2]

[4.2.2.3-008] The San José Airport ATN System vehicle/guideway interface (captive bogey or running surface) and associated guideway switching mechanisms (if applicable) shall be designed for a 30 year operational life. [Tier 2]

[4.2.2.3-009] The San José Airport ATN System support facility buildings and internal structural elements (such as associated guideway tracks for the Maintenance and Repair Facility) shall be designed for a 50 year operational life. [Tier 2]

[4.2.2.3-010] The San José Airport ATN System station and support facility equipment (such as automatic doors, hydraulic lifts, pneumatic machinery, etc.) shall be specified for a minimum of a 15 [TBR] year operational life. [Tier 2]

[4.2.2.3-011] The San José Airport ATN System power distribution subsystem elements shall be designed for a 30 [TBR] year operational life. [Tier 2]
Note: Included in this category are battery charging equipments, power distribution substations, cabling, etc. as applicable for the given system power provisioning concept.

[4.2.2.3-012] The San José Airport ATN System vehicle structures shall be designed for a 20 [TBR] year operational life. [Tier 2]

[4.2.2.3-013] The San José Airport ATN System vehicle propulsion, suspension and braking subsystems elements shall be designed for a 10 [TBR] year operational life. [Tier 2]

[4.2.2.3-014] The San José Airport ATN System communication subsystem elements shall be designed for a 10 [TBR] year operational life. [Tier 2]

[4.2.2.3-015] The San José Airport ATN System computing and control subsystem processing elements shall be designed for a 5 [TBR] year operational life. [Tier 2]

4.2.2.3.2 Design for Safety

[4.2.2.3-016] The San José Airport ATN System shall be designed in accordance with the safety principles described in the ASCE APM Standards, Part 1, Section 3.2. [Tier 1]
Note: Please refer to section 4.2.3.6 of this document for the ATN system implementation requirements related to compliance with Safety principles and standards.

[4.2.2.3-017] The San José Airport ATN System and its subsystems and components shall be designed/selected in accordance with specifications derived from a comprehensive safety engineering analysis. [Tier 2]
Note: The primary goal of the Airport ATN System safety engineering program is to ensure the highest possible level of safety to passengers and the public from unintentional conditions or events affecting the ATN system and service.

[4.2.2.3-018] The San José Airport ATN System shall be designed such that no passenger injury can occur from collisions with external vehicles operating normally on public roadways or as part of other public transit systems. [Tier 2]

[4.2.2.3-019] The San José Airport ATN System shall be designed such that no public injury can occur from normal operation of the ATN. [Tier 2]

[4.2.2.3-020] The San José Airport ATN System shall be designed such that system safety during normal automated operations cannot be compromised by incorrect actions taken on the part of human operators. [Tier 2]

4.2.2.3.3 Design for Service Availability

[4.2.2.3-021] The San José Airport ATN System shall be designed to achieve the service availability targets specified in section 4.2.3.7 of this document. [Tier 1]
Note: Achieving the desired level of service availability is related to a number of factors, including reliability of system components to reduce the need for maintenance, efficient repair/replacement of system elements when necessary, and robustness of system operational procedures to work around anomalous conditions.

[4.2.2.3-022] The design of the San José Airport ATN System shall incorporate subsystem/components for which reliability can be projected based on known pedigree, historical data or objective analysis. [Tier 2]

[4.2.2.3-023] The San José Airport ATN System shall incorporate modular subsystem designs with emphasis on simplified, well-defined inter-subsystem interfaces. [Tier 2]
Note: This design principle facilitates orderly product evolution, simplified maintenance and repair, and evolving maturity of industry interface standards.

[4.2.2.3-024] The design of the San José Airport ATN System shall promote interchangeability of individual components and subsystems at the highest level practical. [Tier 2]
Note: The intent is to minimize maintenance and supply chain complexity.

[4.2.2.3-025] The design of the San José Airport ATN System shall facilitate easy access to maintenance/inspection points and wearing components. [Tier 2]
Note: The intent is to simplify maintenance processes and minimize maintenance-related downtime.

4.2.2.3.4 Design for the San José Operational Environment

[4.2.2.3-026] The San José Airport ATN System shall be designed to operate in the environmental conditions typical to the San José area. [Tier 1]

[4.2.2.3-027] The San José Airport ATN System shall be designed to operate in the San José ambient climatologic environment. [Tier 2]
Note: Details of the climate conditions to be accommodated in the ATN design are specified in the ASCE APM Standards, Part 1, Section 2.1.

[4.2.2.3-028] The San José Airport ATN System shall be designed to operate without introduction of undue noise, vibration or electromagnetic radiation to the San José environment. [Tier 2]
Note: Acceptable levels of induced environmental factors are described in the ASCE APM Standards, Part 1, Section 2.2.

4.2.2.3.5 Design for Sustainability

[4.2.2.3-029] The San José Airport ATN System shall be designed in accordance with principles of sustainable development and operations. [Tier 1]
Note: A useful reference for guidance in design of the Airport ATN is "Design Through the 12 Principles of Green Engineering," by Paul T. Anastas and Julie B. Zimmerman, in Environmental Science and Technology, March 1, 2003.[w]

> [4.2.2.3-030] The San José Airport ATN System shall be designed for sustainable development. [Tier 2]
>
> > [4.2.2.3-031] The San José Airport ATN System shall be designed with the goal of maximizing use of reusable/recyclable materials. [Tier 3]
> >
> > [4.2.2.3-032] The San José Airport ATN System shall be designed with the goal of minimizing waste of materials and energy during construction. [Tier 3]
> >
> > [4.2.2.2-033] The San José Airport ATN System shall be designed with the goal of making maximum use of construction materials with minimum "embodied energy" (energy expended for production, operation, decommissioning/destruction and disposal). [Tier 3]
> >
> > [4.2.2.2-034] The San José Airport ATN System shall be designed with the goal of minimizing use of hazardous substances. [Tier 3]
>
> [4.2.2.3-035] The San José Airport ATN System shall be designed for sustainable operations. [Tier 2]
>
> > [4.2.2.3-036] The San José Airport ATN System shall be designed with the goal of making maximum use of supplies and expendables with minimum "embodied energy" (energy expended for production, operation, decommissioning/destruction and disposal). [Tier 3]
> >
> > [4.2.2.3-037] The San José Airport ATN System shall be designed for the capability to optimize energy consumption amounts and profiles relative to service demand levels and ambient conditions. [Tier 3]
> >
> > [4.2.2.3-038] The San José Airport ATN System shall be designed so as to minimize the frequency and extent of parts replacement. [Tier 3]
> >
> > [4.2.2.3-039] The San José Airport ATN System shall be designed so as to minimize noise from vehicle and facility operations. [Tier 3]
> >
> > [4.2.2.3-040] The San José Airport ATN System shall be designed so as to minimize odorous emissions from facility operations. [Tier 3]
> >
> > [4.2.2.3-041] The San José Airport ATN System shall be designed with processes and procedures for maintaining cleanliness of vehicles, stations and support facilities. [Tier 3]

[4.2.2.3-042] The San José Airport ATN System shall be designed with processes and procedures for water recycling. [Tier 3]

[4.2.2.3-043] The San José Airport ATN System shall be designed with processes and procedures for compliance with air quality standards. [Tier 3]

4.2.2.3.6 Design for Security

[4.2.2.3-044] The design of the San José Airport ATN System shall be in general accordance with the Security requirements described in the ASCE APM Standards, Part 4, Section 12, "Security." [Tier 1]

[4.2.2.3-045] The San JoséAirport ATN System and its subsystems and components shall be designed/selected in accordance with specifications derived from a comprehensive security engineering analysis. [Tier 2]
Note: The primary goal of the security program is to ensure the highest possible level of protection of passengers and the public from intentional acts against the Airport ATN System and the services it provides.

4.2.2.4 Regulatory Codes and Standards

[4.2.2.4-001] The San José Airport ATN System shall be designed and implemented in compliance with applicable local, state and national codes and regulations for construction and operation of public transit systems. [Tier 1]

[4.2.2.4-002] The design and operation of the San José Airport ATN System shall be in general compliance with California Public Utilities Commission (CPUC) General Orders 143-B (Safety Rules and Regulations Governing Light Rail Transit), 164-D (Rules and Regulations Governing State Safety Oversight of Rail Fixed Guideway Systems), 127 (Regulations Governing the Construction, Reconstruction, Maintenance and Operation of Automatic Train Control Systems), and 26-D (Clearances). [Tier 2]
Notes: 1) While these CPUC General Orders pertain generically to light and heavy rail systems, rather than Automated Transit Network technology per se, there is a significant degree of correspondence between the rules and regulations contained therein and the operational safety constraints commonly recognized in current ATN designs. 2) It is presumed that the CPUC will work with local and regional transit authorities to refine and adapt their rail system regulations for specific applicability to ATN implementations in California. In the meantime, the General Orders in their current form provide useful guidance for design and operation of ATN systems with respect to safety, emergency management and related factors.

[4.2.2.4-003] The San José Airport ATN System shall be designed and implemented in compliance with the California Building Code (2007). [Tier 2]
Note: This is the locally adopted code for San José, based on the 2006 edition of the International Building Code (IBC).

[4.2.2.4-009] The San José Airport ATN System shall be designed in compliance with Building Code provisions related to California Seismic Zone 4. [Tier 3]

[4.2.2.4-010] The San José Airport ATN System design shall incorporate safety margins based on International Building Code Occupancy Categories and Importance Factors. [Tier 3]
Note: Different Occupancy Category and Importance Factor values may be appropriate for the ATN's stations, elevated guideways, and support facilities.

[4.2.2.4-004] The San José Airport ATN System shall be designed and implemented in compliance with the California Electrical Code. [Tier 2]
Note: The 2007 edition of the California Electrical Code, based on the 2005 version of the National Electrical Code, is the current locally adopted code for San José; however, Part 3 of Title 24 of the California Code of Regulations provides California-specific additions, changes and deletions relative to the 2008 edition of the National Electrical Code, which may represent a more current regulation.

[4.2.2.4-005] The San José Airport ATN System shall be designed and implemented in compliance with the California Mechanical Code (2007) and California Plumbing Code (2007). [Tier 2]
Note: These are the locally adopted codes for San José, based on the 2006 editions of the Unified Mechanical Code and Unified Plumbing Codes respectively.

[4.2.2.4-006] The San José Airport ATN System shall be designed in compliance with NFPA 130, Fire Safety Design for Rapid Transit Systems, and NFPA 72, National Fire Alarm Code. [Tier 2]

[4.2.2.4-007] San José Airport ATN System stations shall comply with the evacuation time limits specified in NFPA 130 for peak station occupant load from the most remote point of the platform level to safety egress points of the ground level. [Tier 3]
Note: The NFPA requirements related to underground stations are not expected to be applicable to the San José Airport ATN.

[4.2.2.4-008] The San José Airport ATN System shall be designed in compliance with provisions of the Americans with Disabilities Act (ADA) related to the design and operation of public transit systems. [Tier 2]
Note: Various aspects of the Airport ATN will be subject to ADA regulations, including station access and evacuation, vehicle accessibility and accommodations for wheelchairs, assistance for the sight and hearing-impaired, vehicle evacuation and emergency operations.

4.2.2.5 Guideway Design

[4.2.2.5-001] The San José Airport ATN System guideway design shall be designed to applicable structural integrity, safety, and reliability standards. [Tier 1]

[4.2.2.5-002] The guideways of the San José Airport ATN System shall be designed and constructed in general accordance with the ACSE APM Standards, Part 3, Section 11. [Tier 2]

[4.2.2.5-003] The San José Airport ATN System guideways shall be used exclusively by the system's vehicles. [Tier 3]

Note: This implies that no other concurrent uses of the guideway occur during ATN system operations.

[4.2.2.5-004] The San José Airport ATN System guideway design shall provide for installation and operation of the ATN such that other rights-of-way are not encroached upon. [Tier 3]

[4.2.2.5-005] The San José Airport ATN System guideway design shall accommodate installation and operation of the ATN at elevated, at-grade, or below-grade levels. [Tier 2]
Note: The intent is that the system be capable of operationally seamless transition between guideway sections at various grade levels, while maintaining "nominal operations" (ability to operate at design line speed and up to specified acceleration/deceleration limits).

[4.2.2.5-006] Elevated guideways of the San José Airport ATN System shall be designed and constructed for IBC Occupancy Category III [TBR] and Importance Factor 1.25 [TBR]. [Tier 3]

[4.2.2.5-007] The San José Airport ATN System guideway design shall provide accessibility for maintenance of subsystem components, as applicable (e.g., switching mechanisms, power distribution components, lighting, wayside sensors). [Tier 2]

[4.2.2.5-008] The San José Airport ATN System guideway shall be designed for structural integrity under maximum mechanical and environmental load conditions, per the provisions of the ACSE APM Standards, Part 3, Section 11.9. [Tier 2]

[4.2.2.5-009] The San José Airport ATN System guideway design shall be capable of accommodating a minimum nominal span of 19 [TBR] meters at full system and environmental loading. [Tier 3]
Notes: 1) "Full system and environmental loading" means that the span is able to accommodate stationary vehicles of maximum rated gross vehicle weight, nose-to-tail across the entire length of the span (or vehicles of maximum rated gross vehicle weight in operation at design line speed and minimum specified headway), during maximum wind speed conditions [TBD]. 2) This requirement does not preclude the use of shorter spans as needed at terminal approaches or in areas with special routing constraints.

[4.2.2.5-010] The San José Airport ATN System guideway design shall accommodate maximum spans of up to 26 [TBR] meters without intermediate support(s), at full system and environmental loading. [Tier 3]
Note: "Full system and environmental loading" means that the span is able to accommodate stationary vehicles of maximum rated gross vehicle weight, nose-to-tail across the entire length of the span (or vehicles of maximum rated gross vehicle weight in operation at design line speed and minimum specified headway), during maximum wind speed conditions [TBD].

[4.2.2.5-011] The San José Airport ATN System guideway design shall be capable of withstanding vertical load forces comprised of the dead load, live load, and walkway load as defined in the ASCE APM Standards, Part 3, Section 1.1.9.1. [Tier 3]
Note: Snow and ice loads are not anticipated to be a significant design factor for a San José installation.

[4.2.2.5-012] The San José Airport ATN System guideway design shall be capable of withstanding horizontal load forces comprised of longitudinal force (from vehicle acceleration/deceleration), steering force, centrifugal force, and wind loads as defined in the ASCE APM Standards, Part 3, Section 1.1.9.1. [Tier 3]

[4.2.2.5-013] The San José Airport ATN System guideway design shall be capable of withstanding additional forces as defined in the APM Standards, Part 3, Section 1.1.9.1. [Tier 3]
Notes: 1) These include dynamic vibratory and impact forces, thermal expansion/contraction forces, and seismic forces. 2) In addition to local California building codes for Zone 4construction of elevated structures, Section 3.10 of the AASHTO LRFD Bridge Design Specifications, 4th edition, 2007 is suggested as a resource for computation of seismic forces on an elevated guideway.

[4.2.2.5-014] The San José Airport ATN System guideway design shall accommodate the effects of structural deformation and misalignment due to ground settlement. [Tier 3]

[4.2.2.5-015] The San José Airport ATN System guideway design shall provide protection from collision with other vehicular traffic. [Tier 3]
Note: This may involve structural traffic barriers or design of the guideway per the provisions of Section 3.6.5 of the AASHTO LRFD Bridge Design Specifications, 4th edition, 2007.

[4.2.2.5-016] The San José Airport ATN System guideway design shall allow maximum deflection along a single span of 1/800 [TBR] of the span length. [Tier 3]
Note: This complies with AASHTO standards.

[4.2.2.5-017] The San José Airport ATN System guideway design shall be capable of withstanding longitudinal loads 50% [TBR] greater than the combined force of fully loaded vehicles, operating at design line speed and minimum headway, and simultaneously executing an emergency stop. [Tier 3]

[4.2.2.5-018] The San José Airport ATN System guideway/support structure shall be designed and constructed to resist base shear forces as specified in the International Building Code [TBR]. [Tier 3]

[4.2.2.5-019] The San José Airport ATN System guideway design shall accommodate material fatigue stresses for the minimum design life.[p] [Tier 3]
Note: Guidance for accommodating fatigue stresses in the guideway design is provided in the AASHTO LRFD Bridge Design Specifications, 4th edition, 2007.

[4.2.2.5-020] The San José Airport ATN System guideway design shall accommodate accumulated thermal expansion stresses for the minimum design life.[p] [Tier 3]

[4.2.2.5-021] The San José Airport ATN System guideway design shall accommodate vibration damping as required to meet local environmental constraints.[p] [Tier 3]

[4.2.2.5-022] The San José Airport ATN System guideway design shall provide acoustical noise damping as required to meet local environmental constraints.[p] [Tier 3]

[4.2.2.5-023] The San José Airport ATN System guideway shall be designed to remain intact in the event a single guideway support is taken out (e.g., due to an external collision accident) during full system operational loading. [Tier 3]
Notes: 1) "Full system operational loading" means that the span is able to support and clear out vehicles of maximum rated gross vehicle weight in operation at design line speed and minimum specified headway without further structural failure. 2) For the purposes of this requirement it can be assumed that further loads from additional vehicles entering the failed section can be avoided via control system commanding.

[4.2.2.5-024] The San José Airport ATN System guideways shall be designed for aesthetic compatibility with the Airport and surrounding environment. [Tier 2]

[4.2.2.5-025] Elevated sections of the San José Airport ATN System guideway structure shall be less than 2 [TBR] meters in width.
Note: the purpose of this requirement is to minimize the "skyprint" of the guideway for visual/aesthetic reasons.

[4.2.2.5-026] Guideway supports for elevated sections of the San José Airport ATN System shall have a maximum cross-section of .75 [TBR] m^2.
Note: the purpose of this requirement is to minimize functional disruption and negative visual aesthetics at ground level.

[4.2.2.5-027] The San José Airport ATN System guideways shall be capable of simultaneously accommodating elevation and directional differentials (compound curvature) on a given guideway section, within the system's minimum turning radius and ascending/descending grade limits [Tier 2]
Note: Minimum turning radius and grade limits are specified in section 4.2.3.2; please refer specifically to requirements [4.2.3.2-010], [4.2.3.2 -011], and [4.2.3.2-012].

[4.2.2.5-028] The San José Airport ATN System guideways shall incorporate bank angles no greater than 5 [TBR] degrees. [Tier 2]

[4.2.2.5-029] The San José Airport ATN System guideway design shall incorporate protection from the elements.[p] [Tier 2]

[4.2.2.5-030] The San José Airport ATN System guideway design shall provide corrosion protection for exposed metal surfaces.[p] [Tier 3]

[4.2.2.5-031] The San José Airport ATN System guideways shall be designed to resist the effects of natural contaminants (sand, dust, leaves, bird droppings, etc.).[p] [Tier 3]

[4.2.2.5-032] The San José Airport ATN System guideways shall be designed to provide protection from animal habitation (birds, insects, rodents, etc.).[p] [Tier 3]

[4.2.2.5-033] The San José Airport ATN System guideways shall be designed for adequate drainage of rainwater.[p] [Tier 3]

Note: The design should comply with locally applicable codes and ensure that drainage does not fall onto pedestrian or road vehicle rights of way.

[4.2.2.5-034] The San José Airport ATN System guideway design shall provide protection from lightning strikes.[p] [Tier 3]

[4.2.2.5-035] Active or passive electronic or magnetic elements of the San José Airport ATN System guideway shall be resistant to electromagnetic interference.[p] [Tier 3]

[4.2.2.5-036] The San José Airport ATN System guideway design shall incorporate features for resistance to vandalism and sabotage.[p] [Tier 3]
Note: Such features could include use of curved or decoratively textured surfaces, strategically placed lighting and monitoring, etc.

[4.2.2.5-037] The San José Airport ATN System guideway design shall incorporate visual safety features. [Tier 2]

[4.2.2.5-038] The San José Airport ATN System guideway shall provide marker lighting visible from public rights of way. [Tier 3]

[4.2.2.5-039] The San José Airport ATN System guideway shall provide marker lighting visible from the interior of vehicles in operation. [Tier 3]

[4.2.2.5-040] The San José Airport ATN System guideways shall be designed and constructed such that the vehicle clearance requirements are met along the entire length of the alignment. [Tier 2]

[4.2.2.5-041] The San José Airport ATN System guideways shall be designed and constructed such that ride quality standards (shock, vibration, g-force limits, etc.) are met along the entire length of the alignment. [Tier 2]

[4.2.2.5-042] The San José Airport ATN System guideways shall be designed for smooth vehicle transition between guideway sections. [Tier 2]
Note: This implies the use of designs such as "spiral" transitions between straight and curved guideway sections.

4.2.2.6 Vehicle Design

[4.2.2.6-001] The San José Airport ATN System shall incorporate a vehicle design that achieves industry standard levels of performance, safety, accessibility, usability, reliability, and maintainability. [Tier 1]

[4.2.2.6-002] The San José Airport ATN System vehicles shall be designed and implemented in compliance with recognized design criteria for mechanical, electrical, fire safety, and human ergonomics factors. [Tier 2]

[4.2.2.6-003] The San José Airport ATN System vehicles shall be structurally designed in general accordance with the Vehicle Structural Design criteria described in the ASCE APM Standards, Part 2, Section 7.4. [Tier 3]

[4.2.2.6-004] The San José Airport ATN System vehicles shall be designed to withstand a longitudinal compression load of 2 times the weight of an empty vehicle without permanent deformation or damage. [Tier 4]
Note: This requirement is derived from CPUC regulations for public transit systems.

[4.2.2.6-005] The San José Airport ATN System shall be designed such that in the event of a vehicle collision, the vehicles remain in position on the guideway and do not upend or bounce off each other. [Tier 3]
Notes: 1) This requirement is derived from CPUC regulations for public transit systems. 2) A possible design solution for consideration with free-running guideway systems involves "anti-climbing" or interlock devices on the front and rear of the vehicle, such that the vehicles lock together in a collision and stay more or less intact and connected as a unit. Other solutions may also be viable. 3) This requirement is implicitly met in ATN systems that utilize a captive bogey design.

[4.2.2.6-006] The San José Airport ATN System vehicles shall be designed in general accordance with the Passenger Comfort guidelines described in the ASCE APM Standards, Part 2, Section 7.7. [Tier 3]

[4.2.2.6-007] The San José Airport ATN System vehicle propulsion and braking subsystems shall be designed in general accordance with the ASCE APM Standards, Part 2, Section 8. [Tier 3]

[4.2.2.6-008] The San José Airport ATN System vehicles shall be designed to include independent "service" and "emergency" braking subsystems. [Tier 4]

[4.2.2.6-009] San José Airport ATN System vehicles' service brakes shall be jerk-limited for passenger safety and comfort. [Tier 4]
Note: Per CPUC regulations, the emergency braking subsystem does not have to be jerk-limited.

[4.2.2.6-010] The San José Airport ATN System vehicles shall be designed to include mechanical braking capability that can achieve the required deceleration rates even if all vehicle electric power or pneumatic pressure is lost. [Tier 4]

[4.2.2.6-011] The San José Airport ATN System vehicles shall be designed to include an independent parking brake that can be manually actuated at the vehicle and capable of holding a fully loaded vehicle on any existing inclined section of the ATN guideways. [Tier 4]

[4.2.2.6-012] The San José Airport ATN System vehicle electrical equipment shall be designed in general accordance with the ASCE APM Standards, Part 2, Section 9. [Tier 3]

[4.2.2.6-013] The San José Airport ATN System vehicles shall incorporate interior and emergency lighting designed in general accordance with the ASCE APM Standards, Part 2, Section 7.11. [Tier 3]

[4.2.2.6-014] The San José Airport ATN System vehicle doors and access/egress provisions shall be designed in general accordance with the ASCE APM Standards, Part 2, Section 7.8. [Tier 3]

[4.2.2.6-015] The San José Airport ATN System vehicle windows and window operation shall be designed in general accordance with the ASCE APM Standards, Part 2, Section 7.9. [Tier 3]

[4.2.2.6-016] The San José Airport ATN System vehicles shall incorporate a fire protection design compliant with the requirements of Chapter 8 of NFPA 130-2007, Standard for Fixed Guideway Transit and Passenger Rail Systems. [Tier 3]
Notes: 1) Compliant fire protection design includes materials selected for vehicle construction, thermal/overcurrent protection for active components such as drive motors, electrical system sensors and breakers, and smoke detection equipment. 2) Per NFPA 130 requirements, APM vehicles with capacity of fewer than 16 passengers must be equipped with a minimum of one Class ABC fire extinguisher. This may translate to a similar requirement for ATN vehicles [TBD].

[4.2.2.6-017] The San José Airport ATN System vehicles shall be captive to the guideway. [p] [Tier 2]
Note: This means that, except via introduction of unrealistically destructive external forces, the vehicles cannot be separated from the guideway during either normal or anomalous system operations.

[4.2.2.6-018] The San José Airport ATN System vehicle design shall meet the accessibility and usability requirements of the Americans with Disabilities Act, Part 37 and 38, for public transit systems. [Tier 2]
Notes: 1) The essential intent of this requirement is that the ATN vehicles be readily wheelchair-accessible, are provisioned with compliant wheelchair restraints, and provide other protections as afforded to non-disabled passengers. 2) From the perspective of Federal law, it is acceptable that not all ATN system vehicles be provisioned per ADA requirements, as long as a comparable level of service is provided to disabled passengers. This may be accomplished by reserving a small number of ADA-compliant vehicles at each station, having them on call from a nearby staging location, a complementary paratransit service, or other means.

[4.2.2.6-019] The San José Airport ATN System vehicle doors and windows shall be operable either manually or via power assist, actuated by a wheelchair-accessible control. [Tier 3]

[4.2.2.6-020] The San José Airport ATN System vehicles shall provide Braille symbol labels for all passenger-operable controls. [Tier 3]

[4.2.2.6-021] The San José Airport ATN System vehicles shall provide audio aids, such as electronic voice announcements, indicating information including but not necessarily limited to vehicle boarding status, destination, and arrival station. [Tier 3]
Note: The intent of this requirement is to facilitate use of the system by the sight-impaired.

[4.2.2.6-022] The San José Airport ATN System vehicles shall provide visual information displays in the stations and vehicles indicating information including, but not necessarily limited to, vehicle boarding status, destination, and arrival station. [Tier 3]
Note: The intent of this requirement is to facilitate use of the system by the hearing-impaired.

[4.2.2.6-023] The San José Airport ATN System vehicles shall provide seating capacity for a minimum of 2 [TBR] and maximum of 6 [TBR] adults. [Tier 2]
Note: Vehicles that provide for a maximum of four seated adults are acceptable; vehicles large enough to accommodate more than 6 seated adults would be considered beyond the desired size of the standard vehicles for the San José ATN.

[4.2.2.6-024] The San José Airport ATN System vehicles shall provide capacity for additional passenger belongings in addition to the seating accommodations. [Tier 2]

[4.2.2.6-035] The San José Airport ATN System shall provide vehicles that accommodate wheelchairs and provide for restraints to ensure stability of the wheelchairs during vehicle operation. [Tier 3]
Notes: 1) The design choice of whether to equip "some" vs. "all" of the ATN's vehicles with wheelchair provisions is TBD. 2) The system is not required by law to outfit all vehicles for wheelchair accommodation, as long as transit service to the disabled is not materially impacted.

[4.2.2.6-025] The San José Airport ATN System vehicles shall accommodate luggage in addition to the full complement of seated adults. [Tier 3]
Note: Limits on the physical size and weight of passengers' luggage that can be accommodated are TBD.

[4.2.2.6-026] The San José Airport ATN System vehicles shall accommodate a full-size convertible child stroller in addition to the full complement of seated adults, and provide for restraints to ensure stability of the stroller during vehicle operation. [Tier 3]

[4.2.2.6-027] The San José Airport ATN System vehicles shall accommodate at least one full-size adult bicycles in addition to the full complement of seated adults. [Tier 3]

[4.2.2.6-028] The San José Airport ATN System vehicles shall accommodate service animals, with appropriate restraint provisions. [Tier 3]

[4.2.2.6-029] The San José Airport ATN System vehicle design should consider adaptability to accommodate cargo rather than passengers. [Tier 2]
Note: This is a capability for future consideration, not part of the initial baseline but should be considered in the overall system design.

[4.2.2.6-030] The San José Airport ATN System vehicles shall provide, at a minimum, exterior view out both sides and out of the front of the vehicle [TBR]. [Tier 2]
Note: Recommendations for this feature can be found in external design guidance references, but may be open to question based on recent passenger experience in current system trials and should be taken under further consideration.

[4.2.2.6-031] The San José Airport ATN System vehicles should be designed so as to discourage standing passengers. [Tier 2 Objective]
Note: Practical methods for ensuring that all passengers aboard a vehicle are properly seated and (if appropriate) restrained are TBD.

[4.2.2.6-032] The San José Airport ATN System vehicles shall be designed to not introduce sources of electromagnetic interference to other systems or operations. [Tier 2]
Note: This constraint is intended to include, at a minimum, radio frequency, visual-light, and microwave frequencies.

[4.2.2.6-033] The San José Airport ATN System vehicles shall be designed for aesthetic and cultural value, with an eye toward projecting an image of "the future of travel." [Tier 2]

[4.2.2.6-034] The San José Airport ATN System vehicles shall incorporate creative branding and positive identity, reflecting the look and feel of the experience. [Tier 3]

4.2.2.7 Station Design

[4.2.2.7-001] The San José Airport ATN System shall incorporate station design(s) that support system performance requirements and are compliant with applicable structural integrity, safety and usability standards. [Tier 1]
Note: While commonality of ATN station design (for purposes of economies of scale, control system simplicity, and aesthetic conformity) is a reasonable objective, it is recognized that widely varying capacity requirements and space constraints may call for unique station layouts at specific Airport ATN locations.

[4.2.2.7-002] The San José Airport ATN System routing and station design shall allow for station operations "off-line" to the main guideway. [Tier 2]
Notes: 1) "Off-line" stations support vehicle loading and unloading operations on a separate section of guideway, analogous to a rail system siding. 2) While most ATN stations are expected to be off-line, the use of on-line stations is not precluded in special cases of very-low volume "spur" routes that could be considered for incorporation into the ATN.

[4.2.2.7-003] The San José Airport ATN System station design concept shall allow for multiple station configurations, physical designs and operational modes. [Tier 2]
Note: The intent is a flexible common architecture that facilitates matching of station design parameters to anticipated capacity needs and accommodation of particular physical constraints at specific station locations.

[4.2.2.7-004] The San José Airport ATN System stations shall be sized and designed to accommodate the demand levels, vehicle/passenger traffic patterns, and space constraints applicable to each station location. [Tier 3]
Note: The projected demand levels for stations located on the current Airport ATN reference route are provided in section 4.2.1.3.

[4.2.2.7-005] The San José Airport ATN System stations shall be sized and designed to accommodate projected passenger demand, such that average passenger wait time for an available vehicle is no greater than 1 [TBR] minute (for peak hour load

conditions) and no greater than 3 [TBR] minutes (for instantaneous peak load conditions).
Note: Peak hour and instantaneous peak load conditions are defined for each origin station in section 4.2.1.3.

[4.2.2.7-006] The San José Airport ATN System stations and associated input queue/vehicle staging areas shall be sized and designed to accommodate projected vehicle traffic, such that the average proportion of vehicle "wave-offs" (where a vehicle cannot enter a station and is forced to make one or more extra go-around loops) is no greater than 1 [TBR] % (for peak hour load conditions) and no greater than 3 [TBR] % (for instantaneous peak load conditions).
Note: Peak hour and instantaneous peak load conditions are defined for each origin station in section 4.2.1.3.

[4.2.2.7-007] San José Airport ATN System station designs shall be in general compliance with the ASCE APM Standards, Part 3, Section 10, "Stations." [Tier 2]

[4.2.2.7-008] San José Airport ATN System station designs shall accommodate the maximum vehicle/station interface clearances defined in the ASCE APM Standards, Part 2, Section 7.3. [Tier 3]

[4.2.2.7-009] San José Airport ATN System station designs shall comply with the National Fire Protection Association 130 (2007) standard. [Tier 2]

[4.2.2.7-010] San José Airport ATN System station designs shall meet the accessibility requirements of the ADA Part 37 and 38 for public transit systems. [Tier 2]
Note: The essential intent of this requirement is that the ATN stations and facilities be readily wheelchair-accessible, usable by those with sensory disabilities, and offer other protections and safety/security features as afforded to non-disabled passengers.

[4.2.2.7-011] San José Airport ATN System station designs shall incorporate tactile aids, such as textured paths, between station entrances and the vehicle loading berths. [Tier 3]

[4.2.2.7-012] San José Airport ATN System station designs shall incorporate audio aids, such as electronic voice announcements, indicating information including, but not necessarily limited to, vehicle availability/arrival and boarding lineup assistance. [Tier 3]
Note: The intent of this requirement is to facilitate use of the system by the sight-impaired.

[4.2.2.7-013] San José Airport ATN System station designs shall incorporate visual information displays in the stations indicating information including, but not necessarily limited to, vehicle availability/arrival and boarding lineup assistance . [Tier 3]
Note: The intent of this requirement is to facilitate use of the system by the hearing-impaired.

[4.2.2.7-014] The San José Airport ATN System station design shall not preclude single-story integration into existing structures. [Tier 2]

Note: This does not imply a requirement that all of the ATN stations need be confined to a single level.

[4.2.2.7-015] San José Airport ATN System stations shall be designed such that loading and unloading passengers are not required to directly cross active or inactive guideway sections. [Tier 2]

[4.2.2.7-016] San José Airport ATN System stations shall be designed to provide weather protection for entering and waiting patrons. [Tier 2]

[4.2.2.7-017] San José Airport ATN System stations shall be designed and constructed to seismic safety standards as specified for Seismic Zone 4 in the International Building Code. [Tier 2]

> [4.2.2.7-018] San José Airport ATN System stations shall be designed and constructed for IBC Occupancy category III [TBR] and Importance Factor 1.25. [Tier 3]

[4.2.2.7-019] San José Airport ATN System stations shall be designed to provide safety and security for entering, waiting and exiting patrons. [Tier 2]

> [4.2.2.7-020] San José Airport ATN System stations shall be designed to provide open, well-lighted passenger congregation areas. [Tier 3]
> *Note: The intent is to minimize areas where undesirable elements could loiter undetected or "surprise" a patron of the system.*

> [4.2.2.7-021] San José Airport ATN System stations shall be designed to provide remote video surveillance of station operations. [Tier 3]
> *Note: The intent is to minimize areas that cannot be readily monitored by remotely-located operational personnel.*

> [4.2.2.7-022] San José Airport ATN System stations shall be designed to facilitate rapid response to passenger requests for security assistance. [Tier 3]
> *Note: The intent is to make the request and response processes as efficient as practical.*

> [4.2.2.7-023] San José Airport ATN System stations shall be designed with well-marked foot traffic paths and non-slip surfaces. [Tier 3]

[4.2.2.7-024] San José Airport ATN System stations shall be designed for aesthetic and cultural value, with an eye toward projecting an image of "the future of travel." [Tier 2]

> [4.2.2.7-025] San José Airport ATN System stations shall incorporate creative branding and positive identity, reflecting the look and feel of the experience. [Tier 3]

[4.2.2.7-026] San José Airport ATN System stations shall be designed with convenience and stress-reducing features to facilitate usability and appeal of the passenger experience. [Tier 2]

[4.2.2.7-027] San José Airport ATN System stations shall be located and oriented for easy access by transit riders, pedestrians, drop-off passengers, or (when practical) park-and-ride passengers. [Tier 3]

[4.2.2.7-028] San José Airport ATN System stations shall be designed for intuitive usability. [Tier 3]

[4.2.2.7-029] San José Airport ATN System station designs shall provide for wayfinding via techniques such as creative signage and use of "language free" iconic (rather than linguistic) symbols. [Tier 3]

[4.2.2.7-030] San José Airport ATN System stations shall be designed with the goal of net zero energy consumption for station operations. [Tier 2]
Note: Station-related energy use includes, as applicable, lighting, communications, security cameras, information/ticketing kiosks, automated mechanisms (e.g., sliding doors), elevator or escalator mechanisms, and the like.

4.2.2.8 Support Facilities Design

[4.2.2.8-001] The San José Airport ATN System shall incorporate designs for support facilities that are compliant with applicable structural integrity, safety, aesthetic and environmental standards. [Tier 1]

[4.2.2.8-002] The San José Airport ATN System design shall incorporate support facilities located for compatibility with built infrastructure and ready accessibility to vehicles and personnel. [Tier 2]

[4.2.2.8-003] San José Airport ATN System support facilities shall be designed and constructed to applicable zoning, building, and safety codes. [Tier 2]

[4.2.2.8-004] San José Airport ATN System support facilities shall be designed and constructed to seismic safety standards as specified for Seismic Zone 4 in the International Building Code. [Tier 3]

[4.2.2.8-005] San José Airport ATN System support facilities shall be designed and constructed for IBC Occupancy Category II [TBR] and Importance Factor 1.0. [Tier 4]

[4.2.2.8-006] San José Airport ATN System support buildings shall be designed to be compatible with San José aesthetic and environmental standards for light industrial facilities. [Tier 3]

[4.2.2.8-007] San José Airport ATN System support facility buildings shall be designed for adequate control of noise and emissions. [Tier 3]
Note: EPA and CEQA regulations govern handling of hazardous substances, painting processes and materials, etc.

[4.2.2.8-008] San José Airport ATN System support facility buildings shall be designed for appropriate drainage, power, and voice/data communications interfaces. [Tier 3]

[4.2.2.8-009] San José Airport ATN System support facility buildings shall be designed to provide waste water management/recycling per local environmental standards. [Tier 3]

[4.2.2.8-010] San José Airport ATN System support facilities shall be designed for workflow efficiency and accommodation of human factors design principles. [Tier 2]
Note: Please refer to section 4.2.2.10 for additional requirements related to ergonomics and human factors.

[4.2.2.8-011] The San José Airport ATN System maintenance facility shall be designed so that a Maintenance and Recovery Vehicle (essentially a "tug" or tow vehicle) can be manually operated to efficiently move unpowered vehicles to the repair station appropriate for the type of work to be done. [Tier 3]

[4.2.2.8-012] San José Airport ATN System support facilities shall be sized and structured to accommodate the necessary levels of vehicles, personnel, equipment and supplies to serve the intended support function. [Tier 2]

[4.2.2.8-013] The San José Airport ATN System maintenance facility shall be sized for the projected system capacity and associated vehicle count. [Tier 3]
Note: The system vehicle count, along with projected vehicle reliability and repair data, would be expected to factor into the maintenance facility sizing decision.

[4.2.2.8-014] San José Airport ATN System support facilities shall be sized to accommodate all vehicles not in operation or staged in active queues for deployment into service. [Tier 3]
Note: Support facilities to ensure this requirement is met could include the maintenance and repair facility and, potentially, additional off-line storage depot(s).

[4.2.2.8-015] San José Airport ATN System operational facilities shall be sized to accommodate efficient work areas for the full complement of operational staff. [Tier 3]

4.2.2.9 Guidance, Control and Communications Design

[4.2.2.9-001] The San José Airport ATN System shall be designed to provide "Automatic Vehicle Control" (AVC) capabilities in general accordance with the Automatic Train Control requirements defined in the ASCE APM Standards, Part 1, Section 5. [Tier 1]
Notes: 1) The term "Automatic Vehicle Control" is intended as an ATN-specific parallel to the APM-specific notion of trains, such that the applicable train control concepts embodied in the ASCE APM standards can be effectively tailored for Personal Rapid Transit/Automated Transit Network architectures. 2) In this document, the concept of Automatic Vehicle Control is logically organized into Automatic Vehicle Protection (AVP), Automatic Vehicle Operations (AVO), and Automatic Vehicle Supervision (AVS) functions, also as a parallel to the ASCE APM standards. 3) The APM standards recognize the emergence of "Communications-Based Train Control" as a viable approach to its Automated Train Protection and Automated Train Operations functions, and reference IEEE Standard 1474-2004 as requirements guidance for systems electing that approach (which is open for consideration for the San José Airport ATN System). 4) The functional and performance

requirements related to Automatic Vehicle Control for the San José ATN are presented in section 4.2.3.

> [4.2.2.9-002] The San José Airport ATN System's Automatic Vehicle Control capabilities shall be designed to operate in accordance with the operational safety principles described in the ASCE APM standards, Part 1, Section 3.2. [Tier 2]

> [4.2.2.9-003] The San José Airport ATN System's Automatic Vehicle Control design shall incorporate fail-safe design principles as described in the ACSE APM standards, Part 1, Section 3.3. [Tier 2]
> *Note: A variety of recommended design principles such as physical and logical redundancy and minimization of single points of failure, may be employed.*

> [4.2.2.9-004] The San José Airport ATN System's guidance and control function design shall incorporate capabilities for self-determination and communication of state-of-health information. [Tier 2]

> [4.2.2.9-005] The San José Airport ATN System vehicle guidance and control functions shall be designed to operate correctly and reliably in San José weather and environmental conditions. [Tier 2]

[4.2.2.9-006] The San José Airport ATN System's Automatic Vehicle Control function shall incorporate signal and data communications designs with adequate bandwidth, link margin, redundancy, robustness, and resistance to interference. [Tier 1]

> [4.2.2.9-007] The San José Airport ATN System's data and signal communication functions shall be designed with bandwidth and margin to operate correctly and reliably under full system operational loads and speeds. [Tier 2]

> [4.2.2.9-008] The San José Airport ATN System's data and signal communication functions shall be designed to operate correctly and reliably in San José weather and environmental conditions. [Tier 2]

> [4.2.2.9-009] The San José Airport ATN System communication function shall be designed to avoid introducing sources of electromagnetic interference to other systems or operations. [Tier 2]

> [4.2.2.9-010] The San José Airport ATN System communication function shall be designed for resistance to external sources of electromagnetic interference. [Tier 2]

[4.2.2.9-011] The San José Airport ATN System designs for audio and visual communications shall be in general accordance with the ASCE APM Standards, Part 1, Section 6. [Tier 1]

> [4.2.2.9-012] The San José Airport ATN System capabilities for audio communications shall be designed in compliance with the ASCE APM Standards, Part 1, Section 6.1. [Tier 2]
> *Note: The primary audio communication requirements include a) station public address, b) voice communications between central control operational staff and passengers, c) voice communications between central control facility and operations/maintenance staff, and d) emergency station and wayside call-in capability from equipment installed at regular intervals across the system.*

[4.2.2.9-013] The San José Airport ATN System capabilities for video monitoring shall be designed in compliance with the ASCE APM Standards, Part 1, Section 6.2. [Tier 2]
Note: The primary video surveillance requirements include a) video monitoring of unattended stations, b) video monitoring of vehicle interiors [TBR], c) recording of surveillance video for post-event analysis, and d) ability to selectively monitor video camera inputs at the central control facility.

4.2.2.10 Human Factors Design

[4.2.2.10-001] The San José Airport ATN System shall be designed in accordance with industry-recognized human factors standards so as to maximize safety, security, comfort, usability, operability, and maintainability of the ATN service. [Tier 1]
Note: The general goal is to ensure that the San José area public transit ridership community and the operators and maintainers of the San José Airport ATN can effectively use, operate and maintain the system under all operating conditions.

4.2.2.10.1 Passenger Usability

[4.2.2.10-002] The San José Airport ATN System shall be designed so that the San José area public transit ridership community, consisting of the general population as well as special populations (including, but not limited to expectant mothers, children traveling with parents or guardians, older users, riders that require physical and/or cognitive accommodations, individuals with limited or no ability to read in English, and those whose primary language is not English) can effectively use the service. [Tier 2]

[4.2.2.10-003] The San José Airport ATN System shall be designed in accordance with accepted human/machine interface standards to ensure that effective interaction with the system is supported for the population defined in requirement [4.2.2.10-002]. [Tier 3]
Notes: 1) Human/machine interface considerations are especially applicable to the designs of a) vehicle request and destination selection functions in stations and b) destination selection/change, emergency vehicle controls, and communication capabilities in vehicles. 2) The specific human/machine interface standards to be used as guidance for the ATN design are TBD.

[4.2.2.10-004] The San José Airport ATN System shall be designed to provide "language free" service usage instructions, wayfinding directions, signage and marking. [Tier 3]

4.2.2.10.2 Passenger Safety and Comfort

[4.2.2.10-005] Passenger-accessible portions of the San José Airport ATN System shall be designed in accordance with accepted human ergonomics standards for public transit systems. [Tier 2]
Notes: 1) Passenger ergonomics considerations are especially applicable to the designs of vehicle doors, interiors and seating areas; station access, loading/deboarding, and egress, and guideway emergency walkways. 2) The specific ergonomics standards to be used as guidance for the Airport ATN System design are TBD.

[4.2.2.10-006] The San José Airport ATN System shall provide passenger comfort features designed in accordance with the provisions of the ACSE APM Standards, Part 2, Section 7.7. [Tier 2]

[4.2.2.10-007] The San José Airport ATN System vehicles shall provide interior heating and cooling designed in accordance with the provisions of the ACSE APM Standards, Part 2, Section 7.7.1. [Tier 3]

[4.2.2.10-008] The San José Airport ATN System vehicles shall provide passenger cabin ventilation designed in accordance with the provisions of the ACSE APM Standards, Part 2, Section 7.7.2. [Tier 3]

[4.2.2.10-009] The San José Airport ATN System vehicles and guideway interface shall be designed for compliance with the Ride Quality parameters specified in the ACSE APM Standards, Part 2, Section 7.7.3. [Tier 3]

[4.2.2.10-010] The San José Airport ATN System vehicles shall be designed for compliance with the Noise Level and Vibration definitions specified in the ACSE APM Standards, Part 2, Sections 7.7.4 and 7.7.5. [Tier 3]

[4.2.2.10-011] The San José Airport ATN System vehicles shall provide passenger safety restraints designed in accordance with [TBD] standards. [Tier 2]
Note: This requirement is still undergoing analysis and definition.

4.2.2.10.3 System Administration, Operations and Maintenance

[4.2.2.10-012] The San José Airport ATN System shall be designed in accordance with human factors standards so as to maximize safe, secure and effective operability of the ATN service by system administrators, operators and support staff. [Tier 2]
Note: The specific health, safety and ergonomics standards to be used as guidance for ATN operations and maintenance activities are [TBD].

[4.2.2.10-013] The layout of work areas in San José Airport ATN System support facilities shall be designed for safety and work efficiency of administrative staff, system operators, and maintenance personnel. [Tier 3]

[4.2.2.10-014] Access to San José Airport ATN System support facilities shall be designed for safety and work efficiency of system operators, emergency responders and maintenance personnel. [Tier 3]

[4.2.2.10-015] Administrative facilities for the San José Airport ATN System shall be designed for ergonomic health, safety and work efficiency of system administrators and operators, per [TBD] workstation ergonomic standards. [Tier 3]

4.2.3 Airport ATN System Requirements

This section specifies the required functional capabilities of the San José Airport ATN System, and the quantitative measures of performance that the system is expected to achieve. It also contains separate subsections for the special topics of interoperability, flexibility, reliability/ availability, safety, and security.

4.2.3.1 Functional Requirements

[4.2.3.1-001] The San José Airport ATN System shall provide fully autonomous public transit operations under normal operating conditions, along with prescribed capabilities for manual override of the automated control function during off-nominal or emergency conditions. [Tier 1]

[4.2.3.1-002] The San José Airport ATN System shall provide Automatic Vehicle Control (AVC) capabilities comprised of the following primary constituent functional areas: [Tier 2]

- Automatic Vehicle Operation (AVO) functions, to manage the movement of vehicles throughout the ATN in accordance with dynamic traffic conditions and safety constraints
- Automatic Vehicle Protection (AVP) functions, to ensure safe, comfortable and collision-free vehicle operations and eliminate hazards to passengers, equipment and support personnel
- Automatic Vehicle Supervision (AVS) functions, to provide monitoring of the system and management of the interface between the automated control functions and the central control operators.

Notes: 1) The AVO, AVP and AVS functions specified in this document are logically analogous to the Automatic Train Control functions of Automatic Train Operations, Automatic Train Protection, and Automatic Train Supervision, detailed in the ASCE APM Standards, Part 1, Sections 5.1, 5.2 and 5.3, selectively tailored for ATN architectures and operational concepts. (As an example, the automatically programmed door control and automatic dwell time control typical in an APM system's Automatic Train Operation function would not be applicable to ATN systems.) 2) More generally, it is recognized that modern fixed-guideway transit systems may be developed using "communications-based train control" as an underlying precept for Automatic Vehicle Control; the requirements in this document are intended to allow for this conceptual design flexibility.

4.2.3.1.1 Automatic Vehicle Operation

[4.2.3.1-003] The San José Airport ATN System shall be capable of autonomous vehicle operations. [Tier 1]
Note: The intent is that, except in limited anomalous circumstances, the system operates without human operator intervention.

[4.2.3.1-004] The San José Airport ATN System's Automatic Vehicle Operation function shall manage the starting and stopping of vehicles such that acceleration, deceleration and jerk rates are maintained within prescribed passenger comfort limits. [Tier 2]

[4.2.3.1-005] The San José Airport ATN System's Automatic Vehicle Operation function shall actively maintain the speed of each vehicle within maximum allowed velocity limits. [Tier 2]
Note: Maximum allowed velocities may vary for different sections of the guideway and in response to varying operating conditions.

[4.2.3.1-006] The San José Airport ATN System shall provide the capability to automatically route vehicles between any two stations. [Tier 2]
Notes: 1) ATN systems typically use "point to point" routing, meaning that passengers experience no planned intermediate stops between their origin and their selected destination. 2) While the San José ATN system will likely seek the shortest-distance route between a passenger's origin and destination, it is not a requirement that the shortest path always be selected.

[4.2.3.1-007] The San José Airport ATN System shall be able to determine the origin and destination (from passenger selection) of each requested trip. [Tier 3]

[4.2.3.1-008] The San José Airport ATN System shall, prior to each newly-boarded vehicle's departure, perform an optimal routing calculation based on real time conditions on the network, including but not necessarily limited to outages and existing load conditions. [Tier 3]

[4.2.3.1-009] The San José Airport ATN System shall be capable of autonomously making re-routing calculations based on new real-time information regarding system outages and/or changing load conditions. [Tier 3]

[4.2.3.1-010] The San José Airport ATN System shall be capable of automated commanding of vehicles to follow their most-recently computed routes. [Tier 3]

[4.2.3.1-011] The San José Airport ATN System provide the capability to automatically manage the operation of all occupied and empty vehicles on the network. [Tier 2]
Notes: 1) Management of occupied vehicles primarily entails selecting an optimum path between origin and destination given current system loads, computing alternative routes in cases of delays or outages of part of the network, and controlling vehicle operations under nominal and anomalous conditions. 2) Management of empty vehicles primarily involves ensuring an adequate supply of vehicles at each station to meet anticipated demand while minimizing the circulation of empty vehicles on the network.

[4.2.3.1-012] The San José Airport ATN System's Automatic Vehicle Operation function shall provide active load balancing among routes on the network. [Tier 3]

[4.2.3.1-013] The San José Airport ATN System's Automatic Vehicle Operation function shall provide fully automated commanding of each active vehicle's speed, acceleration, deceleration, steering and switching. [Tier 3]
Note: Actively managed steering may not be necessary for ATN systems with a captive-bogey design.

[4.2.3.1-014] The San José Airport ATN System's Automatic Vehicle Operation function shall be capable of autonomously slowing vehicles through particular turns so as to maintain acceptable [TBD] side g-forces for safety and passenger comfort.
Note: The amount of slowing needed may be reduced if the guideway is appropriately banked.

[4.2.3.1-015] The San José Airport ATN System's Automatic Vehicle Operation function shall automatically distribute empty vehicles in accordance with expected usage patterns and/or dynamic demand levels at each station location. [Tier 3]

4.2.3.1.2 Automatic Vehicle Protection

[4.2.3.1-016] The San José Airport ATN System shall provide Automatic Vehicle Protection functionality to ensure safe operation of each individual vehicle in the system and to proactively prevent the possibility of vehicle collisions. [Tier 1]
Note: The primary intent is to ensure that vehicles maintain adequate separation to allow for managed deceleration of trailing vehicles in worst-case situations.

> [4.2.3.1-017] The San José Airport ATN System's Automatic Vehicle Protection function shall be capable of automatically determining the location of all system vehicles. [Tier 2]
>
> > [4.2.3.1-018] The San José Airport ATN System's Automatic Vehicle Protection function shall be capable of automatically determining the location of all system vehicles in active operation. [Tier 3]
> > *Note: This includes vehicles in operation on the guideways or in stations.*
> >
> > [4.2.3.1-019] The San José Airport ATN System's Automatic Vehicle Protection function shall be capable of automatically determining the location of all inactive vehicles. [Tier 3]
> > *Note: This includes vehicles awaiting deployment from staging areas, vehicles in maintenance, etc.*
>
> [4.2.3.1-020] San José Airport ATN System vehicles shall be capable of independently determining and communicating their location as an alternative or backup to centralized location determination by the system. [Tier 2]
>
> [4.2.3.1-021] The San José Airport ATN System's Automatic Vehicle Protection function shall maintain current operational state and location information for all vehicles in the system. [Tier 2]
>
> [4.2.3.1-022] The San José Airport ATN System's Automatic Vehicle Protection function shall ensure that sufficient separation is constantly maintained between vehicles to allow a trailing vehicle to decelerate to a safe stop, given the presumption that the leading vehicle stops on the guideway instantaneously. [Tier 2]
> *Notes: 1) This presumption is commonly referred to as the "brick wall stop" criterion. 2) the intent of the requirements is for the distance between operating vehicles to be actively maintained such that it is, at all times, "not less than the maximum stopping distance of the following vehicle," accounting for variables of grade, weather, communication delay, mechanical reaction time, etc. 3) This requirement may in theory be met by systems using either "constant time headway" or "constant safety spacing" operational modes. In the concept of constant safety spacing, time headway as well as inter-vehicle distance vary with line speed. 4) While there is no Airport ATN System project requirement for a specific minimum constant time headway, current ATN technology is capable of minimum time headways in the 3-6 second range. These headway values provide generously sufficient deceleration time from current systems' typical line speeds to readily comply with the brick-wall stop criterion.*
>
> > [4.2.3.1-023] In an emergency stop scenario, the San José Airport ATN System's Automatic Vehicle Protection function shall ensure that the vehicle stops from full line speed such that no collision can occur with a stationary vehicle on the guideway ahead. [Tier 3]

Note: This requirement implicitly includes the time factors involved in determining that an emergency stop scenario exists, command and communication timing delays, brake actuation time, and the braking time required to bring the vehicle to a stop without exceeding safe deceleration limits.

[4.2.3.1-024] The San José Airport ATN System's Automatic Vehicle Protection function shall take into account the factors listed in the ASCE APM Standards, Part 1, Section 5.1.2 when calculating stopping distances for purposes of separation assurance. [Tier 3]

[4.2.3.1-025] The San José Airport ATN System's Automatic Vehicle Protection function shall specifically protect against rear-end collisions regardless of any manual actions taken by the system's human operators. [Tier 2]
Notes: 1) The intent is that the automated safety and collision avoidance mechanism built into the system not be compromised or overridden by erroneous manual inputs. 2) This requirement derives from CPUC regulations regarding Automatic Train Control functionality for rail-based public transit systems.

[4.2.3.1-026] The San José Airport ATN System's Automatic Vehicle Protection function shall provide the capability to detect unintentional vehicle motion. [Tier 2]
Note: Unintentional vehicle motion is defined as the situation where a vehicle is detected to be moving, in either a forward or reverse direction, without having been so commanded.

[4.2.3.1-027] The San José Airport ATN System's Automatic Vehicle Protection function shall apply emergency braking to vehicles detected to be in unintentional motion. [Tier 3]

[4.2.3.1-028] The San José Airport ATN System's Automatic Vehicle Protection function shall provide the capability to restrict vehicle speeds to prescribed limits. [Tier 2]
Notes: 1) Speed limits on the ATN may vary statically for particular sections of the guideway, and may also be dynamically adjusted depending on current traffic loads and environmental factors such as weather conditions.

[4.2.3.1-029] The San José Airport ATN System's Automatic Vehicle Protection function shall apply emergency braking to vehicles detected to be operating in excess of the prevailing speed limit. [Tier 3]

[4.2.3.1-030] The San José Airport ATN System's Automatic Vehicle Protection function shall provide the capability to automatically prevent vehicles from overrunning their desired stopping points in stations or at the ends of "spur" sections of guideway. [Tier 2]

[4.2.3.1-031] The San José Airport ATN System's Automatic Vehicle Protection function shall automatically detect loss of control signals or data links that support other vehicle protection capabilities. [Tier 2]

[4.2.3.1-032] The San José Airport ATN System shall apply emergency braking to vehicles for which control signal transmission or associated data communication is interrupted for more than a defined threshold period. [Tier 3]
Note: CPUC General Order 127 specifies the maximum signal loss period as 1.0 seconds.

[4.2.3.1-033] The San José Airport ATN System's Automatic Vehicle Protection function shall be capable of automatically detecting that a vehicle previously in motion has come to a stop. [Tier 2]
Notes: 1) Specific definitions of what constitutes a successfully stopped vehicle are provided in the ASCE APM Standards, Part 1, Section 5.1.8. 2) This capability enables the ability to detect and properly react to a stalled vehicle on the guideway.

[4.2.3.1-034] The San José Airport ATN System's Automatic Vehicle Protection function shall be able to declare and effect a "zero speed limit zone" on any portion of the guideway at any time, based on detected anomaly (e.g., stopped vehicle or other guideway obstruction). [Tier 2]

> [4.2.3.1-035] The zero speed limit zone shall be established at a point no closer to the hazard than the maximum stopping distance of any active vehicle on the system. [Tier 3]
>
> [4.2.3.1-036] The San José Airport ATN System's Automatic Vehicle Protection function shall institute automatic emergency braking for any vehicle entering a declared "zero speed limit zone." [Tier 3]

[4.2.3.1-037] The San José Airport ATN System's Automatic Vehicle Protection function shall ensure that vehicle doors are not automatically unlocked or opened unless the train is properly stopped at a station, propulsion power is disconnected from the drive system, and emergency brakes are applied. [Tier 2]
Note: Additional detail regarding door control interlock requirements is provided in the ASCE APM Standards, Part 1, Section 5.1.10.

[4.2.3.1-038] The San José Airport ATN System's Automatic Vehicle Protection function shall ensure that vehicles stopped in a station are automatically prohibited from departing until the vehicle doors are securely closed. [Tier 2]
Note: The system should consider the closing and locking of the vehicle doors as a prerequisite to disengaging the brake and reconnecting the drive propulsion.

[4.2.3.1-039] The San José Airport ATN System's Automatic Vehicle Protection function shall implement interlocks between the vehicle propulsion and braking subsystems per the rules specified in the ASCE APM Standards, Part 1, Section 5.1.13. [Tier 2]

[4.2.3.1-040] The San José Airport ATN System's Automatic Vehicle Protection function shall provide guideway switch interlocks per the rules specified in the ASCE APM Standards, Part 1, Section 5.1.14. [Tier 2]
Note: This requirement is not applicable to ATN system designs that do not incorporate guideway-based switch mechanisms.

> [4.2.3.1-041] The San José Airport ATN System's Automatic Vehicle Protection function shall specifically prevent derailment or collision from a switch being actuated too late or while a vehicle is directly over it. [Tier 3]
> *Note: This requirement is not applicable to ATN system designs that do not incorporate guideway-based switch mechanisms.*

[4.2.3.1-042] The San José Airport ATN System's Automatic Vehicle Protection function shall take operational precedence over other Automatic Vehicle Control functions. [Tier 2]

[4.2.3.1-043] The San José Airport ATN System's Automatic Vehicle Protection function shall include fail-safe design provisions such that the AVP capabilities continue to work even with a failure of any single Automatic Vehicle Control system element. [Tier 2]

4.2.3.1.3 Automatic Vehicle Supervision

[4.2.3.1-044] The San José Airport ATN System shall provide Automatic Vehicle Supervision functions to monitor system operations and manage the visibility and control interface with the central control operators. [Tier 1]
Note: The primary intent is to ensure sufficient information is available to operational staff to accurately assess system operational status, evaluate anomalous conditions, and execute appropriate system control and management actions.

[4.2.3.1-045] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide system status and performance information to the central control operations as described in the ACSE APM Standards, Part 1, Section 5.3.2. [Tier 2]

[4.2.3.1-046] The San José Airport ATN System's Automatic Vehicle Supervision function shall initiate automated system control actions as described in the ACSE APM Standards, Part 1, Section 5.3.3.1. [Tier 2]

[4.2.3.1-047] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability to effect operational mode changes (e.g., from normal operations to "safe mode") upon detection of operational events or anomalous conditions on the system. [Tier 3]

[4.2.3.1-048] The San José Airport ATN System's Automatic Vehicle Supervision function shall maintain dynamic tracking of the location of each active vehicle in service on the system. [Tier 3]

[4.2.3.1-049] The San José Airport ATN System Automatic Vehicle Supervision function shall generate the data necessary to support visualization/ monitoring of vehicle location and operational status. [Tier 3]

[4.2.3.1-050] The San José Airport ATN System's Automatic Vehicle Supervision function shall monitor and adjust the spacing between vehicles (per constant time headway or "constant safety" spacing rules). [Tier 3]

[4.2.3.1-051] The San José Airport ATN System's Automatic Vehicle Supervision function shall monitor congestion and adjust the routing of vehicles between stations to balance loads between network links. [Tier 3]

[4.2.3.1-052] The San José Airport ATN System's Automatic Vehicle Supervision function shall facilitate prescribed manual control and override actions as described in the ACSE APM Standards, Part 1, Section 5.3.3.2. [Tier 2]

[4.2.3.1-053] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to execute control actions to manually start up the system to a state of service readiness. [Tier 3]

[4.2.3.1-054] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to execute control actions to manually shut down the system from an operational state in an orderly fashion. [Tier 3]

[4.2.3.1-055] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to manually initiate specific vehicles into service from off-line staging area(s). [Tier 3]

[4.2.3.1-056] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to manually remove specific vehicles from on-line service to off-line staging, storage or maintenance. [Tier 3]

[4.2.3.1-057] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to manually send vehicles along an assigned route to a specific destination. [Tier 3]

[4.2.3.1-058] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to manually change the operating mode of the system from normal operations to an alternate mode for failure or emergency management. [Tier 3]

[4.2.3.1-059] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to manually hold vehicles in stations. [Tier 3]

[4.2.3.1-060] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to manually initiate a controlled stop of all vehicles on the guideways. [Tier 3]

[4.2.3.1-061] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to manually command system power on/off on a per-power distribution segment basis. [Tier 3]
Note: This requirement is especially applicable to ATN systems that draw primary vehicle power from the guideway, but is also potentially relevant for systems based on fully battery-powered vehicles due to factors such as the distribution of opportunity charging stations.

[4.2.3.1-062] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to manually receive, process, acknowledge, store, search, recall and correlate system messages and alarms. [Tier 3]

[4.2.3.1-063] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to reset alarm indications and thresholds. [Tier 3]
Note: The ATN system control center should have mechanisms in place to ensure that alarms and thresholds are not accidentally reset.

[4.2.3.1-064] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to make audio announcements at any selected station(s) and/or on any selected vehicle(s). [Tier 3]

[4.2.3.1-065] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to generate and transmit input to dynamic message boards. [Tier 3]

[4.2.3.1-066] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to control video surveillance monitoring/recording on a per channel basis. [Tier 3]

[4.2.3.1-067] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide the capability for the operator to control guideway and stations lighting. [Tier 3]

[4.2.3.1-068] The San José Airport ATN System's Automatic Vehicle Supervision function shall provide automated monitoring and alarm reporting functions as described in the ACSE APM Standards, Part 1, Section 5.3.3.3. [Tier 2]

[4.2.3.1-069] The San José Airport ATN System's Automatic Vehicle Control function shall monitor, detect, report and respond to failure conditions on the network. [Tier 1]

[4.2.3.1-070] The San José Airport ATN System shall be capable of automatically detecting and determining appropriate reaction to potentially unsafe conditions. [Tier 2]

[4.2.3.1-071] The San José Airport ATN System shall provide the capability to automatically diagnose, isolate, and route vehicles around local points of failure when safe to do so. [Tier 2]

[4.2.3.1-072] The San José Airport ATN System shall be capable of centrally sensing a vehicle stopped on an active guideway. [Tier 3]

[4.2.3.1-073] The San José Airport ATN System shall be capable of centrally commanding all vehicles, operating on the section of an active guideway on which a disabled vehicle is stationary, to a controlled emergency stop. [Tier 3]

[4.2.3.1-074] The San José Airport ATN System shall be capable of centrally sensing the loss of a guideway structural support. [Tier 3]

[4.2.3.1-075] The San José Airport ATN System shall be capable of centrally commanding all vehicles approaching the section of an active guideway from which a support structure has been lost to a controlled emergency stop. [Tier 3]

[4.2.3.1-076] San José Airport ATN System vehicles shall be capable of individually sensing a stopped vehicle (or other stationary object on the guideway [TBD]), independent of any off-board control function (e.g., a central or zone control subsystem). [Tier 3]

4.2.3.1.4 Communications

[4.2.3.1-077] The San José Airport ATN System shall provide for robust communication of data, command and control information between all system elements (e.g., control functions, vehicles, active guideway or station components). [Tier 1]

[4.2.3.1-078] The San José Airport ATN System shall provide secure data communications between control elements of the system (i.e. a central control point, distributed zone controllers, and/or vehicle-based control subsystems) as necessary to accomplish the AVO, AVP and AVS functions of the overall system. [Tier 2]

[4.2.3.1-079] The San José Airport ATN System shall provide a command and control channel via a secure, encrypted and robust link between the central control facility and the ATN vehicles. [Tier 3]

[4.2.3.1-080] The San José Airport ATN System command and control channel shall provide vehicle state of health to the ATN control center. [Tier 3]
Notes: 1) The contents of this state of health message is [TBD]. 2) The update rate of the state of health message is [TBD].

[4.2.3.1-081] All San José Airport ATN System communication channels shall have a minimum of 3 dB link margin under worst-case conditions that include an allocation for weather, vehicle motion, and other [TBD] requirements. [Tier 3]

[4.2.3.1-082] The San José Airport ATN System data communication function shall operate reliably in all expected San José area weather conditions. [Tier 2]

[4.2.3.1-083] The San José Airport ATN System shall be capable of receiving emergency indications from a vehicle at the highest priority of the communications protocol. [Tier 2]

[4.2.3.1-084] The San José Airport ATN System shall be capable of remotely actuating vehicle controls, including controlling vehicle motion, executing test sequences, and diagnosing anomalies. [Tier 2]
Note: The complete set of remote control functions for implementation in the initial baseline system is TBD.

[4.2.3.1-085] The San José Airport ATN System communication function shall have end-to-end reliability sufficient to support the overall service availability specifications given in section 4.2.3.5. [Tier 2]

[4.2.3.1-086] The San José Airport ATN System communication function shall provide channel capacity sufficient to support both vehicle operations and a passenger information feed. [Tier 2]
Notes: 1) The bandwidth requirements for the passenger information exchange are [TBD]. 2) The data transmitted for passenger informational purposes could include station arrival time, flight schedule information, local weather, current events, and advertisements.

[4.2.3.1-087] The San José Airport ATN System shall provide functional features to increase system utility and passenger comfort. [Tier 1]

[4.2.3.1-088] San José Airport ATN System vehicles shall provide cabin environmental control (air conditioning and heating). [Tier 2]

> [4.2.3.1-089] The San José Airport ATN System vehicle cabin environmental control function shall be capable of maintaining the interior temperature of the vehicle in the range of 60 [TBR] to 80 [TBR] degrees Fahrenheit during steady state (closed door) vehicle operations, given exterior temperatures within a range of 28 [TBR] to 102 [TBR] degrees Fahrenheit. [Tier 3]

[4.2.3.1-090] The San José Airport ATN System vehicles shall provide interior lighting during steady-state (closed door) vehicle operations in accordance with the ACSE APM Standards, Part 2, Section 7.11.1. [Tier 2]

> [4.2.3.1-091] San José Airport ATN System vehicles shall provide additional automatic interior lighting when the vehicles doors are open during night-time operations. [Tier 3]

[4.2.3.1-092] The San José Airport ATN System vehicles shall provide emergency lighting in accordance with the ACSE APM Standards, Part 2, Section 7.11.2. [Tier 2]

[4.2.3.1-093] San José Airport ATN System vehicles shall provide in-vehicle passenger controls for electronic voice communication, route selection, route change, emergency re-routing, and call for emergency response. [Tier 2]

4.2.3.2 Airport ATN System Performance Requirements

4.2.3.2.1 System Throughput

[4.2.3.2-001] The San José Airport ATN System shall be capable of servicing passenger demand with acceptable wait times at all origin and destination points. [Tier 1]
Note: Passenger demand is characterized in terms of both steady-state "peak hour" loads and "instantaneous peak" surge conditions.

> [4.2.3.2-002] San José Airport ATN System stations shall have the capability to accommodate arriving and departing vehicles such that mean passenger wait time for an available vehicle is no greater than 1 [TBR] minute under peak hour load conditions, and no greater than 3 [TBR] minutes under instantaneous-peak surge conditions for that station. [Tier 2]
> *Note: "Peak hour" and "instantaneous peak" load conditions for the Airport ATN System are defined in section 4.2.1.3.*

> [4.2.3.2-003] San José Airport ATN System stations shall have the capability to accommodate arriving and departing vehicles such that "wave-offs" (go-arounds) are necessary for less than 1 [TBR] % of vehicle trips destined for that station under peak hour load conditions, and less than 3 [TBR] % under instantaneous-peak surge conditions. [Tier 2]
> *Note: "Peak hour" and "instantaneous peak" load conditions for the Airport ATN are defined in section 4.2.1.3.*

4.2.3.2.2 Vehicle Operations

[4.2.3.2-004] The San José Airport ATN System shall achieve vehicle dynamic performance consistent with the capacity, transit time, comfort and safety requirements of the system. [Tier 1]
Note: Vehicle dynamic performance includes line speed, acceleration and deceleration within guideway configuration limits.

> [4.2.3.2-005] The San José Airport ATN System shall be capable of operating with a nominal line velocity of a minimum of 56 [TBR] kph. [Tier 2]
> *Note: This does not imply that this speed be maintained through all guideway sections under all dynamic conditions; rather, it is the nominal maximum speed that would be generally achieved on straight guideway sections under normal conditions.*
>
>> [4.2.3.2-006] The San José Airport ATN System's control subsystem shall provide the capability to limit vehicle speeds to the nominal velocity stated in requirement [4.2.3.2-005]. [Tier 3]
>>
>> [4.2.3.2-007] The San José Airport ATN System shall limit vehicle acceleration and deceleration in normal operations to a maximum of 0.25g (approximately ±2.45 m/s^2). [Tier 3]
>>
>> [4.2.3.2-008] The San José Airport ATN System vehicles shall be capable of emergency braking deceleration up to 0.6g [TBR] (approximately -5.9 [TBR] m/s^2). [Tier 3]
>
> [4.2.3.2-009] The San José Airport ATN System shall be capable of autonomous operation with headways of 6 [TBR] seconds at nominal operating velocity of 56 [TBR] kph. [Tier 2]
> *Note: Operation at no greater than 6 second headways is considered to be the minimum basic operational capability required for the Airport ATN system. The capability to operate with fully verified safety and regulatory compliance at shorter headways is considered as a desirable feature.*
>
> [4.2.3.2-010] The San José Airport ATN System shall be capable of operation at specified maximum line speed around uniform curves having a centerline radius no greater than 16 [TBR] meters. [Tier 2]
> *Note: The ability of the system to negotiate tighter curves, having centerline radii of 5 - 15 [TBR] meters, possibly at less than maximum line speed, is a desirable feature.*
>
> [4.2.3.2-011] The San José Airport ATN System shall be capable of nominal operations on ascending grades up to 10 [TBR] % (5.7 [TBR] degrees). [Tier 2]
> *Note: "Nominal operations" includes the ability to maintain normal operational line speed on the ascending grade.*
>
> [4.2.3.2-012] The San José Airport ATN System shall be capable of nominal operations on descending grades of -6.25 [TBR]% (-3.6 [TBR] degrees). [Tier 2]
> *Note: "Nominal operations" includes the ability to maintain normal operational line speed as well as to execute controlled braking action at specified deceleration rates on descending grades.*
>
> [4.2.3.2-013] The San José Airport ATN System shall be capable of nominal vehicle performance on guideways that are elevated, at grade level, or below grade. [Tier 2]

Notes: 1) "Nominal operation" means the ability to operate at design line speed and up to specified acceleration/deceleration limits, with seamless transition between guideways at various grade levels. 2) It is not a requirement that the ATN guideway layout actually contain structures at all three potential grade levels; it is only required that there be no performance impacts from use of a particular grade level relative to another.

[4.2.3.2-014] San José Airport ATN System vehicle ride quality during steady state operation at nominal line speed shall meet or exceed industry-accepted ride quality standards. [Tier 2]

> [4.2.3.2-015] The San José Airport ATN System ride quality during steady state operation at nominal line speed shall be compliant with industry standard measures of in-vehicle vibration induced by roughness in the vehicle/guideway interface. [Tier 3]
> *Note: One such industry-accepted measure is the International Roughness Index, which is calculated as an integration of z-axis (vertical) displacement of a vehicle rolling across a paved surface, weighted to emphasize frequencies that have been empirically shown to cause particular types of discomfort. Measured in meters/kilometer, a rule-of thumb IRI value for "good" roughness would be 1.5 m/km.*

> [4.2.3.2-016] The San José Airport ATN System ride quality during steady state operation at nominal line speed shall be compliant with industry standard measures of human whole-body vibration (WBV), experienced by passengers during the ride. [Tier 3]
> *Note: Industry-accepted definitions and quantitative measures of WBV are defined in ISO 2631-1.*

> [4.2.3.2-017] The San José Airport ATN System ride quality during vehicle acceleration, deceleration and maneuvers shall be compliant with the definitions and limits given in the ASCE APM Standards, Part 2, Section 7.7.3. [Tier 3]
> *Note: The ASCE APM standards specify maximum sustained acceleration levels, maximum jerk rates, and test conditions for ride quality testing.*

[4.2.3.2-018] The San José Airport ATN System shall operate within defined vehicle noise level limits. [Tier 2]

> [4.2.3.2-019] The San José Airport ATN System shall operate without exceeding the following vehicle interior noise level limits, under the operational and test conditions defined in the ASCE APM Standards, Part 2, Section 7.7.4: [Tier 3]
> - Vehicle stationary, doors shut: <68dBA [TBR]
> - Vehicle moving up to 20 kph: <70dBA [TBR]
> - Vehicle moving up to 40 kph: <74dBA [TBR]

> [4.2.3.2-020] The San José Airport ATN System shall operate without exceeding the exterior noise level limits and operational/test conditions defined in the ASCE APM Standards, Part 1, Section 2.2.1. [Tier 3]
> *Note: It is recommended that additional investigation be performed with an eye toward validation and recommendation of lower dBA levels for the Airpot ATN system than those specified for APM systems in the ACSE Standards.*

[4.2.3.2-021] The San José Airport ATN System guideway switching mechanism shall have a maximum cycle time of [TBD]. [Tier 2]
Notes: 1) This parameter is related to vehicle line speed and headway. 2) This requirement is not applicable to systems that do not employ switching mechanisms to guide the vehicles along the correct path.

[4.2.3.2-022] The San José Airport ATN System guidance and control function shall provide the capability to maintain vehicle position, velocity and heading within specified levels of precision. [Tier 2]

[4.2.3.2-023] The San José Airport ATN System guidance and control function shall be capable of maintaining longitudinal positioning of the ATN vehicles within 0.1 [TBR] m. [Tier 3]

[4.2.3.2-024] The San José Airport ATN System guidance and control function shall be capable of maintaining lateral positioning of the vehicles within 0.04 [TBR] m. [Tier 3]

[4.2.3.2-025] The San José Airport ATN System guidance and control function shall be capable of maintaining velocity of the vehicles within 0.2 [TBR] kph. [Tier 3]

[4.2.3.2-026] The San José Airport ATN System guidance and control function shall be capable of determining and maintaining the heading of the vehicles within 3 [TBR] degrees. [Tier 3]

[4.2.3.2-027] All San José Airport ATN System vehicle control loops shall have a minimum gain margin of 6 dB and a minimum phase margin of 30 degrees under all conditions. [Tier 3]

4.2.3.2.3 Anomaly Detection and Resolution

[4.2.3.2-028] The San José Airport ATN System shall be capable of detecting, communicating and taking mitigation actions in time to mitigate the effects of failures or anomalies in system operation. [Tier 1]

[4.2.3.2-029] The San José Airport ATN System shall be capable of detecting and reacting to guideway blockages in time to ensure avoidance of collisions. [Tier 2]

[4.2.3.2-030] The San José Airport ATN System shall be capable of communicating emergency stop commands to vehicles within 0.2 [TBR] seconds of detection of a stopped vehicle on an active guideway. [Tier 3]

[4.2.3.2-031] The San José Airport ATN System shall be capable of re-routing all vehicles around the section of an active guideway on which a disabled vehicle is stationary within 1 [TBR] second of detection of the stationary vehicle. [Tier 3]

[4.2.3.2-032] San José Airport ATN System vehicles shall be capable of beginning controlled deceleration (e.g., actuating their braking mechanism in emergency deceleration mode) within 0.2 [TBR] seconds of a) independently detecting a stopped vehicle or other obstruction on the guideway ahead, or b) receiving indication from an external control function (e.g., a central control subsystem) that a vehicle is stopped on an active guideway. [Tier 3]

[4.2.3.2-033] All operational San José Airport ATN System vehicles shall be notified within 0.4 [TBR] seconds when a stopped vehicle (or other stationary object on the guideway [TBD]) is independently detected by a particular vehicle. [Tier 3]

[4.2.3.2-034] All operational San José Airport ATN System vehicles shall be notified within 0.2 [TBR] seconds when a stopped vehicle (or other stationary object on the guideway [TBD]) is detected by an off-board control function (e.g., a central or zone control subsystem). [Tier 3]

4.2.3.2.4 Physical Clearances

[4.2.3.2-035] The San José Airport ATN System shall be capable of nominal operation within the physical clearances provided for in the system guideway route layout. [Tier 1]
Note: "Nominal operation" means the system is in service at specified functional, performance, and safety levels.

[4.2.3.2-036] The San José Airport ATN System shall be capable of nominal operation with a minimum of 1.0 [TBR] meter clearances between each side of the guideway and laterally-adjacent structures or obstructions. [Tier 2]

[4.2.3.2-037] The San José Airport ATN System shall be capable of nominal operation with a minimum of 1.0 [TBR] meter clearance between the top of the vehicle and overhead structures or obstructions. [Tier 2]
Note: This requirement is applicable only for systems with guideway-supported vehicles.

[4.2.3.2-038] The San José Airport ATN System shall be capable of nominal operation with a minimum of 1.5 [TBR] meter clearance between the bottom of the vehicle and the underlying grade level during nominal vehicle operation in a restricted right-of-way. [Tier 2]
Notes: 1) A restricted right-of-way means that the vehicle operates over an area that is fenced off and/or otherwise made inaccessible to pedestrians or other vehicle traffic. 2) This requirement is applicable only for systems with guideway-suspended vehicles.

[4.2.3.2-039] The San José Airport ATN System shall be capable of nominal operation with a minimum of 5.1 [TBR] meter clearance between the bottom of the vehicle and the underlying grade level during nominal vehicle operation in an unrestricted right-of-way. [Tier 2]
Notes: 1) An unrestricted right-of-way means that the vehicle operates over an area that pedestrians and/or other vehicle traffic may traverse. 2) This requirement is applicable only for systems with guideway-suspended vehicles.

4.2.3.2.5 Operating Environment

[4.2.3.2-040] The San José Airport ATN System shall be capable of nominal operation in local San José environmental conditions. [Tier 1]
Note: "Nominal operation" means the ATN system is in service at specified functional, performance, and safety levels.

[4.2.3.2-041] The San José Airport ATN System shall be capable of nominal operation in night-time and low-visibility fog conditions. [Tier 2]
Note: It is intended that the system operate normally even when visual line of sight between vehicles and stations is obscured by fog or darkness.

[4.2.3.2-042] The San José Airport ATN System shall be capable of nominal vehicle acceleration, steady-state operation, and braking/deceleration in heavy rain conditions. [p] [Tier 2]
Note: Heavy rain conditions are defined as [TBD].

[4.2.3.2-043] The San José Airport ATN System shall be capable of nominal vehicle acceleration, steady-state operation, and braking/deceleration in hard frost and ice conditions. [p] [Tier 2]
Notes: 1) Hard frost and ice conditions are defined as [TBD]. 2) While heavy snowfall is not typical in the San José area, frost and ice can occur under certain weather conditions. Guideway design should incorporate measures, such as conformation and/or shielding, to limit the effects of these conditions on traction, power distribution, and other system functions.

[4.2.3.2-044] The San José Airport ATN System shall be capable of nominal vehicle operation in side winds of 100 [TBR] kph (sustained) and 150 [TBR] kph (gusts). [Tier 2]

4.2.3.3 Interoperability Requirements

[4.2.3.3-001] The design and implementation of the San José Airport ATN System shall promote interoperability among its subsystems and components. [Tier 1]
Note: Key goals of interoperability include a) maximizing commonality of designs and components for economies of scale, b) encouraging standardization and multi-sourcing opportunities, and c) simplifying ongoing operations and maintenance.

[4.2.3.3-002] The San José Airport ATN System vehicles shall be capable of using all guideways and stations of the system. [Tier 2]
Note: This does not mean that the guideways and stations comprising the ATN infrastructure are required to be of a uniform or homogeneous design.

[4.2.3.3-003] A well-specified guideway-vehicle interface shall be defined and published as a result of the San José Airport ATN guideway design process. [Tier 2]
Note: The intent of this requirement is that the Airport ATN System not preclude use of other vehicles that meet the guideway interface specs.

[4.2.3.3-004] San José Airport ATN System vehicles shall have a well-specified, published vehicle-guideway interface. [Tier 2]
Note: The intent of this requirement is that the system not preclude use of alternate guideway structures as long as they meet the vehicle interface specs.

4.2.3.4 Flexibility Requirements

[4.2.3.4-001] The San José Airport ATN System shall be designed to accommodate flexibility, growth and evolution of transportation needs in the SJC area. [Tier 1]
Notes: 1) The goal is to maximize the benefits of the ATN service in San José and to adapt to changing transportation needs in the area. 2) It is important to note that in California, the CPUC must approve all system changes, route extensions, and realignments of public transit systems.

> [4.2.3.4-002] The San José Airport ATN System guideway design and construction shall be modular, i.e., it must generally support the ability to swap and replace guideway sections with minimal or no collateral reconstruction. [Tier 2]
>
> [4.2.3.4-003] Automated vehicle control algorithms and software of the San José Airport ATN System shall be scalable to handle additional vehicles, stations, merge/diverge intersections, empty vehicle staging areas, and support functions. [Tier 2]
>
> [4.2.3.4-004] Operational monitoring and control functions of the San José Airport ATN System shall be scalable to handle additional vehicles, stations and guideway sections. [Tier 2]
>
> [4.2.3.4-005] The San José Airport ATN System shall be capable of supporting eventual airport expansion, including the ability to accommodate new layouts serving future operational facilities. [Tier 2]
> *Notes: 1) Such expansion could include additional terminal areas, parking, activity centers, etc. 2) Although the need to service expanded facilities is not immediate, it is important to consider the ramifications of future expansion in the initial design.*

4.2.3.5 Reliability and Availability Requirements

[4.2.3.5-001] The San José Airport ATN System, and its subsystems and components, shall be designed and selected in accordance with specifications derived from a comprehensive reliability engineering program. [Tier 1]
Note: The primary goals of the Airport ATN Project reliability engineering program are to increase ATN service availability and minimize maintenance cost and complexity.

[4.2.3.5-002] San José Airport ATN System service availability shall meet or exceed the availability of comparable bus and rail transit services in San José. [Tier 1]

> [4.2.3.5-003] The San José Airport ATN System service shall progressively achieve increasing levels of overall system availability in accordance with the following milestones: [Tier 2]
>
> - 98.0% [TBR] during the system's pre-acceptance demonstration period
> - 98.5% [TBR] during the first three months of passenger operations
> - 99.0% [TBR] during next three months of passenger operations
> - 99.5% [TBR] after six months of passenger operations
> - 99.8% [TBR] after one year of passenger operations

Note: These availability values are to be calculated using the definitions provided in the ACSE APM standards, Part 1, Section 4.3.

[4.2.3.5-004] The San José Airport ATN System service shall operate with overall long-term availability of .998 [TBR]. [Tier 2]
Note: An availability target of .998 means that system downtime (the time during which the system is incapable of supporting nominal operations and connectivity between any two stations) is less than 18 [TBR] hours/year, not counting scheduled maintenance.

[4.2.3.5-005] The San José Airport ATN System and its constituent subsystems and components shall be designed and/or selected for reliability sufficient to meet overall service availability targets.[t] [Tier 2]

[4.2.3.5-006] The San José Airport ATN System vehicles shall be designed for a Mean Time Between Failure (MTBF) of [TBD]. [Tier 3]

[4.2.3.5-007] The San José Airport ATN System vehicles shall be designed for a Mean Time To Repair (MTTR) of [TBD]. [Tier 3]

[4.2.3.5-008] The San José Airport ATN System vehicles shall not become disabled due the failure of a single motor and/or that motor's associated drive mechanism. [Tier 3]

[4.2.3.5-009] The San José Airport ATN System guideway switching mechanisms (if applicable) shall have a reliability of .9999 [TBR]. [Tier 3]

[4.2.3.5-010] The San José Airport ATN System command and control channel shall be available 99.99% [TBR] of the time. [Tier 3]

[4.2.3.5-011] The San José Airport ATN System command and control channel shall have a bit error rate no greater than 1e-8 [TBR]. [Tier 3]

4.2.3.6 Safety Requirements

4.2.3.6.1 General Safety Requirements

[4.2.3.6-001] A System Safety Program shall be established for the San José Airport ATN System, commencing in the system planning and design phase and maintained throughout the implementation and operation of the system. [Tier 1]
Note: Guidance for System Safety Program procedures for systematic identification, resolution and reporting of hazards are specified in the ASCE APM Standards - Part 1, Annex A, "System Safety Program Requirements."

[4.2.3.6-002] A System Safety Program Plan (SSPP) shall be developed and adopted by the public agency responsible for procuring and operating the San José Airport ATN System, which describes the safety policies, objectives, responsibilities and procedures to be followed in implementation and operation of the system. [Tier 2]
Note: This requirement is in accordance with U.S. Code of Federal Regulations (CFR) 659, CPUC General Orders 143-B and 164-D, and the ASCE APM Standards, Part 1, Annex A.

[4.2.3.6-003] The San José Airport ATN System shall implement safety features and functions consistent with the safety principles stated in the ACSE APM Standards, Part 1, Section 3.2. [Tier 1]
Note: The safety principles codified in the APM Standards include hazard avoidance, fail-safe design of critical subsystems, continuous positive confirmation of safe conditions as a requisite of continuing operations, and operational safety "interlocks" to ensure proper coordination of automatic and manual operational control functions.

4.2.3.6.2 Fire Protection Program

[4.2.3.6-004] The San José Airport ATN System shall implement a fire protection program per Chapter 8 of NFPA 130-2007, *Standard for Fixed Guideway Transit and Passenger Rail Systems*. [Tier 1]

4.2.3.6.3 Vehicle Fire Safety

[4.2.3.6-005] San José Airport ATN System vehicles shall be designed, implemented, and operated in accordance with applicable fire safety standards. [Tier 1]

> [4.2.3.6-006] The San José Airport ATN System shall comply with the fire protection and flammability requirements defined in the ASCE APM Standards, Part 2, Section 7.10. [Tier 2]
>
>> [4.2.3.6-007] The San José Airport ATN System vehicles shall utilize flame-retardant materials per the provisions of the ASCE APM Standards, Part 2, Section 7.10.1. [Tier 3]
>>
>> [4.2.3.6-008] The San José Airport ATN System vehicles shall provide thermal protection of electrical components per the provisions of the ASCE APM Standards, Part 2, Section 7.10.2. [Tier 3]
>>
>> [4.2.3.6-009] The San José Airport ATN System vehicles shall incorporate smoke/fire detection and fire extinguisher equipment per the provisions of the ASCE APM Standards, Part 2, Sections 7.10.3 and 7.10.4. [Tier 3]

[4.2.3.6-010] The San José Airport ATN System shall provide for orderly passenger control and evacuation of vehicles in safety critical situations. [Tier 1]

> [4.2.3.6-011] The San José Airport ATN System shall provide the capability for a passenger to initiate a controlled stop of the vehicle. [Tier 2]
> *Note: It is intended that this be used only in cases of medical or security emergency.*
>
>> [4.2.3.6-012] The capability for a passenger to initiate a controlled stop of the vehicle shall be interlocked with other alarms or condition indicators, such as smoke or over-temperature detectors, such that the vehicle does not actually stop on the guideway unless an immediate evacuation to the emergency walkways is necessary. [Tier 3]
>> *Note: It is considered impractical to allow passengers the unrestricted ability to stop a vehicle on the guideway. However, it is crucial from a safety standpoint that an immediate stop and evacuation be enabled under emergency conditions such as an in-vehicle fire.*

[4.2.3.6-013] The default destination for a passenger-requested controlled stop of a vehicle, in the absence of auxiliary emergency indicators (e.g., smoke alarms or fire detection), shall be [the nearest station | the nearest manned security station] [TBR]. [Tier 3]
Notes: 1) It is considered impractical to allow passengers the unrestricted ability to stop a vehicle on the guideway. 2) For the purposes of this requirement, "nearest" may be determined by the system on either a closest-distance or least-transit time basis, per current traffic conditions.

[4.2.3.6-014] Automatic operation of the San José Airport ATN System vehicle doors shall be inhibited unless the vehicle is stopped. [Tier 2]

[4.2.3.6-015] The San José Airport ATN System vehicles shall allow manual egress from a stopped vehicle in emergency conditions, including but not limited to fire or smoke detected in the vehicle interior. [Tier 2]
Notes: 1) This implies that automatic door control/locking mechanisms include a capability for the passenger to override and operate the door manually. 2) It is intended that this capability be used only in cases of medical or security emergency.

[4.2.3.6-016] Manual operation of the San José Airport ATN System vehicle doors shall be inhibited unless the vehicle is stopped. [Tier 3]

[4.2.3.6-017] The San José Airport ATN System vehicles' manual emergency egress capability shall be operable with or without the availability of power in the vehicle. [Tier 3]

[4.2.3.6-018] The San José Airport ATN System vehicles' manual emergency egress capability shall be operable and usable by visual and hearing-disabled passengers. [Tier 3]

[4.2.3.6-019] The San José Airport ATN System vehicles' manual emergency egress capability shall be operable and usable by wheelchair users. [Tier 3]

[4.2.3.6-020] The San José Airport ATN System shall incorporate emergency walkways on all elevated guideway sections. [Tier 2]
Notes: 1) This is a CPUC requirement for all public transit systems in California. 2) CPUC regulations allow one emergency walkway to serve up to two guideway tracks.

[4.2.3.6-021] The San José Airport ATN System emergency walkways shall be a minimum of 30" [TBR] wide and have a minimum of 30" clearance from the exterior surface of a passing vehicle. [Tier 3]
Note: This CPUC regulation originally predates the Americans with Disabilities Act, which may impose additional requirements and design constraints on the walkway.

[4.2.3.6-022] The San José Airport ATN System emergency walkways shall be ADA compliant. [Tier 3]
Notes: 1) The CPUC regulation requiring emergency walkways along the full length of elevated-track transit systems originally predates the Americans with Disabilities Act. 2) An expected implication of this requirement is that the walkways be at vehicle floor level for easy wheelchair egress from the vehicle in emergency situations.

4.2.3.6.4 Station Fire Safety

[4.2.3.6-023] San José Airport ATN System stations shall be designed, implemented and operated in accordance with applicable fire safety standards. [Tier 1]

[4.2.3.6-024] San José Airport ATN System stations shall be designed for fire protection and evacuation in compliance with applicable provisions of NFPA 130. [Tier 2]
Note: The portions of NFPA 130 that specify fire protection requirements for underground stations and facilities will likely not be relevant for the San José Airport ATN.

[4.2.3.6-025] San José Airport ATN System stations shall be designed such that the travel distance between any point in the public area to a point of egress from the station ground level shall not exceed 91.4 meters. [Tier 3]

[4.2.3.6-026] San José Airport ATN System stations shall not rely on operation of elevators or escalators to achieve the required evacuation times. [Tier 3]

[4.2.3.6-027] San José Airport ATN System stations shall provide emergency ambient lights and exit marker lighting indicating the shortest egress paths. [Tier 2]

[4.2.3.6-028] San José Airport ATN System stations' emergency ambient lights and exit marker lighting shall be automatically switched to a secondary power supply in case of loss of primary power. [Tier 3]

[4.2.3.6-029] San José Airport ATN System stations shall incorporate code-compliant fire detection and protection features. [Tier 2]

[4.2.3.6-030] San José Airport ATN System stations shall incorporate a code-compliant automatic fire alarm system. [Tier 3]

[4.2.3.6-031] San José Airport ATN System stations shall incorporate a code-compliant automatic fire sprinkler system. [Tier 3]

[4.2.3.6-032] San José Airport ATN System stations shall incorporate a code-compliant fire hose reel system and fire extinguishers. [Tier 3]

[4.2.3.6-033] San José Airport ATN System stations shall incorporate a code-compliant Fireman's Intercom system. [Tier 3]

4.2.3.6.5 Transit Operations Safety

[4.2.3.6-034] The San José Airport ATN System shall incorporate operational safety features to protect passengers and the public during all aspects of system operation. [Tier 1]

[4.2.3.6-035] A means shall be provided to ensure that passengers cannot enter, cross or egress onto an active guideway in the San José Airport ATN System's stations or at any points along the guideway route. [Tier 2]
Note: Potential solutions to this requirement include basic station layout design for user safety, along with fences, rails, station doors, and other barriers to ensure that guideways remain clear.

[4.2.3.6-036] San José Airport ATN System vehicles shall provide the capability to detect gross weight overload conditions while stopped in the station vehicle berths. [Tier 2]

> [4.2.3.6-037] The San José Airport ATN System vehicles shall self-disable their drive mechanism until the overload condition is resolved. [Tier 3]
> *Note: This could be accomplished via power control, mechanical interlock, or other means.*

[4.2.3.6-038] San José Airport ATN System vehicles shall provide a safety interlock such that the vehicle is not enabled to move forward from passenger loading berths until doors are closed and secured, passengers are seated [TBR] and properly restrained [TBR]. [Tier 2]
Note: Specific requirements related to enforcement of passengers in seated position, and the appropriate type (if any) of required passenger restraints, such as seat belts or air bags, are [TBD].

[4.2.3.6-039] San José Airport ATN System vehicles shall provide sufficient energy absorption capability (e.g., crush bumpers) to prevent passenger injury, as appropriate for the system's maximum line speeds and the level of passenger restraint provided. [Tier 2]

[4.2.3.6-040] The San José Airport ATN System vehicles shall be capable of self-propulsion in the event of loss of their primary power source, with automatic routing to the nearest station or egress point. [Tier 2]
Note: The intent is to minimize the incidence of stopped vehicles on the guideway and the attendant safety risks.

> [4.2.3.6-041] San José Airport ATN System vehicles shall be capable of self-propulsion in the event of a system-wide power outage, with automatic routing to the nearest station or egress point. [Tier 3]
> *Note: This requirement is implicitly met by ATN systems that utilize on-board batteries as a primary power source.*

> [4.2.3.6-042] San José Airport ATN System vehicles shall be capable of self-propulsion in the event of a primary battery discharge or failure, with automatic routing to the nearest station or egress point. [Tier 3]
> *Notes: 1) This implies that battery-powered vehicles have backup on-board battery power. 2) This requirement is not applicable to systems that draw propulsion power from the guideway.*

[4.2.3.6-043] The San José Airport ATN System shall ensure that routing decisions are not commanded such that vehicle or guideway switching mechanisms could be in an indeterminate state upon the vehicle's arrival at the guideway diverge point. [Tier 2]
Note: The intent of this requirement is to ensure that the control, communications and switching subsystems have sufficient reaction time to safely execute the switch action. 2) This requirement is not applicable to active-steering systems that do not utilize explicit vehicle or guideway switch mechanisms.

[4.2.3.6-044] The San José Airport ATN System shall be designed to operate with a long-term collision rate of [TBD] and a passenger injury rate of [TBD]. [Tier 2]
Note: The intent is to specify the safety of the San José Airport ATN System at a factor of 2-10 times better than that of traditional automobile traffic. [m]

[4.2.3.6-045] The San José Airport ATN System shall be designed to protect the public from hazards resulting from any aspect of system operations, such as objects or substances falling from the guideways or emitted from the vehicles. [Tier 2]
Note: Solutions to this requirement may include restricting public right of way under or near the ATN system elements, and/or providing catch structures under sections of guideway for which public access restriction is not practical.

4.2.3.7 Security Requirements

[4.2.3.7-001] A System Security Program shall be established for the San José Airport ATN System Project , commencing in the system planning and design phase and maintained throughout the implementation and operation of the system. [Tier 1]
Note: Guidance for System Security Program procedures for systematic identification, resolution and reporting of security events and emergencies are specified in the ASCE APM Standards - Part 4, Section 12.1, "System Security Program."

[4.2.3.7-002] A System Security Program Plan (SSPP) shall be developed and adopted by the transit agency responsible for procuring and operating the San José Airport ATN System, describing the security policies, objectives, responsibilities and procedures to be followed in implementation and operation of the system. [Tier 2]
Note: This requirement is in accordance with U.S. Code of Federal Regulations (CFR) 659, CPUC General Orders 143-B and 164-D, and the references listed in the ASCE APM Standards, Part 4, Annex C.

[4.2.3.7-003] A regulatory approval process shall be developed and adopted by the transit agency responsible for procuring and operating the San José Airport ATN System, which describes and implements the following safety/security responsibilities: [Tier 2]

- Provision of Airport ATN System technical specifications to California safety regulators of fixed guideway systems
- Formation of an independent safety/security team
- Development of a Safety and Security Certification Plan for regulatory review prior to system implementation, acceptance, or operation
- Development of a comprehensive set of hazard/safety cases
- Successful performance of safety/security testing and validation against the complete set of hazard/safety cases
- Planning and conduct of public hearing(s) as provided for by law
- Development of a process for continuing internal safety/security audits and reporting

Note: This process will include active participation of the procuring agency and regulatory authorities, and involves close coordination with the system supplier(s) to ensure that regulatory compliance is well defined in terms of contract provisions and system requirements prior finalizing the system design and project plan.

[4.2.3.7-004] Security features and functions consistent with the principles stated in the ACSE APM Standards, Part 4, Section 12 shall be implemented for the San José Airport ATN System. [Tier 1]

Note: The security principles codified in the APM Standards include threat identification, interagency coordination, emergency preparedness planning, and emergency response training.

[4.2.3.7-005] The San José Airport ATN System shall incorporate audio/visual security features, including but not necessarily limited to: [Tier 2]

- Video surveillance at stations
- Video surveillance in vehicles
- Two-way passenger voice communication with a central control point from vehicles and stations
- Audio announcement capability

[4.2.3.7-006] The San José Airport ATN System shall incorporate additional physical, communications and data security features, including but not necessarily limited to: [Tier 2]

- Automatic and passenger-initiated emergency alarm functions in vehicles
- Automatic and passenger-initiated emergency station re-route controls provided in vehicles
- System data communications security (e.g., data encryption, anti-jamming)
- System control security (anti-hacking) to ensure against malicious spoofing of the control center

4.2.4 Airport ATN System Operational Requirements

This section presents the requirements related to ongoing technical operation of the San José Airport ATN System, as well as operational support for the transit service as experienced by ATN passengers.

4.2.4.1 System Operations

[4.2.4.1-001] The operation of the San José Airport ATN service shall be conducted in accordance with systematic operations planning, documentation and training processes. [Tier 1]
Note: Industry standard guidelines for the conduct and output of these operational processes are described in the ASCE APM Standards, Part 4, Section 15.

[4.2.4.1-002] The operating concepts, processes, procedures and staffing approach for the San José Airport ATN service shall be documented in a System Operations Plan. [Tier 2]
Note: The System Operations Plan should be a contract deliverable finalized prior to the transition from system verification into passenger service operations.

[4.2.4.1-003] The San José Airport ATN System shall operate under 24 hour/day human supervision of the system. [Tier 1]
Note: While the intent is that the ATN be able to normally operate with minimal human intervention, an important part of the operational concept is the provision of system-wide visibility at a manned control center, along with the capability for operators to initiate managed control actions to properly resolve anomalous conditions, safety issues and emergencies.

[4.2.4.1-004] The San José Airport ATN System shall have a procedural method for orderly system startup and shutdown under human operator control. [Tier 2]

Note: Even with the goal of around-the-clock operation, it is anticipated that the ability to institute actions to initialize and shut down the system may be occasionally needed.

[4.2.4.1-005] A method for orderly system startup shall be defined and documented as part of the delivery of the San José Airport ATN System. [Tier 3]

[4.2.4.1-006] The San José Airport ATN System startup sequence shall be manually initiated via established operational procedure. [Tier 3]
Note: The procedure itself is likely to include both human-initiated and automated actions.

[4.2.4.1-007] The San José Airport ATN System startup sequence shall include control system initialization, energizing of power systems, and enablement of vehicles. [Tier 3]

[4.2.4.1-008] A method for orderly system shutdown shall be defined and documented as part of the delivery of the San José Airport ATN System. [Tier 3]
Notes: 1) Even with a 24-hour/day operational concept, it is necessary to have a well-managed system shutdown process for emergency response, major maintenance and repair situations, etc. 2) It may be appropriate for multiple shutdown modes and corresponding procedural action sequences to be defined. For example, a non-emergency shutdown might allow for active vehicles to complete their planned trips, whereas an emergency shutdown sequence might appropriately call for an immediate routing of all vehicles to the nearest station, or even a complete and immediate cessation of vehicle motion. The definition of such modes and their procedural details are TBD.

[4.2.4.1-009] The San José Airport ATN System shutdown sequence shall be manually initiated via established operational procedure. [Tier 3]
Note: The procedure itself is likely to include both human-initiated and automated actions.

[4.2.4.1-010] As part of system shutdown, the San José Airport ATN System shall automatically distribute vehicles to off-line stations, maintenance facilities, and/or other staging areas. [Tier 3]
Note: The intent is to ensure that vehicles a) are not left stopped on a main guideway during the shutdown state, and b) are placed in position to facilitate efficient restart of the system.

[4.2.4.1-011] The capability shall be provided to control and manage the operation of the San José Airport ATN System for maximum passenger and public safety and security. [Tier 1]
Note: The intent of this requirement is ensure that operational actions and responses to safety conditions or emergency situations are facilitated.

[4.2.4.1-012] The San José Airport ATN System shall provide the capability for human operators to take a specifiable set of stations and inter-station guideway links out of service, while leaving the remaining links of the system operating normally. [Tier 2]
Note: the intent of this requirement is facilitate graceful shutdown of selected portions of the system for special events, security situations, emergency response, etc., while maintaining the ability of the system to re-route service to destinations intended to remain available.

[4.2.4.1-013] The San José Airport ATN System shall provide the capability to operationally route vehicles to Terminal stations on an alternate guideway located outside of the TSA-defined blast hazard zone. [Tier 3]
Notes: 1) The precise definition of the TSA blast hazard zone is [TBD]. 2) The intent of this requirement is to ensure that the ATN service can remain operational and passengers can still get to Terminal-accessible stations even during heightened security situations, during which passenger pickup and drop-off adjacent to the Terminals may be severely restricted or completely disallowed. 3) The requirement could be potentially be met by running a guideway behind the existing parking structures opposite the Terminals, and locating station facilities in or near the rear (east) side of the parking structures [TBD].

[4.2.4.1-014] The capability shall be provided to manage the operations of the San José Airport ATN System for maximum system efficiency and economy. [Tier 1]
Note: the intent of this requirement is ensure that operational actions and responses to maximize system usage and minimize associated costs are facilitated.

[4.2.4.1-015] The San José Airport ATN System shall be operated such that the total number of in-service vehicles needed to serve passenger demand levels is minimized. [Tier 2]

[4.2.4.1-016] The San José Airport ATN System shall be operated such that the number of empty vehicles in active circulation is minimized. [Tier 2]

[4.2.4.1-017] The San José Airport ATN System shall provide a manned Control Center facility with capabilities for monitoring, analysis and control of Airport ATN System operations by authorized operational staff. [Tier 1]

[4.2.4.1-018] The San José Airport ATN System Control Center shall provide the system monitoring interface for capabilities including, at a minimum, the following: [Tier 2]

- Selective monitoring of video surveillance feeds from all stations
- Selective monitoring of video surveillance feeds for all guideway segments
- Displaying indication of overall system operational status
- Displaying indication of individual vehicle health and operational status
- Providing display/alarm indications for detected operational anomalies:
  - Disabled or stopped vehicles
  - Collisions
  - Guideway obstructions or failures
  - Vehicle(s) not responsive to commands
  - Loss of communication with individual vehicle(s)
  - Loss of power at station(s) or along guideway
  - Control system error conditions (out-of-limit parameters, loss of sensor data)
  - Computer/communication subsystem failures

- Data gathering for performance measurement and trend analysis

[4.2.4.1-019] The San José Airport ATN System Control Center shall provide the system control interface for capabilities including, at a minimum, the following: [Tier 2]

- Initiating system startup/shutdown sequences
- Override of the Automatic Vehicle Control functionality as specified in section 4.2.3.1, including
  - Taking over control of one or more individual vehicles, including acceleration, deceleration, routing
  - Manually routing vehicles to designated stations or depots
  - Issuing temporary holds on vehicle movements
  - Manually controlling the system operational mode
  - Manually designating route segments as operational or temporarily decommissioned
  - Manually controlling power distribution on a per-zone basis
- Initiating emergency responses

[4.2.4.1-020] The San José Airport ATN System Control Center shall provide the system control interface to operational communication functions including, at a minimum, the following: [Tier 2]

- Voice and video [TBR] links with individual vehicles
- Voice and video links with individual stations
- Communication with Airport Operations/Security and emergency response teams

[4.2.4.1-021] Operational procedures shall be developed and published for the San José Airport ATN System, including detailed operating instructions for all system modes and functions. [Tier 1]

[4.2.4.1-022] The San José Airport ATN System operational procedures shall cover, at a minimum, the following: [Tier 2]

- Execution of the startup and shutdown sequences
- Operational mode control
- Vehicle dispatching
- Vehicle dynamic control
- Power distribution management
- Security surveillance and communication
- Management of alarms and indications
- Failure management

- Emergency response
- Incident reporting procedures
- Service restoration procedures

[4.2.4.1-023] The San José Airport ATN System operational procedures for handling anomaly/failure/outage scenarios and emergency events shall include, at a minimum, the following: [Tier 2]

- Rescue of passengers in a disabled vehicle from any section of the ATN guideway
- Removal of debris from any section of the ATN guideway
- Removal of a failed vehicle from any section of the ATN guideway
    - with failed vehicle movable
    - with failed vehicle immovable
- Re-routing around an inoperable section of the ATN guideway (for vehicle stoppage, guideway damage, etc.)
- "Safing" of vehicle operation upon detection of vehicle failure or loss of communication with a vehicle
- Contacting and deploying emergency response teams

4.2.4.2 Service Operations

[4.2.4.2-001] Enterprise-level service functions that support the role of the San José Airport ATN System as a public transportation service shall be provided. [Tier 1]
Notes: 1) The intent of this requirement is to ensure the quality and consistency of the ATN service as perceived by its clientele, sponsors and operational agencies. 2) The enterprise management functions in this category may include, but are not necessarily limited to, billing and revenue management, customer service, supplier relations, marketing and advertising, enterprise analytics, product support and supply chain management.

[4.2.4.2-002] The San José Airport ATN service shall incorporate Business Services functions including, at a minimum, the following: [Tier 2]

- Consumer fare collection (point of sale)
- Retail sales (monthly passes, etc.)
- Third party revenue (affinity programs, advertising)
- Revenue settlement and reconciliation
- Revenue accounting and data management

[4.2.4.2-003] The San José Airport ATN service shall incorporate Customer Service functions including, at a minimum, the following: [Tier 2]

- "Business to Consumer" Customer Service (for passengers)

- “Business to Business” Customer Service (for suppliers, partners and associated agencies)

[4.2.4.2-004] The San José Airport ATN service shall incorporate Enterprise Analytics functions including, at a minimum, capabilities for: [Tier 2]

- Service usage data analysis
- System performance analysis
- Failure and maintenance event trend analysis

[4.2.4.2-005] The San José Airport ATN service shall provide a Product Support function including, at a minimum, the following: [Tier 2]

- Product development/evolution planning
- Supply chain/logistics management

[4.2.4.2-006] Formal operational monitoring of the San José Airport ATN System shall be conduct in general compliance with ASCE APM Standards, Part 4, Section 16. [Tier 1]

[4.2.4.2-007] Operational monitoring of the San José Airport ATN System shall include annual internal auditing, reporting, and independent audit assessment. [Tier 2]

[4.2.4.2-008] Operational monitoring of the San José Airport ATN System shall result in a evaluation of compliance with Service Level Agreements with suppliers. [Tier 2]

4.2.4.3 Maintenance Operations

[4.2.4.3-001] The San José Airport ATN System shall provide maintenance facilities, processes and services as needed to ensure optimum continuity of ATN service operations. [Tier 1]
Note: The intent of this requirement is to ensure that ATN service availability and system performance are well and consistently maintained at specified levels.

[4.2.4.3-002] The San José Airport ATN System shall operate one or more support facilities for vehicle maintenance and repair. [Tier 2]
Notes: 1) ATN maintenance facilities will be equipped to handle all scheduled and non-scheduled maintenance, repair and testing of vehicles. 2) Specific design constraints relevant to the ATN maintenance and support facilities are described in section 4.2.2.8.

[4.2.4.3-003] The San José Airport ATN System Maintenance Operations function shall provide for vehicle movements between the active guideways and internal guideway sections devoted to maintenance, storage, and staging of vehicles back into active service. [Tier 3]
Notes: 1) These internal maintenance facility guideways are sometimes referred to as “vehicle receiving tracks” and “vehicle-ready tracks.”

[4.2.4.3-004] The San José Airport ATN System Maintenance Operations function shall provide a vehicle control capability to manage intra-facility vehicle movements within the system’s maintenance and storage facilities. [Tier 3]

Notes: 1) Movements of operable vehicles within the maintenance facility would typically be performed under the direction of a separate control system (or special-purpose mode of the system-wide control function). 2) Movements of inoperable vehicles would typically be performed via manual operation of a Maintenance and Recovery Vehicle, acting essentially as a "tug" or towing device.

[4.2.4.3-005] The San José Airport ATN System shall operate one or more facilities for vehicle cleaning. [Tier 2]
Note: The maintenance, repair, and cleaning facilities may but do not have to be collocated.

[4.2.4.3-006] The San José Airport ATN System Maintenance and Repair Facility shall provide the tooling, equipment, supplies, parts, and services to accomplish all vehicle maintenance and repair operations. [Tier 2]

[4.2.4.3-007] The San José Airport ATN System Maintenance and Repair Facility shall provide storage for parts and supplies, arranged for safety and ready accessibility by maintenance personnel. [Tier 3]

[4.2.4.3-008] The San José Airport ATN System Maintenance Operations function shall provide at least one Maintenance and Recovery Vehicle (MRV) at each maintenance and repair facility. [Tier 2]

[4.2.4.3-009] The San José Airport ATN System Maintenance and Recovery Vehicle(s) shall be fully self-powered. [Tier 3]
Note: The intent is that the MRV(s) be usable for all maintenance and recovery operations even in the absence of normal system power.

[4.2.4.3-010] The San José Airport ATN System Maintenance and Recovery Vehicle(s) shall be fully controllable via manual operations from the central control facility. [Tier 3]

[4.2.4.3-011] The San José Airport ATN System Maintenance and Recovery Vehicle(s) shall be fully controllable via manual inputs from within the vehicle. [Tier 3]
Note: The intent is that the MRV(s) be capable of operating in true manual mode, not relying on control actions from the Central Control Facility operational staff.

[4.2.4.3-012] The San José Airport ATN System Maintenance and Recovery Vehicle(s) shall be immediately deployable from the maintenance and repair facilities for recovery operations. [Tier 3]

[4.2.4.3-013] The San José Airport ATN System Maintenance Operations function shall incorporate a process for stocking and replenishment of parts and supplies per an approved Maintenance Plan. [Tier 2]

[4.2.4.3-014] The San José Airport ATN System Maintenance Operations function shall develop, implement and conduct an ongoing formal program of periodic vehicle inspections and maintenance record keeping. [Tier 2]

4.2.4.4 Emergency Operations

[4.2.4.4-001] The San José Airport ATN System shall be designed, implemented and operated in accordance with an Emergency Preparedness Program per the provisions of the ASCE APM Standards, Part 4, Section 13, “Emergency Preparedness.” [Tier 1]

> [4.2.4.4-002] An Emergency Preparedness Program Plan shall be developed and documented for the San José Airport ATN System. [Tier 2]
> *Note: The Emergency Preparedness Program Plan describes the overall emergency management process, roles and responsibilities of the ATN’s supervisory and operational staff, interfaces with ATN System-internal and -external emergency responders, detailed emergency response scenarios, and Continuous Training requirements.*

> [4.2.4.4-003] Operational procedures shall be developed and published detailing the chains of authority, roles and responsibilities, and specific response actions to be taken for the emergency scenarios enumerated in the Emergency Preparedness Program Plan. [Tier 2]

>> [4.2.4.4-004] Operational procedures for emergency response shall include, at a minimum, detailed description of the following for each emergency scenario: [Tier 3]
>> - Notifications and associated communications channels within the ATN system
>> - External notifications and communication channels (e.g., to emergency medical/law enforcement agents)
>> - Specific response actions to be taken in the Control Center and, if applicable, in the field by Airport ATN operational and maintenance staff
>> - Evacuation and rescue procedures, as applicable
>> - Documentation and incident reporting procedures

4.2.5 Airport ATN System Sustainability Objectives

This section describes the Sustainability goals and objectives for the San José Airport ATN System Project , which are designed to be compatible with and complementary to the San José Green Vision.

4.2.5.1 Energy Efficiency

[4.2.5.1-001] The design, implementation and operation of the San José Airport ATN System shall, as a goal, provide improved energy efficiency per unit of transit service between ATN route connections as compared with other transit modes. [Tier 1]
Note: The intent is that the ATN system facilitate transportation-related energy savings in the San José Airport area.

> [4.2.5.1-002] The San José Airport ATN System shall, as a goal, provide transit service with relative energy savings as compared with an average private car trip of the same length. [Tier 2]

[4.2.5.1-003] The San José Airport ATN System shall, as a goal, provide transit service with lower energy consumption per passenger-trip than that needed for other available public transit modes. [Tier 2]
Note: Other modes for comparison could include buses and taxis.

[4.2.5.1-004] The San José Airport ATN System shall incorporate designs to reduce energy use through techniques including, but not necessarily limited to, aerodynamics, regenerative braking, efficient motors, minimization of translational (rolling) resistance, efficient vehicle interior lighting, passive climate control (to the extent possible in meeting cabin environment specifications), and insulation. [Tier 3]

[4.2.5.1-005] The San José Airport ATN System vehicles shall be designed to reduce energy use via a coefficient of drag target value of 0.31 [TBR] or less. [Tier 4]

[4.2.5.1-006] The San José Airport ATN System vehicles shall be designed to reduce energy use via a translational resistance target value of 0.008 [TBR] or less. [Tier 4]

4.2.5.2 Energy Sources

[4.2.5.2-001] The San José Airport ATN System shall utilize renewable energy resources to the maximum extent practical. [Tier 1]

[4.2.5.2-002] The San José Airport ATN System shall be fully powered by non-fossil fuel energy sources at the point of vehicle power utilization. [Tier 2]
Notes: 1) The intent of this requirement is that the vehicles be electrically powered, either via on-board batteries or by drawing electrical power from the guideway. While technically possible, it is specifically <u>not</u> desired that the ATN vehicles be powered by gasoline, diesel, propane, CNG, or other fossil fuel sources. 2) Ethanol and other biofuels, while renewable, are also not desired for use in this San José application due to reasons related to air quality.

[4.2.5.2-003] The San José Airport ATN System shall, to the extent practical, utilize renewable energy sources at the point of power generation. [Tier 2]
Note: It is not a hard requirement that all electricity used in powering of the ATN vehicles and infrastructure be generated from renewable sources; however, it is desired that the proportion be as high as practical in order to limit secondary environmental effects from the generation process.

[4.2.5.2-004] The San José Airport ATN System stations shall, as a goal, be fully powered by non-fossil fuel energy sources for all passenger station operational functions. [Tier 2]
Notes: 1) Passenger station operational functions include lighting, security monitoring, safety elements such as sliding doors, if applicable, and powering of ticketing kiosks, message boards, etc. 2) The inclusion of station elevators and escalators (if applicable) in the scope of this requirement is TBD. 3) A possible approach for consideration relative to this objective is for the ATN system, as a whole, to produce enough renewable energy such that there is zero net fossil fuel energy use at points of passenger station operations (given proper accounting for grid interaction). This could be expected to significantly reduce the amount of energy storage required, thus saving costs.

[4.2.5.2-005] The San José Airport ATN System stations shall incorporate photovoltaic electricity generation equipment as part of station overhead roof structures. [Tier 3]
Note: This requirement is not applicable for stations built and operating inside existing infrastructure.

4.2.5.3 Environmental Compliance

[4.2.5.3-001] The San José Airport ATN System shall, as a goal, operate in compliance with Green Vision goals for maximum environmental protection. [Tier 1]

[4.2.5.3-002] The San José Airport ATN System shall operate with a minimum of direct and indirect greenhouse gas (GHG) emissions. [Tier 2]

[4.2.5.3-003] The San José Airport ATN System shall operate with no direct vehicle GHG emissions. [Tier 3]

[4.2.5.3-004] The San José Airport ATN System shall operate with minimum indirect GHG emissions. [Tier 3]
Note: "Indirect" GHG emissions include those related to electric power generated remotely using fossil fuel sources such as coal or natural gas.

[4.2.5.3-005] The design of the Airport ATN System shall be environmentally compliant with local, state and national regulations and community interests. [Tier 1]

[4.2.5.3-006] The San José Airport ATN System shall operate within community noise standards. [Tier 2]

[4.2.5.3-007] A procedural method shall be implemented for identification, analysis and mitigation of noise or vibration issues arising from operation of the San José Airport ATN System. [Tier 3]

[4.2.5.3-008] The San José Airport ATN System shall be designed, implemented and operated in compliance with local regulations for handling water runoff from ATN facilities. [Tier 2]

[4.2.5.3-009] The San José Airport ATN System shall be designed, implemented and operated in compliance with local regulations and standards for facility aesthetic design, unintended barrier effects on views or accessibility to other public areas, and related zoning and encroachment issues. [Tier 2]

[4.2.5.3-010] The San José Airport ATN System shall be designed, implemented and operated in compliance with locally applicable regulations regarding Electromagnetic Interference (EMI) and Electromagnetic Resonance (EMR) testing, evaluations, and limits. [Tier 2]

[4.2.5.3-011] The San José Airport ATN System shall be designed and implemented so as to protect environmentally sensitive areas in and adjacent to SJC airport property (e.g., the Guadalupe River). [Tier 2]

4.2.5.4 Materials and Recyclability

[4.2.5.4-001] The San José Airport ATN System shall, as a goal, minimize negative environmental impacts from the materials and supplies used in the implementation, operation, and maintenance of the system. [Tier 1]

> [4.2.5.4-002] The San José Airport ATN System components shall be designed, implemented and operated so as to minimize use of hazardous materials and supplies. [Tier 2]
>
> > [4.2.5.4-003] Electrical storage batteries used in the San José Airport ATN System shall contain less than 0.0005% mercury and 0.002% cadmium. [Tier 3]
> >
> > [4.2.5.4-004] The San José Airport ATN System shall be designed, implemented, and operated so as to maximize recyclability of batteries and other waste products. [Tier 3]
> >
> > [4.2.5.4-005] The San José Airport ATN System shall be designed, implemented, and operated in accordance with a recycling plan that ensures that all potentially hazardous materials, including but not necessarily limited to mercury, cadmium, lead, battery casings and internal materials, and electronic components, will be properly and accountably disposed. [Tier 3]
>
> [4.2.5.4-006] The San José Airport ATN System vehicles and other system components shall be designed to be easily maintained with minimum material/supply wastage and energy expenditure. [Tier 2]
>
> [4.2.5.4-007] The San José Airport ATN System vehicles and other system components shall be designed to be easily deconstructed at end of life. [Tier 2]

4.2.6 Airport ATN System Economic Objectives

This section specifies the economic objectives for the San José Airport ATN System, in terms of capital investment, operational expense, revenue potential, and related factors.

4.2.6.1 Investment Constraints

[4.2.6.1-001] The San José Airport ATN System shall be developed, procured, and operated within a defined cost and schedule envelope. [Tier 1]
Note: The intent is to ensure that the investment required for the system acquisition is limited to an amount acceptable to the primary stakeholders.

> [4.2.6.1-002] The San José Airport ATN System shall be implemented within a per-mile capital investment cost of $[TBD] million. [Tier 2]
> *Note: The per-mile capital cost includes the procurement of all system components (guideways, vehicles, stations, control elements, and supporting facilities and services), in addition to any design, development, and testing costs required to enable procurement of the system components.*

[4.2.6.1-003] The San José Airport ATN System shall be operated and maintained within an annual budget that does not exceed current levels of recurring expenditure (adjusted for inflation) on comparable public transit services in and around the airport. [Tier 2]
Notes: 1) The intent is that the ATN system be, at most, "cost-neutral" to the airport relative to current airport transit operation expenses. 2) The recurring cost elements of the ATN system include operation, maintenance, repair, replacement, and depreciation [TBR] of all system components (guideways, vehicles, stations, control elements, and supporting facilities and services), but not including amortization of the original capital investment [TBR].

[4.2.6.1-004] The San José Airport ATN System shall, as a goal, meet a "cost per unit of service" target of [TBD]. [Tier 1]

4.2.6.2 Airport Revenue Objectives

[4.2.6.2-001] The implementation and operation of the San José Airport ATN System shall be designed so as to enhance the San José International Airport revenue stream. [Tier 1]
Note: The intent is that the ATN system facilitate direct and indirect benefit to the airport's current and future financial goals.

[4.2.6.2-002] The San José Airport ATN System shall be implemented such that it will encourage additional use of the SJC Airport. [Tier 1]
Note: The intent is that the ATN will add potential revenue to the airport due to increased use of airport facilities and services.

[4.2.6.2-003] The San José Airport ATN System shall be designed, implemented, and operated to improve the access to the San José International Airport for economically disadvantaged groups. [Tier 2]
Note: The intent is that the ATN will make the airport more accessible to economically-disadvantaged groups that are unable to use private automobiles.

[4.2.6.2-004] The implementation and operation of the San José Airport ATN System shall be such that no fare is required for San José International Airport customers to use the system for travel between the terminals and any other Airport facilities. [Tier 2]
Note: The intent is that the ATN fulfill a primary role of providing free transportation to airport customers. It may, however, ultimately be part of a larger integrated system with potential fare-carrying additional routes. The revenue concept for such an extended system is TBD.

[4.2.6.2-005] The San José Airport ATN System shall not devalue or detract in any way from the Airport's current revenue sources (e.g., parking fees, rental car fees) without providing compensating revenue additions. [Tier 2]

[4.2.6.2-006] The San José Airport ATN System shall be implemented such that it will encourage additional use of other public transportation systems in the San José International Airport area. [Tier 1]
Note: The intent is that the ATN will enhance the desirability and utilization of the area's existing public transit services.

4.2.6.3 Land Use/Transit-Oriented Development Objectives

[4.2.6.3-001] The San José Airport ATN System functionality and route connectivity shall promote efficient land use in and around the Airport. [Tier 1]
Note: The intent is that the ATN facilitate a wider range of choices for airport-area property development by offering ready accessibility to key airport locations.

[4.2.6.3-002] The San José Airport ATN System functionality and route connectivity shall facilitate opportunities for Transit-Oriented Development in and around the Airport. [Tier 1]
Note: The intent is that the ATN facilitate a wider range of choices for airport-area property development by offering ready accessibility to key Airport-related commercial locations.

4.2.6.4 Economic Opportunity Objectives

[4.2.6.4-001] The design, implementation and operation of the San José Airport ATN System shall be performed so as to enhance the presence and involvement of the City of San José, and its resident industrial and technology base, in the ATN industry. [Tier 1]
Note: The intent is that the Airport ATN System project facilitate ATN industry evolution in the San José area.

[4.2.6.4-002] The design, implementation and operation of the San José Airport ATN System shall be performed so as to enhance number and quality of professional, technical, "green" manufacturing, and service employment opportunities in the San José area. [Tier 1]
Note: The intent is that the Airport ATN System project facilitate direct and indirect ATN industry employment in the San José area.

4.2.7 Airport ATN System Acquisition and Delivery Requirements

The purpose of this section is to specify Airport ATN System Project objectives related to key procurement decision factors and other attributes important to a successful acquisition.

4.2.7.1 Financing Objective

[4.2.7.1-001] The San José Airport ATN System Project shall establish a process for identification and analysis of alternative financing options, and conduct a comparative assessment to determine the optimal financing approach to achieve the Project goals and objectives. [Tier 1]

4.2.7.2 Funding Objective

[4.2.7.2-001] The San José Airport ATN System Project shall establish and conduct a process to determine the most efficient use of federal and state funding sources available to achieve the Project Goals and Objectives. [Tier 1]

> [4.2.7.2-002] A well-defined plan for funding the acquisition of the San José Airport ATN System Project will be developed before letting contracts for system procurement. [Tier 2]
> *Note: The intent is to avoid contract penalties that may result if a poorly-defined funding plan results in acquisition funds being delayed or not materializing.*

[4.2.7.2-003] The ability to use commercial financing (e.g., a partnership with the private entity developing the system) will be investigated as a potential source for funding the acquisition of the San José Airport ATN System Project. [Tier 3]
Note: The intent is to try to identify and take advantage of potential private partnership opportunities for the Airport ATN System Project development.

4.2.7.3 Value for Money Objective

[4.2.7.3-001] The San José Airport ATN System Project shall perform the analysis necessary to identify a solution that demonstrates the maximum Project benefit measured against the Airport ATN System Project Goals and Objectives over the life of the project. [Tier 1]

4.2.7.4 Risk Transfer Objective

[4.2.7.4-001] The San José Airport ATN System Project shall achieve an optimal level of risk transfer from the public sector to the private sector through a commercial and contract structure. [Tier 1]

4.2.7.5 Cost and Schedule Certainty Objective

[4.2.7.5-001] The San José Airport ATN System Project shall achieve cost and schedule certainty to the greatest extent practical. [Tier 1]

[4.2.7.5-002] The cost of procuring the San José Airport ATN System shall be estimated using the Federal Transit Administration (FTA) Standard Cost Categories (SCC). [Tier 2]
Note: The intent is that the cost estimates for procuring the Airport ATN system will be in a format comparable with other transit systems, and will also meet the FTA New Start funding program guidelines for cost estimates.

[4.2.7.5-003] If the San José Airport ATN System requires additional design, development, and testing before procurement, this additional cost will be estimated separately from the procurement cost. [Tier 3]
Note: The intent is to estimate separately any additional costs required to mature the system to the point of being able to be procured in a manner similar to other transit systems.

[4.2.7.5-004] The time required to procure the San José Airport ATN System will be estimated using the standard FTA acquisition phases. [Tier 2]
Note: Any additional time required for the design, development, and testing of the system should be estimated in a separate category. The intent is to estimate the schedule required to procure the system using standard acquisition phases, as well as capture any additional time required to mature the system to the point of being able to be procured in a manner similar to other transit systems.

[4.2.7.5-005] Any cost and schedule estimates for the San José Airport ATN System will incorporate uncertainty as appropriate (e.g., by providing the confidence level associated with the cost or schedule estimate, such that it captures uncertainties in the model and model inputs). [Tier 2]
Note: The intent is that the uncertainty in the cost and schedule estimate of the ATN system be well defined, and capture the uncertainties in both models and model inputs.

[4.2.7.5-006] Any private entity acting as a prime contractor during the acquisition of the San José Airport ATN System Project shall establish cost and schedule commitments to the public entity managing the acquisition regarding the development and procurement of the system components. [Tier 2]
Note: The intent is to establish clearly-defined cost and schedule targets for the development and procurement of the system.

[4.2.7.5-007] The San José Airport ATN System Project acquisition process will utilize contractor incentives as appropriate to reduce the cost and schedule risk in the acquisition. [Tier 3]
Note: The intent is to incentivize the contractor(s) to meet cost and schedule commitments through the use of appropriate mechanisms (e.g., bonuses for early completion, withholding of award fee for poor performance, etc.).

4.2.7.6 Operations and Maintenance Investment Objective

[4.2.7.6-001] The San José Airport ATN System Project shall perform analysis and make the investment necessary to achieve an optimally cost-effective level of operations and maintenance service over the life of the project. [Tier 1]

4.2.7.7 Revenue Objective

[4.2.7.7-001] The San José Airport ATN System Project shall achieve an optimal level of revenue without compromising other Airport ATN System Project Goals and Objectives. [Tier 1]
Notes:1) For example, maximizing passenger ridership and increasing the energy efficiency of transit in and around the SJC Airport could be considered as objectives of equal or greater importance than revenue generation. 2) The San José Airport ATN could ultimately be a zero revenue generating project, yet still be successful in optimally achieving the overall Project Goals and Objectives.

4.2.7.8 Service Quality Objective

[4.2.7.8-001] The San José Airport ATN System Project shall achieve an optimal level of service quality without compromising other Project Goals and Objectives, such as achieving Value for Money. [Tier 1]

4.2.7.9 Acquisition Roles and Responsibilities

[4.2.7.9-001] The San José Airport ATN System Project shall be procured in accordance with well-established buyer and supplier roles and responsibilities. [Tier 1]

[4.2.7.9-002] The acquisition of the San José Airport ATN System Project will be managed by a public entity and may use private entities as contractors to build the system. [Tier 2]
Note: The intent is that the system acquisition be managed by a public group with no vested commercial interests in the system design.

[4.2.7.9-003] The public entity managing the San José Airport ATN System Project acquisition shall consider the use of qualified consultants to provide technical expertise, system integration and project management support during the acquisition of the system. [Tier 3]

[4.2.7.9-004] The public entity managing the San José Airport ATN System Project acquisition shall consider the use of an independent integration and verification contractor to provide objective assessment of the acquired system prior to formal acceptance. [Tier 3]

[4.2.7.9-005] The public entity managing the acquisition of the San José Airport ATN System will establish and communicate clearly-defined requirements and constraints on the system (e.g., station locations, minimum performance requirements, etc.) to all entities involved in the system acquisition. [Tier 3]
Note: The intent is to ensure that the requirements on the system acquisition are clearly defined and understood among all parties involved in the acquisition.

4.2.7.10 Procurement Integrity

[4.2.7.10-001] The San José Airport ATN System Project shall be procured in accordance with the highest standards of procurement transparency and integrity. [Tier 1]

[4.2.7.10-002] The San José Airport ATN System Project shall be procured in compliance with local, state and national codes, standards, and regulations applicable to the procurement of public transit systems. [Tier 2]
Note: The intent is that the ATN system be procured in manner meeting the letter and the spirit of all legal requirements and obligations.

[4.2.7.10-003] The acquisition of the San José Airport ATN System shall be conducted in compliance with [TBD] procurement regulations and codes. [Tier 3]

[4.2.7.10-004] The acquisition of the San José Airport ATN System shall be conducted so as to ensure competition, fairness, transparency and accountability throughout the procurement process. [Tier 3]

[4.2.7.10-005] The San José Airport ATN System Project shall be procured in a manner that provides maximum protection of the public interest. [Tier 2]

[4.2.7.10-006] The acquisition of the San José Airport ATN System shall be managed in compliance with [TBD] accounting and auditing standards. [Tier 3]

4.2.8 Airport ATN System Project Management Requirements

The purpose of this section is to highlight the key project management and system development life cycle processes to be used for the San José Airport ATN System Project.

4.2.8.1 Project Management Process

[4.2.8.1-001] The San José Airport ATN System Project shall be executed in accordance with processes defined in a formal Project Management Plan, tailored to the selected procurement methodology. [Tier 1]

[4.2.8.1-002] The San José Airport ATN System Project shall be managed in accordance with a Work Breakdown Structure that defines all Project tasks and deliverables. [Tier 2]

[4.2.8.1-003] The San José Airport ATN System Project shall define the hierarchy and content of documents and data products per a Contract Data Requirements List. [Tier 2]

[4.2.8.1-004] The San José Airport ATN System Project shall incorporate a Master Project Scheduling and progress tracking system. [Tier 2]

[4.2.8.1-005] The San José Airport ATN System Project shall define a schedule of regular progress meetings and status reports. [Tier 2]

[4.2.8.1-006] The San José Airport ATN System Project shall define and conduct a process to ensure ongoing integration and coordination of effort between the City and all suppliers, associate contractors and consultants participating in the Project. [Tier 2]

4.2.8.2 Risk Management

[4.2.8.2-001] The San José Airport ATN System Project shall establish a Risk Management program at the inception of the project and conduct an associated Risk Management process throughout the procurement. [Tier 1]

[4.2.8.2-002] As part of the acquisition process, a risk management system shall be implemented such that discrete threats and opportunities will be identified, tracked, and mitigated to the extent possible. [Tier 2]
Note: The intent is to use industry-standard practices to manage the risk to the system acquisition, and to help identify potential opportunities for technical improvements and/or cost savings.

[4.2.8.2-003] Threats and opportunities will be defined using the industry-standard process of assessing the likelihood of occurrence and the consequence if the threat occurs. [Tier 3]
Note: The intent is to use industry-standard practices to manage the risk to the system acquisition.

[4.2.8.2-004] The likelihood of occurrence and the consequence will be used to calculate an expected value (likelihood multiplied by the estimated cost impact if the threat occurs). [Tier 3]
Note: The intent is to use industry-standard practices to manage the risk to the system acquisition.

[4.2.8.2-005] For each threat tracked in the risk management system, a mitigation plan will be developed. [Tier 3]
Note: While a mitigation plan will be developed for each risk, it is expected that in some cases, complete mitigation may not be possible.

[4.2.8.2-006] Threats and opportunities will be reassessed at regular intervals (e.g., monthly), such that the risk descriptions, likelihoods, consequences, expected values, mitigation plans, and status are updated as appropriate. [Tier 3]

Note: The intent is to keep the understanding of the threats and opportunities up to date as the acquisition progresses.

[4.2.8.2-007] A threat will be removed from the risk management system and converted into a lien when it is determined that the likelihood of occurrence is 100%. [Tier 3]
Note: A lien will be encumbered into the acquisition budget at the next available opportunity.

4.2.8.3 Systems Engineering and Integration

[4.2.8.3-001] The San José Airport ATN System Project shall follow industry standard Systems Engineering precepts and processes as defined in a Project Systems Engineering Management Plan (SEMP), established and baselined at the inception of the Project and followed throughout the procurement. [Tier 1]

4.2.8.3.1 System Analysis and Planning
[4.2.8.3-002] The San José Airport ATN System Project's System Engineering and Integration processes shall provide for systematic analysis and planning of the overall system prior to the commencement of design and development activity. [Tier 1]

[4.2.8.3-003] The San José Airport ATN System Project shall define the high-level external requirements and constraints on system design, implementation and operation prior to specification of the system configuration and development requirements. [Tier 2]

[4.2.8.3-004] The San José Airport ATN System Project shall determine the regulatory certification and approval process requirements for the ATN system as a prerequisite for system design and development. [Tier 2]
Note: The goal is to firmly establish the requirements for permits, regulatory compliance, compliance verification and certification prerequisites early in the System Engineering process.

[4.2.8.3-005] The San José Airport ATN System Project shall generate a high-level Operational Concept and associated reference drawings as a prerequisite to detailed requirements definition and generation of engineering specification/blueprints. [Tier 2]

[4.2.8.3-006] The San José Airport ATN System Project shall generate a Software Development Plan detailing the development processes and methodologies for all non-COTS software to be deployed in the ATN system. [Tier 2]

[4.2.8.3-007] Non-COTS software for use in the San José Airport ATN System shall be developed in accordance with the principles of CMMI Level 3 or higher. [Tier 3]

4.2.8.3.2 Requirements Management

[4.2.8.3-008] The San José Airport ATN System Project shall establish and conduct an INCOSE-compliant Requirements Management process throughout the entire System Development Life Cycle process for the ATN system. [Tier 1]

[4.2.8.3-009] The Requirements Management process for the San José Airport ATN System Project shall facilitate systematic definition and documentation of all project technical and programmatic requirements. [Tier 2]

[4.2.8.3-010] The Requirements Management process for the San José Airport ATN System Project shall provide for systematic reconciliation of conflicting requirements within and between Project specifications, regulatory codes, design and implementation standards, legal requirements, and related influences. [Tier 2]

[4.2.8.3-011] The Requirements Management process for the San José Airport ATN System Project shall provide for baseline management and version control for all requirements specifications and documents. [Tier 2]

[4.2.8.3-012] The Requirements Management process for the San José Airport ATN System Project shall operate in conjunction with the Project's overall change control and impact assessment processes, such that proposed changes to baselined requirements are introduced, tracked, assessed and formally dispositioned in a systematic fashion. [Tier 2]

[4.2.8.3-013] The Requirements Management process for the San José Airport ATN System Project shall incorporate sub-processes for requesting, evaluating, approving and recording requirement waivers and variances. [Tier 2]

4.2.8.3.3 System Design

[4.2.8.3-014] The San José Airport ATN System Project shall establish and conduct a system design process compliant with industry standard System Development Life Cycle methodologies, with tailored applicability to the ATN system. [Tier 1]

[4.2.8.3-015] The San José Airport ATN System Project shall establish and conduct a sequence of progressively detailed system design reviews per a Design Review plan established as part of the Project Management Plan. [Tier 2]

[4.2.8.3-016] Approval of each Design Review baseline shall be a pre-requisite for approval to proceed to the subsequent phase of the development life cycle. [Tier 3]

4.2.8.3.4 System Interface Management

[4.2.8.3-017] The San José Airport ATN System Project shall establish and conduct a System Interface Management process compliant with industry standard System Engineering and Integration methodologies, with tailored applicability to the Airport ATN system. [Tier 1]

[4.2.8.3-018] The San José Airport ATN System Project shall define and include appropriate Interface Control Documents in the Project document hierarchy. [Tier 2]

[4.2.8.3-019] Interface Control Documents shall be generated for all integrations of Airport ATN System elements with external infrastructure, including but not necessarily limited to fixed facilities and equipment, airport structures, local power distribution and existing communications networks. [Tier 3]

[4.2.8.3-020] Interface Control Documents shall be generated for all interfaces between major subsystems of the Airport ATN system. [Tier 3]
Note: Examples include the vehicle/guideway interface and the control subsystem/propulsion subsystem interface.

[4.2.8.3-021] The San José Airport ATN System Project shall establish and conduct an Interface Control process to define and manage the technical interfaces between ATN system elements. [Tier 2]
Notes: 1) The Interface Control process should be actively supported by all suppliers, contractors, consultants and buyer representatives/agents. 2) It is especially important that interfaces be carefully managed and documented between deliverable components sourced from multiple suppliers, including interfaces to public utilities.

4.2.8.3.5 System Implementation Management

[4.2.8.3-022] The San José Airport ATN System Project shall establish and conduct a System Implementation Management process with tailored applicability to the Airport ATN system. [Tier 1]

[4.2.8.3-023] The San José Airport ATN System Project shall establish and conduct a process for overall system development and installation oversight. [Tier 2]

[4.2.8.3-024] The San José Airport ATN System Project shall establish and conduct a process for work site coordination. [Tier 2]

[4.2.8.3-025] The San José Airport ATN System Project shall establish and conduct a process for construction and installation safety per a Project Site Safety Plan. [Tier 2]

[4.2.8.3-026] The San José Airport ATN System Project shall establish and conduct a process for construction reviews and inspections. [Tier 2]

4.2.8.4 Airport ATN Service Integration

[4.2.8.4-001] The San José Airport ATN System and its operational support functions, including operational monitoring and control, maintenance and repair, and enterprise support services, shall be integrated and verified in accordance with an Airport ATN Service Integration Plan. [Tier 1]
Note: The intent of the Service Integration process, as documented in the Service Integration Plan, is to ensure that the operational elements of the overall ATN service are well-integrated with the ATN technical system.

4.2.8.5 System Configuration Management and Change Control

[4.2.8.5-001] The San José Airport ATN System Project shall establish and conduct formal system Configuration Management and Data Management processes in order to maintain orderly management of all aspects of design, construction, fabrication and installation and documentation of the ATN system. [Tier 1]

[4.2.8.5-002] The San José Airport ATN System Project shall establish and comply with a System Configuration Management Plan (SCMP). [Tier 2]

Note: The SCMP describes processes and procedures for maintaining controlled versions of requirements, interface specifications, designs, verification plans and results, and related documentation.

[4.2.8.5-003] The San José Airport ATN System Project shall establish a Project Data Management system, featuring a document, data and correspondence repository with version maintenance, change logging and change history, and kept current and active throughout the life of the Project. [Tier 2]

[4.2.8.5-004] The San José Airport ATN System Project shall establish and conduct a Change Control process in order to facilitate and communicate changes to the Project requirements, design, and documentation baselines in a timely and orderly fashion. [Tier 1]

4.2.8.6 System Verification and Demonstration

[4.2.8.6-001] The San José Airport ATN System Project shall establish and conduct a formal System Verification and Demonstration process in accordance with the ASCE APM Standards, Part 4, Section 14. [Tier 1]

[4.2.8.6-002] The San José Airport ATN System Project shall establish a System Verification Plan, generated by the primary system supplier and approved by the City, that clearly defines the overall verification process and criteria for successful demonstration of the delivered ATN system. [Tier 2]

[4.2.8.6-003] The San José Airport ATN System Project shall establish System Verification procedures, generated by the primary system supplier and approved by the City, that clearly define the verification scenarios (test cases) and associated inputs, processes, outputs, test conditions and success criteria for all required features, functions, and performance levels of the delivered ATN system. [Tier 2]

[4.2.8.6-004] The San José Airport ATN System Project shall conduct QA-witnessed tests and demonstrations of ATN system features, functions and performance in accordance with the System Verification Procedures. [Tier 2]

[4.2.8.6-005] The San José Airport ATN System Project shall record, document and report the results of all tests and demonstrations of ATN system features, functions and performance in accordance with the System Verification Procedures. [Tier 2]

[4.2.8.6-006] The San José Airport ATN System Project shall generate liens and work-off plans for all tests and demonstrations of ATN system features, functions, and performance levels for which the success criteria were not fully met. [Tier 2]

4.2.8.7 System Acceptance

[4.2.8.7-001] The San José Airport ATN System Project shall establish and conduct a formal System Acceptance process in accordance with the ACSE APM standards, Part 4, Annex A. [Tier 1]

4.2.8.8 Quality Assurance

[4.2.8.8-001] The San José Airport ATN System Project shall be conducted in accordance with a Quality Assurance program compliant with ISO 9000 - 9004. [Tier 1]

> [4.2.8.8-002] The San José Airport ATN System Project shall be implemented in accordance with a Quality Assurance Plan that describes how the Quality Assurance program will be conducted over the life cycle of the Project. [Tier 2]
> *Note: The Quality Assurance Plan will be an implementation contractor-deliverable document.*

> [4.2.8.8-003] The San José Airport ATN System Project implementation contractor shall institute a Quality Management System that assures the quality and integrity of, at a minimum, the following: [Tier 2]

- Adequate documentation of all planning, construction, manufacturing, installation and testing
- The processes for packaging, shipping, handling and storage of subsystems, components and materials
- The processes for acceptance testing of all items procured through the supply chain (e.g., vehicles)
- The processes for inspection and acceptance of all constructed elements of the system
- The processes for on-site integration and checkout of the constructed system

4.2.9 Additional Airport ATN System Requirements

This final section captures additional requirements potentially relevant to the design, development, verification, operation and maintenance of the San José Airport ATN System and the overall public transit service is supports.

4.2.9.1 Legal Requirements

[4.2.9.1-001] The San José Airport ATN System Project shall establish and adhere to policies and procedures for protection of proprietary information and trade secrets of the Project's suppliers and/or or Partners in accordance with the California Public Records Act (CPRA). [Tier 1]

4.2.9.2 Indemnification Requirements

[4.2.9.2-001] The San José Airport ATN System Project shall formulate a strategy for protecting the City and associated suppliers, contractors, and consultants from liability from implementation and operation of the Airport ATN service. [Tier 1]

4.2.9.3 Promotion of Industry Standards

[4.2.9.3-001] The San José Airport ATN System Project shall actively promote and support ATN industry efforts to define common standards for ATN system interfaces, protocols, technologies, and modular components. [Tier 1]

4.2.9.4 Support for Regulatory Requirements Definition

[4.2.9.4-001] The San José Airport ATN System Project shall actively engage and support the efforts of cognizant regulatory agencies with authority over public transit systems in California, to assist in the definition of effective, ATN-specific regulatory rules, restrictions and constraints. [Tier 1]

4.2.10 Miscellaneous Requirements

[TBD]

4.3 Airport ATN System Project Requirement Attributes and Traceability

This section includes traceability information and additional metadata for each Project Requirement as listed in the following table. The data elements listed for each requirement are:

- *Requirement ID:* A unique reference number for each individual requirement.
- *Short Title:* An abbreviated statement of the requirement content, to assist in interpreting traceability relationships and verification information (e.g., in separate Verification Plans).
- *Tier:* The hierarchical level of the requirement, as described in section 3.
- *R/O:* An indication of whether the requirement is to be considered as a formal compliance item (R) or a statement of objective (O) not intended for official verification.
- ↑ *Trace:* The higher level "parent" (superordinate) requirement(s) from which this requirement is derived.
- ↓ *Trace:* The lower level "child" (subordinate) requirement(s) which flow down from this requirement.
- *Cat.:* The topical category of the requirement, per the category definitions in section 3.
- *VM:* The verification method(s) recommended for assessing the extent to which the requirement is satisfied. The verification methods assigned in this document include the following:
    - *I (Inspection):* Satisfaction of the requirement is shown by direct observation of a specific artifact or system element
    - *A (Analysis):* Compliance is verified via use of numeric methods, mathematical models, qualified simulation, or similar means
    - *D (Demonstration):* Satisfaction of the requirement is shown via normal use or operation of the system or process element
    - *T (Test):* Compliance is verified with the assistance of hardware or software instrumentation, test/measurement equipment, test databases, etc.

- *V (Validation):* A long-range process of data gathering, performance monitoring, and trend analysis to verify continuous compliance over the system life cycle

- *Eff:* The "effectivity" (temporal applicability) of the requirement. The values for effectivity used in this document are the following:
  - Φ3: "Phase 3," indicating the requirement is intended to be effective in the initial baseline development phase of the Airport ATN System per the current three-phase Project definition
  - TBD: Indicates a to-be-defined "future" effectivity for the requirement, for which consideration should generally be given during the initial phase design process

- *Alloc.:* The entity(ies) to which responsibility for meeting the requirement is assigned. The values for allocation used in this document are the following:
  - S: Supplier and/or supplier agents
  - B: Buyer and/or buyer's consultants or agents

In future revisions of this document, the range of values for the Alloc. field may be refined to indicate more specifically the organizational entities, system element(s), subsystem(s) or component(s) that bear full or partial responsibility for ensuring the requirement is met.

Req't ID	Short Title	Tier	R/O	↑ Trace	↓ Trace	Cat.	VM	Eff.	Alloc.
4.1	Project Goals and Objectives								
4.1-001	Airport connections to fulfill Measure A ballot initiative	0	R	n/a	(a)	PGO	D	Φ3	S, B
4.1-002	Improve local public transit around the airport	0	O	n/a	(b)	PGO	V	Φ3	S, B
4.1-003	Improve the convenience of access to and from the airport	0	O	n/a	(c)	PGO	V	Φ3	S, B
4.1-004	Reduce airport transit service operational costs	0	O	n/a	(d)	PGO	V	Φ3	S, B
4.1-005	Facilitate increased utilization of other transit services	0	O	n/a	(e)	PGO	V	Φ3	S, B
4.1-006	Provide environmentally sound and energy efficient transit	0	O	n/a	(f)	PGO	V	Φ3	S, B
4.1-007	Promote innovation in transportation technology	0	O	n/a	(g)	PGO	V	Φ3	S, B
4.1-008	Generate "clean technology" employment opportunities	0	O	n/a	(h)	PGO	V	Φ3	S, B
4.1-009	Provide foundation for sustainable development	0	O	n/a	(i)	PGO	V	Φ3	S, B
4.1-010	Address key stakeholder needs, objectives and constraints	0	O	n/a	(j)	PGO	V	Φ3	S, B
4.2.1	ATN Transit Service Needs								
4.2.1.1	ATN Connectivity								
4.2.1.1-001	Connect SJC Terminals with local transit services	1	R	4.1-001	4.2.1.1-002	SVC	D	Φ3	S

Req't ID	Short Title	Tier	R/O	↑ Trace	↓ Trace	Cat.	VM	Eff.	Alloc.
4.2.1.1-002	Bidirectional connection between Terminals A and B	2	R	4.2.1.1-001	4.2.1.1-003	SVC	D	Φ3	S
4.2.1.1-003	Connection with a terminal of the VTA LRT system	2	R	4.2.1.1-001	4.2.1.1-004	SVC	D	Φ3	S
4.2.1.1-004	Connection from any ATN station to Metro-Airport station	3	R	4.2.1.1-003	-	SVC	D	Φ3	S
4.2.1.1-005	Connection with a terminal of the Caltrain system	2	R	4.2.1.1-001	4.2.1.1-006	SVC	D	Φ3	S
4.2.1.1-006	Connection from any ATN station to Santa Clara station	3	R	4.2.1.1-005	-	SVC	D	Φ3	S
4.2.1.1-007	Connection with a terminal of the BART system	2	R	4.2.1.1-001	4.2.1.1-008	SVC	D	TBD	S
4.2.1.1-008	Connection from ATN stations to Santa Clara BART station	3	R	4.2.1.1-007	-	SVC	D	TBD	S
4.2.1.1-009	Provide connection between current and future terminals	2	R	4.2.1.1-001	-	SVC	D	TBD	S
4.2.1.1-010	System must serve the Airport Terminal facilities equitably	2	R	4.2.1.1-001	4.2.1.1-011, 4.2.1.1-012	SVC	D	Φ3	S
4.2.1.1-011	Symmetrical connections between Terminals A and B	3	R	4.2.1.1-010	-	SVC	D	Φ3	S
4.2.1.1-012	Symmetrical connections with future terminal facilities	3	R	4.2.1.1-010	-	SVC	D	TBD	S
4.2.1.1-013	Connect with other stations in the Airport area	1	R	4.1-002	4.2.1.1-014	SVC	D	Φ3	S
4.2.1.1-014	Select other station locations to minimize walking distances	3	R	4.2.1.1-013	-	SVC	A	Φ3	S
4.2.1.1-015	Extend connections to other locations in the San José area	1	R	4.1-002, 4.1-005, 4.1-009	-	SVC	D	Φ3	S
4.2.1.2	Service Transit Times								
4.2.1.2-001	Provide ATN time-efficient transit service	1	R	4.1-002	4.2.1.2-002	SVC	A	Φ3	S
4.2.1.2-002	Achieve specified transit service times	2	R	4.2.1.2-001	-	SVC	D	Φ3	S
4.2.1.3	System Capacity								
4.2.1.3-001	Support system-wide peak service demand	1	R	4.1-002, 4.1-003	4.2.1.3-002	SVC	A, D	Φ3	S
4.2.1.3-002	Support system-wide peak hour demand	2	R	4.2.1.3-001	4.2.1.3-003	SVC	A, D	Φ3	S
4.2.1.3-003	Provide sufficient vehicles to serve peak hour demand	3	R	4.2.1.3-002	-	SVC	A, D	Φ3	S

Req't ID	Short Title	Tier	R/O	↑ Trace	↓ Trace	Cat.	VM	Eff.	Alloc.
4.2.1.3-004	Support expected usage between O-D pairs	1	R	4.1-002, 4.1-003	4.2.1.3-005, 4.2.1.3-006, 4.2.1.3-007	SVC	A, D	Φ3	S
4.2.1.3-005	Support peak hour demand between O-D pairs	2	R	4.2.1.3-004	-	SVC	A, D	Φ3	S
4.2.1.3-006	Support asymmetrical traffic patterns	2	R	4.2.1.3-004	-	SVC	A, D	Φ3	S
4.2.1.3-007	Support instantaneous peak demand between O-D pairs	2	R	4.2.1.3-004	-	SVC	A, D	Φ3	S
4.2.1.4	ATN Service Features								
4.2.1.4-001	Provide service to all stations	1	R	4.1-002, 4.1-003	4.2.1.4-002, 4.2.1.4-003, 4.2.1.4-004, 4.2.1.4-005, 4.2.1.4-006	SVC	D	Φ3	S
4.2.1.4-002	Provide service 24/7/365	2	R	4.2.1.4-001	-	SVC	D	Φ3	S
4.2.1.4-003	All ATN stations active all day	2	R	4.2.1.4-001	-	SVC	D	Φ3	S
4.2.1.4-004	No need for advance vehicle request	2	R	4.2.1.4-001	-	SVC	D	Φ3	S
4.2.1.4-005	Can make an advance vehicle request	2	R	4.2.1.4-001	-	SVC	D	Φ3	S
4.2.1.4-006	Provide an empty vehicle upon request	2	R	4.2.1.4-001	-	SVC	D	Φ3	S
4.2.1.4-007	Provide freely accessible service	1	R	4.1-002, 4.1-003	4.2.1.4-008, 4.2.1.4-009, 4.2.1.4-010, 4.2.1.4-011, 4.2.1.4-012	SVC	D	Φ3	S
4.2.1.4-008	No prior purchase action required for primary stations	2	R	4.2.1.4-007	-	SVC	D	Φ3	S
4.2.1.4-009	No need for passenger identification	2	R	4.2.1.4-007	-	SVC	D	Φ3	S
4.2.1.4-010	Passengers can select desired destination	2	R	4.2.1.4-007	-	SVC	D	Φ3	S
4.2.1.4-011	Passengers can change desired destination en route	2	R	4.2.1.4-007	-	SVC	D	Φ3	S
4.2.1.4-012	Passengers can request emergency re-routing	2	R	4.2.1.4-007	-	SVC	D	Φ3	S
4.2.1.4-013	Ability to charge for ATN service	1	R	4.1-004	4.2.1.4-014, 4.2.1.4-015, 4.2.1.4-016, 4.2.1.4-017, 4.2.1.4-018	SVC	D	TBD	S
4.2.1.4-014	Manage ticketing and fare collection	2	R	4.2.1.4-013	-	SVC	D	TBD	S

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4.2.1.4-015	Transfers to other transit services	2	O	4.2.1.4-013	-	SVC	D	TBD	S
4.2.1.4-016	Protect personally identifiable information	2	R	4.2.1.4-013	-	SVC	D	TBD	S
4.2.1.4-017	Provide automatic vehicle destination selection	2	R	4.2.1.4-013	-	SVC	D	TBD	S
4.2.1.4-018	Provide emergency destination override	2	R	4.2.1.4-013	-	SVC	D	TBD	S
4.2.1.4-019	Provide ability for vehicle pre-reservation	1	R	4.1-002, 4.1-003	-	SVC	D	TBD	S
4.2.2	ATN Design Requirements								
4.2.2.1	System Design Constraints								
4.2.2.1-001	Conform to typical PRT features and characteristics	1	R	4.1-001, 4.1-004	-	DSN	I, D	Φ3	S
4.2.2.1-002	Utilize small vehicles	2	R	4.2.2.1-001	-	DSN	I	Φ3	S
4.2.2.1-003	Provide on-demand service	2	R	4.2.2.1-001	-	DSN	D	Φ3	S
4.2.2.1-004	Provide direct vehicle routing	2	R	4.2.2.1-001	-	DSN	D	Φ3	S
4.2.2.1-005	Provide automatic vehicle operation	2	R	4.2.2.1-001	-	DSN	D	Φ3	S
4.2.2.1-006	Accommodate off-line stations	2	R	4.2.2.1-001	-	DSN	D	Φ3	S
4.2.2.1-007	Design for general ATN physical constraints	1	R	4.1-001	4.2.2.1-008 - 4.2.2.1-020	DSN	I, A	Φ3	S
4.2.2.1-008	Allow for sufficient side clearances	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S
4.2.2.1-009	Allow for sufficient clearance above vehicle	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S
4.2.2.1-010	Allow for sufficient clearance below vehicle (supported)	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S
4.2.2.1-011	Allow for sufficient clearance below vehicle (suspended)	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S
4.2.2.1-012	Design to accommodate guideway curves	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S
4.2.2.1-013	Design to accommodate ascending grades	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S
4.2.2.1-014	Design to accommodate descending grades	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S
4.2.2.1-015	Design to accommodate bank angles	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S
4.2.2.1-016	Design to accommodate compound curves	2	R	4.2.2.1-007	-	DSN	I, A	Φ3	S

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4.2.2.1-017	Design to accommodate merge intersections	2	R	4.2.2.1-007	-	DSN	I, D	Φ3	S
4.2.2.1-018	Design to accommodate diverging intersections	2	R	4.2.2.1-007	-	DSN	I, D	Φ3	S
4.2.2.1-019	Design to provide sufficient vehicle staging areas	2	R	4.2.2.1-007	-	DSN	I, D	Φ3	S
4.2.2.1-020	Design for access to maintenance facilities	2	R	4.2.2.1-007	-	DSN	I, D	Φ3	S
4.2.2.1-021	Increase appeal and desirability of using SJC Airport	1	R	4.1-002, 4.1-003	4.2.2.1-022 - 4.2.2.1-025	DSN	V	Φ3	S
4.2.2.1-022	Design to minimize walking distances	2	R	4.2.2.1-021	-	DSN	I	Φ3	S
4.2.2.1-023	Reduce passenger transit time to gate area	2	R	4.2.2.1-021	-	DSN	A	Φ3	S
4.2.2.1-024	Increase predictability of transit time to/from airport	2	R	4.2.2.1-021	-	DSN	A	Φ3	S
4.2.2.1-025	Design for architectural and aesthetic compatibility	2	R	4.2.2.1-021	-	DSN	I, A	Φ3	S
4.2.2.1-026	Design for technical compatibility with Airport	1	R	4.1-010	4.2.2.1-027, 4.2.2.1-028, 4.2.2.1-030, 4.2.2.1-031, 4.2.2.1-032, 4.2.2.9-009, 4.2.2.9-010	DSN	A, T	Φ3	S
4.2.2.1-027	Compatible with runway clearance requirements	2	R	4.2.2.1-026	-	DSN	A, T	Φ3	S
4.2.2.1-028	Compatible with Airport RF environment	2	R	4.2.2.1-026	4.2.2.1-029	DSN	A, T	Φ3	S
4.2.2.1-029	Comply with FCC regulations for airport-area operations	3	R	4.2.2.1-028	-	DSN	A, T	Φ3	S
4.2.2.1-030	Resistance to electromagnetic interference	2	R	4.2.2.1-026	-	DSN	A, T	Φ3	S
4.2.2.1-031	Restrict use of laser equipment outside of protective shielding	2	R	4.2.2.1-026	-	DSN	I, D	Φ3	S
4.2.2.1-032	Accommodate existing infrastructure	2	R	4.2.2.1-026	-	DSN	I, A	Φ3	S
4.2.2.1-033	Design for Airport-area environmental/safety factors	1	R	4.1-010	4.2.2.1-034, 4.2.2.1-035	DSN	A, T	Φ3	S
4.2.2.1-034	Avoid jet blast effects near runways	2	R	4.2.2.1-033	-	DSN	A, T	Φ3	S
4.2.2.1-035	Avoid jet fume accumulation in vehicle	2	R	4.2.2.1-033	-	DSN	A, T	Φ3	S
4.2.2.1-036	Design in conjunction with	1	R	4.1-010	-	DSN	I, A	Φ3	S

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	local utility infrastructure								
4.2.2.2	ATN Route Selection Constraints								
4.2.2.2-001	Route alignment within available rights-of-way	1	R	4.1-010	4.2.2.2-002	DSN	I, A	Φ3	S
4.2.2.2-002	Provide exclusive right-of-way for ATN vehicles	2	R	4.2.2.2-002	-	DSN	I, A	Φ3	S
4.2.2.2-003	Compatibility with built infrastructure	1	R	4.1-010	4.2.2.2-004, 4.2.2.2-005, 4.2.2.2-006, 4.2.2.2-007	DSN	I, A	Φ3	S
4.2.2.2-004	Accommodate runway buffer zones	2	R	4.2.2.2-003	-	DSN	I, A	Φ3	S
4.2.2.2-005	Accommodate vertical height restrictions	2	R	4.2.2.2-003	-	DSN	I, A	Φ3	S
4.2.2.2-006	Accommodate built infrastructure on Airport	2	R	4.2.2.2-003	-	DSN	I, A	Φ3	S
4.2.2.2-007	Accommodate installed utility infrastructure on Airport	2	R	4.2.2.2-003	-	DSN	I, A	Φ3	S
4.2.2.2-008	Select route alignments per ATN technology constraints	1	R	4.1-001, 4.1-010	-	DSN	I, A	Φ3	S
4.2.2.2-009	Select routes/locations to maintain current revenue	1	R	4.1-004	-	DSN	V	Φ3	S, B
4.2.2.3	ATN Design Standards								
4.2.2.3-001	Design/implementation per criteria, standards and practices	1	R	4.1-001, 4.1-002, 4.1-010	4.2.2.3-002, 4.2.2.3-003	DSN	A	Φ3	S
4.2.2.3-002	Comply with ASCE APM Standards	2	R	4.2.2.3-001	-	DSN	I, A	Φ3	S
4.2.2.3-003	Design with guidance from additional standards	2	R	4.2.2.3-001	-	DSN	I, A	Φ3	S
4.2.2.3-004	System design derived from proven technology	1	R	4.1-001, 4.1-002, 4.1-010	4.2.2.3-005	DSN	I, A, D	Φ3	S
4.2.2.3-005	Subsystem designs derived from proven technology	2	R	4.2.2.3-004	-	DSN	I, A, D	Φ3	S
4.2.2.3-006	Design to longevity targets	1	R	4.1-010	4.2.2.3-007 - 4.2.2.3-015	DSN	A	Φ3	S
4.2.2.3-007	Guideway and station operational lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S
4.2.2.3-008	Vehicle/guideway interface and switch mechanism lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S
4.2.2.3-009	Building and support facility lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S

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4.2.2.3-010	Support facility equipment lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S
4.2.2.3-011	Power distribution subsystem lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S
4.2.2.3-012	Vehicle structure lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S
4.2.2.3-013	Vehicle propulsion, braking, suspension lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S
4.2.2.3-014	Communication subsystem lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S
4.2.2.3-015	Computing and control subsystem lifespan	2	R	4.2.2.3-006	-	DSN	A	Φ3	S
4.2.2.3-016	Comply with ACSE APM safety standards	1	R	4.1-010	4.2.2.3-017, 4.2.2.3-018, 4.2.2.3-019, 4.2.2.3-020	DSN	A	Φ3	S
4.2.2.3-017	Subsystems selected per safety analysis	2	R	4.2.2.3-016	-	DSN	A	Φ3	S
4.2.2.3-018	Design to eliminate external collision hazard	2	R	4.2.2.3-016	-	DSN	A	Φ3	S
4.2.2.3-019	Design to eliminate hazard to public	2	R	4.2.2.3-016	-	DSN	A	Φ3	S
4.2.2.3-020	Design to protect from erroneous human control action	2	R	4.2.2.3-016	-	DSN	A	Φ3	S
4.2.2.3-021	Design to achieve service availability targets	1	R	4.1-001, 4.1-010	4.2.2.3-022, 4.2.2.3-023, 4.2.2.3-024, 4.2.2.3-025	DSN	A	Φ3	S
4.2.2.3-022	Utilize subsystem components with reliability history	2	R	4.2.2.3-021	-	DSN	A	Φ3	S
4.2.2.3-023	Incorporate modular subsystem designs	2	R	4.2.2.3-021	-	DSN	A	Φ3	S
4.2.2.3-024	Promote component interchangeability	2	R	4.2.2.3-021	-	DSN	A	Φ3	S
4.2.2.3-025	Design to facilitate inspection and maintenance	2	R	4.2.2.3-021	-	DSN	A	Φ3	S
4.2.2.3-026	Design to operate in San José conditions	1	R	4.1-001, 4.1-010	4.2.2.3-027, 4.2.2.3-028, 4.2.2.6-032	DSN	A	Φ3	S
4.2.2.3-027	Design for San José climate conditions	2	R	4.2.2.3-026	-	DSN	A	Φ3	S
4.2.2.3-028	Design for minimal disruption to San José environment	2	R	4.2.2.3-026	-	DSN	A	Φ3	S
4.2.2.3-029	Design for sustainable development and operation	1	R	4.1-006, 4.1-009	4.2.2.3-030, 4.2.2.3-035	DSN	A	Φ3	S

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4.2.2.3-030	Design for sustainable ATN development	2	R	4.2.2.3-029	4.2.2.3-031, 4.2.2.3-032, 4.2.2.3-033, 4.2.2.3-034	DSN	A	Φ3	S
4.2.2.3-031	Design to maximize reusability/ recyclability	3	R	4.2.2.3-030	-	DSN	A	Φ3	S
4.2.2.3-032	Design to minimize construction waste	3	R	4.2.2.3-030	-	DSN	A	Φ3	S
4.2.2.3-033	Design for minimum embedded energy (materials)	3	R	4.2.2.3-030	-	DSN	A	Φ3	S
4.2.2.3-034	Design to minimize hazardous substances	3	R	4.2.2.3-030	-	DSN	A	Φ3	S
4.2.2.3-035	Design for sustainable ATN operations	2	R	4.2.2.3-029	4.2.2.3-036 - 4.2.2.3-043	DSN	A	Φ3	S
4.2.2.3-036	Design for minimum embedded energy (supplies)	3	R	4.2.2.3-035	-	DSN	A	Φ3	S
4.2.2.3-037	Design for operational energy conservation	3	R	4.2.2.3-035	-	DSN	A	Φ3	S
4.2.2.3-038	Design to minimize parts replacement	3	R	4.2.2.3-035	-	DSN	A	Φ3	S
4.2.2.3-039	Design to minimize noise from operations	3	R	4.2.2.3-035	-	DSN	A	Φ3	S
4.2.2.3-040	Design to minimize odors from operations	3	R	4.2.2.3-035	-	DSN	A	Φ3	S
4.2.2.3-041	Design to maintain cleanliness	3	R	4.2.2.3-035	-	DSN	A	Φ3	S
4.2.2.3-042	Design for water recycling	3	R	4.2.2.3-035	-	DSN	A	Φ3	S
4.2.2.3-043	Design for air quality compliance	3	R	4.2.2.3-035	-	DSN	A	Φ3	S
4.2.2.3-044	Design for Security per ASCE APM Standards	1	R	4.1-001, 4.1-002, 4.1-010	4.2.2.3-045	DSN	A	Φ3	S
4.2.2.3-045	Design per security engineering analysis	2	R	4.2.2.3-044	-	DSN	A	Φ3	S
4.2.2.4	Regulatory Codes and Standards								
4.2.2.4-001	Design per Regulatory codes and standards	1	R	4.1-001, 4.1-002, 4.1-010	4.2.2.4-002, 4.2.2.4-003, 4.2.2.4-006, 4.2.2.4-008, 4.2.2.4-009	DSN	I, A	Φ3	S
4.2.2.4-002	Comply with CPUC General Orders	2	R	4.2.2.4-001	-	DSN	I, A	Φ3	S
4.2.2.4-003	Comply with California Building Code	2	R	4.2.2.4-001	4.2.2.4-009, 4.2.2.4-010, 4.2.2.5-006,	DSN	I, A	Φ3	S

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					4.2.2.5-018				
4.2.2.4-004	Comply with California Electrical Code	2	R	4.2.2.4-001	-	DSN	I, A	Φ3	S
4.2.2.4-005	Comply with California Mechanical, Plumbing Codes	2	R	4.2.2.4-001	-	DSN	I, A	Φ3	S
4.2.2.4-006	Comply with NFPA 130 and 72	2	R	4.2.2.4-001	4.2.2.4-007	DSN	I, A	Φ3	S
4.2.2.4-007	Comply with station evacuation time limits	3	R	4.2.2.4-006	-	DSN	I, A	Φ3	S
4.2.2.4-008	Comply with ADA	2	R	4.2.2.4-001	-	DSN	I, A	Φ3	S
4.2.2.4-009	Design for California Seismic Zone 4	3	R	4.2.2.4-003	-	DSN	I, A	Φ3	S
4.2.2.4-010	Design to incorporate safety factors	3	R	4.2.2.4-003	-	DSN	I, A	Φ3	S
4.2.2.5	Guideway Design								
4.2.2.5-001	Guideway design compliant with applicable standards	1	R	4.1-010	4.2.2.5-002, 4.2.2.5-005, 4.2.2.5-007, 4.2.2.5-008, 4.2.2.5-024, 4.2.2.5-027, 4.2.2.5-028, 4.2.2.5-029, 4.2.2.5-037, 4.2.2.5-040, 4.2.2.5-041, 4.2.2.5-042	DSN	I, A, D, T	Φ3	S
4.2.2.5-002	Comply with ASCE APM Standards	2	R	4.2.2.5-001	4.2.2.5-003, 4.2.2.5-004	DSN	I, D	Φ3	S
4.2.2.5-003	Guideways exclusively for ATN use	3	R	4.2.2.5-002	-	DSN	I, D	Φ3	S
4.2.2.5-004	Guideways separate from other rights-of-way	3	R	4.2.2.5-002	-	DSN	I, D	Φ3	S
4.2.2.5-005	Guideways can be at multiple grade levels	2	R	4.2.2.5-001	4.2.2.5-006	DSN	I, D	Φ3	S
4.2.2.5-006	Elevated guideways compliant with seismic standards	3	R	4.2.2.4-003, 4.2.2.5-005	-	DSN	I, A	Φ3	S
4.2.2.5-007	Design for maintenance accessibility	2	R	4.2.2.5-001	-	DSN	I, A	Φ3	S
4.2.2.5-008	Design for structural integrity under load	2	R	4.2.2.5-001	4.2.2.5-009 - 4.2.2.5-023	DSN	I, A	Φ3	S
4.2.2.5-009	Guideway minimum nominal span length	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-010	Guideway maximum span length	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S

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4.2.2.5-011	Guideway design for vertical load forces	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-012	Guideway design for horizontal load forces	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-013	Guideway design for additional load forces	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-014	Guideway designed for resistance to ground settlement	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-015	Guideway design protects from collision with external traffic	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-016	Guideway design for maximum deflection	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-017	Guideway design for longitudinal loads	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-018	Guideway designed for resistance to base shear forces	3	R	4.2.2.4-003, 4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-019	Guideway design for material fatigue stresses	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-020	Guideway design for accumulated thermal stresses	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-021	Incorporate vibration damping	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-022	Incorporate acoustical noise damping	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-023	Guideway remains intact after loss of support	3	R	4.2.2.5-008	-	DSN	I, A	Φ3	S
4.2.2.5-024	Design for aesthetic compatibility	2	R	4.2.2.5-001	4.2.2.5-025, 4.2.2.5-026	DSN	I, A	Φ3	S
4.2.2.5-025	Minimized guideway skyprint	3	R	4.2.2.5-024	-	DSN	I, A	Φ3	S
4.2.2.5-026	Minimized vertical support cross-section	3	R	4.2.2.5-024	-	DSN	I, A	Φ3	S
4.2.2.5-027	Guideways accommodate compound curvature	2	R	4.2.2.5-001	-	DSN	I, A	Φ3	S
4.2.2.5-028	Guideway bank angle limits	2	R	4.2.2.5-001	-	DSN	I, A	Φ3	S
4.2.2.5-029	Guideway design incorporates protection from the elements	2	R	4.2.2.5-001	4.2.2.5-030 - 4.2.2.5-036	DSN	I, A	Φ3	S
4.2.2.5-030	Guideway corrosion protection	3	R	4.2.2.5-029	-	DSN	I, A	Φ3	S
4.2.2.5-031	Guideways resistant to natural contaminants	3	R	4.2.2.5-029	-	DSN	I, A	Φ3	S
4.2.2.5-032	Guideways resistant to animal	3	R	4.2.2.5-029	-	DSN	I, A	Φ3	S

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	habitation								
4.2.2.5-033	Guideways designed for adequate drainage	3	R	4.2.2.5-029	-	DSN	I, A	Φ3	S
4.2.2.5-034	Guideways designed for lightning protection	3	R	4.2.2.5-029	-	DSN	I, A	Φ3	S
4.2.2.5-035	Guideway components resistant to EMI	3	R	4.2.2.1-030, 4.2.2.5-029	-	DSN	I, A	Φ3	S
4.2.2.5-036	Guideways resistant to vandalism/sabotage	3	R	4.2.2.5-029	-	DSN	I, A	Φ3	S
4.2.2.5-037	Guideway visual safety features	2	R	4.2.2.5-001	4.2.2.5-038, 4.2.2.5-039	DSN	I, A	Φ3	S
4.2.2.5-038	Guideway marker lighting (public)	3	R	4.2.2.5-037	-	DSN	I, A	Φ3	S
4.2.2.5-039	Guideway marker lighting (passengers)	3	R	4.2.2.5-037	-	DSN	I, A	Φ3	S
4.2.2.5-040	Guideway design for continuous clearance	2	R	4.2.2.5-001	-	DSN	I, A	Φ3	S
4.2.2.5-041	Guideway design for continuous ride quality	2	R	4.2.2.5-001	-	DSN	I, A	Φ3	S
4.2.2.5-042	Guideway design for smooth operation over section joins	2	R	4.2.2.5-001	-	DSN	I, A	Φ3	S
4.2.2.6	Vehicle Design								
4.2.2.6-001	Vehicle design compliant with industry standards for quality and safety	1	R	4.1-010	4.2.2.6-002, 4.2.2.6-017, 4.2.2.6-018, 4.2.2.6-023, 4.2.2.6-024, 4.2.2.6-030, 4.2.2.6-031, 4.2.2.6-032, 4.2.2.6-033	DSN	I, A, D, T	Φ3	S
4.2.2.6-002	Vehicles implemented per recognized design criteria	2	R	4.2.2.6-001	4.2.2.6-003, 4.2.2.6-005, 4.2.2.6-007, 4.2.2.6-012 - 4.2.2.6-016	DSN	I, A, D, T	Φ3	S
4.2.2.6-003	Vehicle structural design criteria	3	R	4.2.2.6-002	4.2.2.6-004	DSN	I,A	Φ3	S
4.2.2.6-004	Vehicle compression load limit	4	R	4.2.2.6-003	-	DSN	T	Φ3	S
4.2.2.6-005	Vehicles remain on guideway after colliding	3	R	4.2.2.6-002	-	DSN	A, D	Φ3	S
4.2.2.6-006	Vehicles designed to passenger comfort standards	3	R	4.2.2.6-002	-	DSN	A, T	Φ3	S
4.2.2.6-007	Vehicle propulsion and	3	R	4.2.2.6-002	4.2.2.6-008, 4.2.2.6-009,	DSN	I, A,	Φ3	S

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	braking designed to standards				4.2.2.6-010, 4.2.2.6-011		D, T		
4.2.2.6-008	Vehicles have independent braking systems	4	R	4.2.2.6-007	-	DSN	I	Φ3	S
4.2.2.6-009	Vehicle service brakes jerk-limited	4	R	4.2.2.6-007	-	DSN	I, T	Φ3	S
4.2.2.6-010	Vehicle mechanical brake backup	4	R	4.2.2.6-007	-	DSN	I, T	Φ3	S
4.2.2.6-011	Vehicle independent parking brake	4	R	4.2.2.6-007	-	DSN	I, D	Φ3	S
4.2.2.6-012	Vehicle electrical design to standards	3	R	4.2.2.6-002	-	DSN	I, A	Φ3	S
4.2.2.6-013	Vehicle design with emergency lighting	3	R	4.2.2.6-002	-	DSN	I, D	Φ3	S
4.2.2.6-014	Vehicle doors designed to standards	3	R	4.2.2.6-002	-	DSN	I, D	Φ3	S
4.2.2.6-015	Vehicle windows designed to standards	3	R	4.2.2.6-002	-	DSN	I, D	Φ3	S
4.2.2.6-016	Vehicle design for fire protection	3	R	4.2.2.6-002	-	DSN	I, A	Φ3	S
4.2.2.6-017	Vehicles captive to the guideway	2	R	4.2.2.6-001	-	DSN	I, D	Φ3	S
4.2.2.6-018	Vehicle design is ADA compliant	2	R	4.2.2.6-001	4.2.2.6-019 - 4.2.2.6-022	DSN	I, D	Φ3	S
4.2.2.6-019	Vehicle door and window manual operability	3	R	4.2.2.6-018	-	DSN	I, D	Φ3	S
4.2.2.6-020	Braille symbol labels for passenger controls	3	R	4.2.2.6-018	-	DSN	I, D	Φ3	S
4.2.2.6-021	In-vehicle audio information	3	R	4.2.2.6-018	-	DSN	I, D	Φ3	S
4.2.2.6-022	In-vehicle visual information displays	3	R	4.2.2.6-018	-	DSN	I, D	Φ3	S
4.2.2.6-023	Vehicle seating capacity	2	R	4.2.2.6-001	-	DSN	I, D	Φ3	S
4.2.2.6-024	Vehicle capacity for passenger belongings	2	R	4.2.2.6-001	4.2.2.6-025 - 4.2.2.6-028	DSN	I, D	Φ3	S
4.2.2.6-025	Vehicle luggage capacity	3	R	4.2.2.6-024	-	DSN	I, D	Φ3	S
4.2.2.6-026	Vehicle accommodation of child stroller	3	R	4.2.2.6-024	-	DSN	I, D	Φ3	S
4.2.2.6-027	Vehicle accommodation of full-size bicycle	3	R	4.2.2.6-024	-	DSN	I, D	Φ3	S
4.2.2.6-028	Vehicle accommodation of service animals	3	R	4.2.2.6-024	-	DSN	I, D	Φ3	S
4.2.2.6-029	Vehicles adaptable for cargo	2	O	4.2.2.6-001	-	DSN	I, A	TBD	S

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4.2.2.6-030	Exterior view out of vehicle windows	2	R	4.2.2.6-001	-	DSN	A, D	Φ3	S
4.2.2.6-031	Vehicle designed to discourage standing passengers	2	O	4.2.2.6-001	-	DSN	A	TBD	S
4.2.2.6-032	Vehicles designed not to be a source of EMI	2	R	4.2.2.3-026, 4.2.2.6-001	-	DSN	A, T	Φ3	S
4.2.2.6-033	Vehicles designed for aesthetic value	2	R	4.2.2.6-001	4.2.2.6-034	DSN	I	Φ3	S
4.2.2.6-034	Vehicles incorporate positive brand identity	3	R	4.2.2.6-033	-	DSN	I	Φ3	S
4.2.2.7	Station Design								
4.2.2.7-001	Stations designed for performance, safety and usability	1	R	4.1-001, 4.1-010	4.2.2.7-002, 4.2.2.7-003, 4.2.2.7-007, 4.2.2.7-009, 4.2.2.7-010, 4.2.2.7-014 - 4.2.2.7-017, 4.2.2.7-019, 4.2.2.7-024, 4.2.2.7-026, 4.2.2.7-030	DSN	I, A, D	Φ3	S
4.2.2.7-002	System designed to facilitate off-line stations	2	R	4.2.2.7-001	-	DSN	I, A, D	Φ3	S
4.2.2.7-003	Allow for multiple station designs	2	R	4.2.2.7-001	4.2.2.7-004, 4.2.2.7-005, 4.2.2.7-006	DSN	I, A, D	Φ3	S
4.2.2.7-004	Stations designed and sized for passenger demand	3	R	4.2.2.7-003	-	DSN	I, A, D	Φ3	S
4.2.2.7-005	Passenger wait time targets	3	R	4.2.2.7-003	-	DSN	A, D	Φ3	S
4.2.2.7-006	Vehicle wave-off targets	3	R	4.2.2.7-003	-	DSN	A, D	Φ3	S
4.2.2.7-007	Station design complies with ASCE APM Standards	2	R	4.2.2.7-001	4.2.2.7-008	DSN	I, A	Φ3	S
4.2.2.7-008	Vehicle/station interface clearances	3	R	4.2.2.7-007	-	DSN	I, D	Φ3	S
4.2.2.7-009	Stations comply with NFPA 130	2	R	4.2.2.7-001	-	DSN	I, A, D	Φ3	S
4.2.2.7-010	Stations comply with ADA accessibility/usability rules	2	R	4.2.2.7-001	4.2.2.7-011, 4.2.2.7-012, 4.2.2.7-013	DSN	I, D	Φ3	S
4.2.2.7-011	Tactile aids to identify station foot paths	3	R	4.2.2.7-010	-	DSN	I, D	Φ3	S
4.2.2.7-012	Station audio announcements	3	R	4.2.2.7-010	-	DSN	I, D	Φ3	S
4.2.2.7-013	Station visual information displays	3	R	4.2.2.7-010	-	DSN	I, D	Φ3	S

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4.2.2.7-014	Station design accommodates integration to existing structure	2	R	4.2.2.7-001	-	DSN	I, D	Φ3	S
4.2.2.7-015	Station layout for safe passenger movement	2	R	4.2.2.7-001	-	DSN	I, D	Φ3	S
4.2.2.7-016	Stations provide weather protection	2	R	4.2.2.7-001	-	DSN	I, D	Φ3	S
4.2.2.7-017	Stations constructed for seismic safety	2	R	4.2.2.7-001	4.2.2.7-018	DSN	I, A	Φ3	S
4.2.2.7-018	Stations designed per seismic safety factors	3	R	4.2.2.7-017	-	DSN	I, A	Φ3	S
4.2.2.7-019	Stations designed for safety and security	2	R	4.2.2.7-001	4.2.2.7-020, 4.2.2.7-021, 4.2.2.7-022, 4.2.2.7-023	DSN	I, A	Φ3	S
4.2.2.7-020	Open, well-lighted station layouts	3	R	4.2.2.7-019	-	DSN	I, D	Φ3	S
4.2.2.7-021	Remote video surveillance of station operations	3	R	4.2.2.7-019	-	DSN	I, D	Φ3	S
4.2.2.7-022	Passenger security request and response	3	R	4.2.2.7-019	-	DSN	I, D	Φ3	S
4.2.2.7-023	Well-marked, non-slip foot paths	3	R	4.2.2.7-019	-	DSN	I, D	Φ3	S
4.2.2.7-024	Stations designed for aesthetic and cultural value	2	R	4.2.2.7-001	4.2.2.7-025	DSN	I, A	Φ3	S
4.2.2.7-025	Stations incorporate positive branding	3	R	4.2.2.7-024	-	DSN	I, A	Φ3	S
4.2.2.7-026	Stations designed for passenger convenience	2	R	4.2.2.7-001	4.2.2.7-027, 4.2.2.7-028, 4.2.2.7-029	DSN	I, A	Φ3	S
4.2.2.7-027	Stations designed for easy access	3	R	4.2.2.7-026	-	DSN	I, A	Φ3	S
4.2.2.7-028	Stations designed for intuitive usability	3	R	4.2.2.7-026	-	DSN	I, A	Φ3	S
4.2.2.7-029	Stations designed for easy wayfinding	3	R	4.2.2.7-026	-	DSN	I, A	Φ3	S
4.2.2.7-030	Station design goal of net zero energy usage	2	R	4.2.2.7-001	-	DSN	A, D	Φ3	S
4.2.2.8	Support Facilities Design								
4.2.2.8-001	Support facilities designed for efficiency, safety and environmental compatibility	1	R	4.1-001, 4.1-010	4.2.2.8-002, 4.2.2.8-003, 4.2.2.8-010, 4.2.2.8-012	DSN	I, A, D	Φ3	S
4.2.2.8-002	Support facilities located for compatibility and accessibility	2	R	4.2.2.8-001	-	DSN	I, A	Φ3	S

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4.2.2.8-003	Support facilities designed per building and safety codes	2	R	4.2.2.8-001	4.2.2.8-004 - 4.2.2.8-009	DSN	I, A	Φ3	S
4.2.2.8-004	Support facilities compliant with seismic codes	3	R	4.2.2.8-003	4.2.2.8-005	DSN	I, A	Φ3	S
4.2.2.8-005	Support facilities designed per seismic safety factors	4	R	4.2.2.8-004	-	DSN	I, A	Φ3	S
4.2.2.8-006	Support facilities compatible with local aesthetic standards	3	R	4.2.2.8-003	-	DSN	I, A	Φ3	S
4.2.2.8-007	Support facility noise and emission control	3	R	4.2.2.8-003	-	DSN	A, T	Φ3	S
4.2.2.8-008	Support facility utility interfaces	3	R	4.2.2.8-003	-	DSN	I, A	Φ3	S
4.2.2.8-009	Support facility waste water management	3	R	4.2.2.8-003	-	DSN	I, A	Φ3	S
4.2.2.8-010	Support facility workflow efficiency	2	R	4.2.2.8-001	4.2.2.8-011	DSN	I, A	Φ3	S
4.2.2.8-011	Facilitate manual operation of MRV in maintenance facility	3	R	4.2.2.8-010	-	DSN	D	Φ3	S
4.2.2.8-012	Facilities sized for support operations	2	R	4.2.2.8-001	4.2.2.8-013, 4.2.2.8-014, 4.2.2.8-015	DSN	I, A	Φ3	S
4.2.2.8-013	Maintenance facility sized for vehicle count	3	R	4.2.2.8-012	-	DSN	I, A	Φ3	S
4.2.2.8-014	Adequate vehicle storage facilities provided	3	R	4.2.2.8-012	-	DSN	I, A	Φ3	S
4.2.2.8-015	Operational centers sized for staff requirements	3	R	4.2.2.8-012	-	DSN	I, A	Φ3	S
4.2.2.9	Guidance, Control and Communications Design								
4.2.2.9-001	Provide Automatic Vehicle Control per APM Standards	1	R	4.1-001, 4.1-010	4.2.2.9-002, 4.2.2.9-003, 4.2.2.9-004, 4.2.2.9-005	DSN	A, D, T	Φ3	S
4.2.2.9-002	AVC incorporates ASCE APM safety principles	2	R	4.2.2.9-001	-	DSN	A, T	Φ3	S
4.2.2.9-003	AVC incorporates fail-safe designs	2	R	4.2.2.9-001	-	DSN	A, T	Φ3	S
4.2.2.9-004	AVC design incorporates self-diagnosis	2	R	4.2.2.9-001	-	DSN	A, T	Φ3	S
4.2.2.9-005	AVC design is tolerant to environmental conditions	2	R	4.2.2.9-001	-	DSN	A, T	Φ3	S
4.2.2.9-006	AVC incorporates essential communications design parameters	1	R	4.1-001, 4.1-010	4.2.2.9-007, 4.2.2.9-008, 4.2.2.9-009, 4.2.2.9-010	DSN	A, T	Φ3	S

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4.2.2.9-007	Communications link bandwidth and margin	2	R	4.2.2.9-006	-	DSN	A, T	Φ3	S
4.2.2.9-008	Communications link is weather-resistant	2	R	4.2.2.9-006	-	DSN	A, T	Φ3	S
4.2.2.9-009	Communications function does not source EMI	2	R	4.2.2.1-026, 4.2.2.9-006	-	DSN	A, T	Φ3	S
4.2.2.9-010	Communications function resistant to external EMI	2	R	4.2.2.1-026 4.2.2.9-006	-	DSN	A, T	Φ3	S
4.2.2.9-011	Audio/Visual communications per ASCE standards	2	R	4.2.2.9-001	4.2.2.9-012, 4.2.2.9-013	DSN	A, D	Φ3	S
4.2.2.9-012	Provide audio communications	3	R	4.2.2.9-011	-	DSN	A, D	Φ3	S
4.2.2.9-013	Provide video monitoring	3	R	4.2.2.9-011	-	DSN	A, D	Φ3	S
4.2.2.10	Human Factors Design								
4.2.2.10-001	System design per industry human factors standards	1	R	4.1-002, 4.1-010	4.2.2.10-002, 4.2.2.10-005, 4.2.2.10-006, 4.2.2.10-011, 4.2.2.10-012	DSN	A, D	Φ3	S
4.2.2.10-002	System designed for usability by diverse population	2	R	4.2.2.10-001	4.2.2.10-003, 4.2.2.10-004	DSN	A, D	Φ3	S
4.2.2.10-003	System designed to human/ machine interface standards	3	R	4.2.2.10-002	-	DSN	A, D	Φ3	S
4.2.2.10-004	Provide language-independent iconic symbols	3	R	4.2.2.10-002	-	DSN	I, D	Φ3	S
4.2.2.10-005	Ergonomically designed passenger accommodations	2	R	4.2.2.10-001	-	DSN	I, D	Φ3	S
4.2.2.10-006	Passenger comfort features per ASCE APM Standards	2	R	4.2.2.10-001	4.2.2.10-007, 4.2.2.10-008, 4.2.2.10-009, 4.2.2.10-010	DSN	A, T	Φ3	S
4.2.2.10-007	Cabin heating and cooling	3	R	4.2.2.10-006	-	DSN	A, T	Φ3	S
4.2.2.10-008	Cabin ventilation	3	R	4.2.2.10-006	-	DSN	A, T	Φ3	S
4.2.2.10-009	Vehicle ride quality	3	R	4.2.2.10-006	-	DSN	A, T	Φ3	S
4.2.2.10-010	Vehicle noise and vibration	3	R	4.2.2.10-006	-	DSN	A, T	Φ3	S
4.2.2.10-011	Provide passenger safety restraints	2	R	4.2.2.10-001	-	DSN	D	Φ3	S
4.2.2.10-012	Ergonomic designs for operations and maintenance	2	R	4.2.2.10-001	4.2.2.10-013, 4.2.2.10-014, 4.2.2.10-015	DSN	I, D	Φ3	S
4.2.2.10-013	Work area layout for staff safety and work efficiency	3	R	4.2.2.10-012	-	DSN	I, D	Φ3	S
4.2.2.10-014	Facility access design for	3	R	4.2.2.10-012	-	DSN	I, D	Φ3	S

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	safety and work efficiency								
4.2.2.10-015	Workstation ergonomics	3	R	4.2.2.10-012	-	DSN	A, D	Φ3	S
4.2.3	ATN System Requirements								
4.2.3.1	Functional Requirements								
4.2.3.1-001	Provide fully automatic system operation with prescribed manual override	1	R	4.1-001, 4.1-002, 4.1-004, 4.1-010	4.2.3.1-002	SYS	D	Φ3	S
4.2.3.1-002	Provide Automatic Vehicle Control	2	R	4.2.3.1-001	-	SYS	D, T	Φ3	S
4.2.3.1-003	Provide autonomous vehicle operation	1	R	4.1-001, 4.1-002, 4.1-004, 4.1-010	4.2.3.1-004, 4.2.3.1-005, 4.2.3.1-006, 4.2.3.1-011	SYS	D, T	Φ3	S
4.2.3.1-004	Automatically manage vehicle start and stop	2	R	4.2.3.1-003	-	SYS	T	Φ3	S
4.2.3.1-005	Automatically limit maximum speeds	2	R	4.2.3.1-003	-	SYS	T	Φ3	S
4.2.3.1-006	Automatically determine inter-station routes	2	R	4.2.3.1-003	4.2.3.1-007, 4.2.3.1-008, 4.2.3.1-009, 4.2.3.1-010	SYS	T	Φ3	S
4.2.3.1-007	Determine origin and destination of each trip	3	R	4.2.3.1-006	-	SYS	D	Φ3	S
4.2.3.1-008	Perform optimal routing calculation	3	R	4.2.3.1-006	-	SYS	A, D	Φ3	S
4.2.3.1-009	Perform re-route calculations for changing conditions	3	R	4.2.3.1-006	-	SYS	A, D	Φ3	S
4.2.3.1-010	Automatically command vehicle to follow routes	3	R	4.2.3.1-006	-	SYS	D	Φ3	S
4.2.3.1-011	Automatically manage occupied and empty vehicles	2	R	4.2.3.1-003	4.2.3.1-012, 4.2.3.1-013, 4.2.3.1-014, 4.2.3.1-015	SYS	A, D	Φ3	S
4.2.3.1-012	Balance loads on network routes	3	R	4.2.3.1-011	-	SYS	A, D	Φ3	S
4.2.3.1-013	Automated commanding of vehicle dynamics	3	R	4.2.3.1-011	-	SYS	A, T	Φ3	S
4.2.3.1-014	Autonomous slowing through turns	3	R	4.2.3.1-011	-	SYS	A, T	Φ3	S
4.2.3.1-015	Automatically distribute empty vehicles	3	R	4.2.3.1-011	-	SYS	A, D	Φ3	S
4.2.3.1-016	Provide Automatic Vehicle Protection to ensure safe operation without collisions	1	R	4.1-001, 4.1-010	4.2.3.1-017, 4.2.3.1-020, 4.2.3.1-021, 4.2.3.1-022, 4.2.3.1-025,	SYS	A, T	Φ3	S

Req't ID	Short Title	Tier	R/O	↑ Trace	↓ Trace	Cat.	VM	Eff.	Alloc.
					4.2.3.1-026, 4.2.3.1-028, 4.2.3.1-030, 4.2.3.1-031, 4.2.3.1-033, 4.2.3.1-034, 4.2.3.1-037 - 4.2.3.1-040, 4.2.3.1-042, 4.2.3.1-043				
4.2.3.1-017	Automatically determine location of all vehicles	2	R	4.2.3.1-016	4.2.3.1-018, 4.2.3.1-019	SYS	A, T	Φ3	S
4.2.3.1-018	Determine location of active vehicles	3	R	4.2.3.1-017	-	SYS	D	Φ3	S
4.2.3.1-019	Determine location of inactive vehicles	3	R	4.2.3.1-017	-	SYS	D	Φ3	S
4.2.3.1-020	Independent location determination by vehicles	2	R	4.2.3.1-016	-	SYS	D	Φ3	S
4.2.3.1-021	Maintain vehicle location state information	2	R	4.2.3.1-016	-	SYS	D	Φ3	S
4.2.3.1-022	Maintain safe stopping distance between vehicles	2	R	4.2.3.1-016	4.2.3.1-023, 4.2.3.1-024	SYS	D	Φ3	S
4.2.3.1-023	Ensure safe emergency stops	3	R	4.2.3.1-022	-	SYS	A, T	Φ3	S
4.2.3.1-024	Account for stopping distance calculation variables	3	R	4.2.3.1-022	-	SYS	A, T	Φ3	S
4.2.3.1-025	Automatic protection with erroneous manual action	2	R	4.2.3.1-016	-	SYS	D	Φ3	S
4.2.3.1-026	Detect unintentional vehicle motion	2	R	4.2.3.1-016	4.2.3.1-027	SYS	D	Φ3	S
4.2.3.1-027	Emergency braking of vehicles moving erroneously	3	R	4.2.3.1-026	-	SYS	D	Φ3	S
4.2.3.1-028	Restrict vehicle speed to prescribed limits	2	R	4.2.3.1-016	4.2.3.1-029	SYS	D	Φ3	S
4.2.3.1-029	Automatic emergency braking of speeding vehicles	3	R	4.2.3.1-028	-	SYS	D	Φ3	S
4.2.3.1-030	Prevent vehicle overrun	2	R	4.2.3.1-016	-	SYS	D	Φ3	S
4.2.3.1-031	Detect loss of control signal	2	R	4.2.3.1-016	4.2.3.1-032	SYS	T	Φ3	S
4.2.3.1-032	Automatic braking after control signal loss	3	R	4.2.3.1-031	-	SYS	D	Φ3	S
4.2.3.1-033	Automatic detection of active vehicle stop	2	R	4.2.3.1-016	-	SYS	D	Φ3	S
4.2.3.1-034	Automatic enforcement of "zero speed limit" zones	2	R	4.2.3.1-016	4.2.3.1-035, 4.2.3.1-036	SYS	D	Φ3	S
4.2.3.1-035	Maintain maximum stopping distance within safety zone	3	R	4.2.3.1-034	-	SYS	T	Φ3	S

Req't ID	Short Title	Tier	R/O	↑ Trace	↓ Trace	Cat.	VM	Eff.	Alloc.
4.2.3.1-036	Automatic emergency braking upon zone entry	3	R	4.2.3.1-034	-	SYS	D	Φ3	S
4.2.3.1-037	Door opening interlocked with vehicle stop	2	R	4.2.3.1-016	-	SYS	D	Φ3	S
4.2.3.1-038	Door closing interlocked with vehicle motion	2	R	4.2.3.1-016	-	SYS	D	Φ3	S
4.2.3.1-039	Propulsion and braking subsystem interlocks	2	R	4.2.3.1-016	-	SYS	D	Φ3	S
4.2.3.1-040	Guideway switch interlocks per ASCE APM Standards	2	R	4.2.3.1-016	4.2.3.1-041	SYS	T	Φ3	S
4.2.3.1-041	Prevent late or incomplete switch actuation	3	R	4.2.3.1-040	-	SYS	T	Φ3	S
4.2.3.1-042	AVP prioritized over other AVC functions	2	R	4.2.3.1-016	-	SYS	A, D	Φ3	S
4.2.3.1-043	AVP operates with fail-safe mechanisms	2	R	4.2.3.1-016	-	SYS	A, D	Φ3	S
4.2.3.1-044	Provide Automatic Vehicle Supervision for system operations monitoring	1	R	4.1-001, 4.1-010	4.2.3.1-045, 4.2.3.1-046, 4.2.3.1-052, 4.2.3.1-068	SYS	A, D	Φ3	S
4.2.3.1-045	Provide system status and control information	2	R	4.2.3.1-044	-	SYS	D	Φ3	S
4.2.3.1-046	Initiate automatic system control actions	2	R	4.2.3.1-044	4.2.3.1-047 - 4.2.3.1-051	SYS	D	Φ3	S
4.2.3.1-047	Initiate operational mode changes as required	3	R	4.2.3.1-046	-	SYS	D	Φ3	S
4.2.3.1-048	Maintain dynamic vehicle tracking	3	R	4.2.3.1-046	-	SYS	D	Φ3	S
4.2.3.1-049	Generate vehicle tracking visualization data	3	R	4.2.3.1-046	-	SYS	D	Φ3	S
4.2.3.1-050	Monitor and adjust vehicle spacing	3	R	4.2.3.1-046	-	SYS	D	Φ3	S
4.2.3.1-051	Monitor congestion and adjust routing	3	R	4.2.3.1-046	-	SYS	D	Φ3	S
4.2.3.1-052	Allow prescribed manual control operations	2	R	4.2.3.1-044	4.2.3.1-053 - 4.2.3.1-067	SYS	D	Φ3	S
4.2.3.1-053	Manual system startup	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-054	Manual system shutdown	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-055	Manually initiate specific vehicle(s) into service	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-056	Manually remove specific vehicle(s) from service	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-057	Manually route vehicles over specific network links	3	R	4.2.3.1-052	-	SYS	D	Φ3	S

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4.2.3.1-058	Manually effect change of operational mode	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-059	Manually hold vehicle(s) in stations	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-060	Manually initiate controlled stop of all active vehicles	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-061	Manually command system power on/off	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-062	Provide operator message/ alarm processing	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-063	Ability of operator to reset alarm thresholds	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-064	Operator ability to make audio announcements	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-065	Operator ability to generate message board content	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-066	Operator ability to control video monitoring	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-067	Operator ability to control guideway and station lighting	3	R	4.2.3.1-052	-	SYS	D	Φ3	S
4.2.3.1-068	Automated alarm and reporting per ASCE standards	2	R	4.2.3.1-044	-	SYS	D	Φ3	S
4.2.3.1-069	Automated detection and response to failure conditions	1	R	4.1-001, 4.1-002, 4.1-003	4.2.3.1-070, 4.2.3.1-071	SYS	D	Φ3	S
4.2.3.1-070	Automatic detection and response to unsafe conditions	2	R	4.2.3.1-069	-	SYS	D	Φ3	S
4.2.3.1-071	Automatically diagnose and route around failures	2	R	4.2.3.1-069	4.2.3.1-072 - 4.2.3.1-076	SYS	D	Φ3	S
4.2.3.1-072	Ability to centrally sense stopped vehicle	3	R	4.2.3.1-071	-	SYS	D	Φ3	S
4.2.3.1-073	Automatic emergency stop for disabled vehicle	3	R	4.2.3.1-071	-	SYS	D	Φ3	S
4.2.3.1-074	Ability to centrally sense loss of guideway support	3	R	4.2.3.1-071	-	SYS	D	Φ3	S
4.2.3.1-075	Automatic emergency stop for guideway outage	3	R	4.2.3.1-071	-	SYS	D	Φ3	S
4.2.3.1-076	Vehicle ability to individually sense stoppage on guideway	3	R	4.2.3.1-071	-	SYS	D	Φ3	S
4.2.3.1-077	Robust system-wide data/ control communications	1	R	4.1-001, 4.1-002 4.1-010	4.2.3.1-078, 4.2.3.1-082 - 4.2.3.1-086	SYS	A, T	Φ3	S
4.2.3.1-078	Secure communications for guidance and control	2	R	4.2.3.1-077	4.2.3.1-079, 4.2.3.1-080, 4.2.3.1-081	SYS	A, T	Φ3	S

Req't ID	Short Title	Tier	R/O	↑ Trace	↓ Trace	Cat.	VM	Eff.	Alloc.
4.2.3.1-079	Secure, encrypted command and control channel	3	R	4.2.3.1-078	-	SYS	A, T	Φ3	S
4.2.3.1-080	Vehicle state of health sent to control center	3	R	4.2.3.1-078	-	SYS	D	Φ3	S
4.2.3.1-081	Minimum link margin	3	R	4.2.3.1-078	-	SYS	A, T	Φ3	S
4.2.3.1-082	Reliable operation in weather conditions	2	R	4.2.3.1-077	-	SYS	A, T	Φ3	S
4.2.3.1-083	Protocol prioritization of emergency data	2	R	4.2.3.1-077	-	SYS	A, T	Φ3	S
4.2.3.1-084	Remote control of vehicle operation and diagnosis	2	R	4.2.3.1-077	-	SYS	D	Φ3	S
4.2.3.1-085	Communication function end-to-end reliability	2	R	4.2.3.1-077	-	SYS	A	Φ3	S
4.2.3.1-086	Sufficient channel capacity for passenger information	2	R	4.2.3.1-077	-	SYS	A, D	Φ3	S
4.2.3.1-087	Provide functional features for usability and comfort	1	R	4.1-002, 4.1-003, 4.1-010	4.2.3.1-088, 4.2.3.1-090, 4.2.3.1-092, 4.2.3.1-093	SYS	D, T	Φ3	S
4.2.3.1-088	Provide cabin environmental control	2	R	4.2.3.1-087	4.2.3.1-089	SYS	T	Φ3	S
4.2.3.1-089	Maintain heating and cooling within comfort range	3	R	4.2.3.1-088	-	SYS	T	Φ3	S
4.2.3.1-090	Provide interior lighting per ASCE standards	2	R	4.2.3.1-087	4.2.3.1-091	SYS	D	Φ3	S
4.2.3.1-091	Provide additional interior lighting for night operations	3	R	4.2.3.1-090	-	SYS	D	Φ3	S
4.2.3.1-092	Provide emergency lighting per ASCE standards	2	R	4.2.3.1-087	-	SYS	D	Φ3	S
4.2.3.1-093	Provide in-vehicle passenger controls	2	R	4.2.3.1-087	-	SYS	D	Φ3	S
4.2.3.2	Performance Requirements								
4.2.3.2-001	Serve passenger demand with acceptable wait times	1	R	4.1-002 4.1-003 4.1-010		SYS	A, D	Φ3	S
4.2.3.2-002	Mean passenger wait time to depart	2	R	4.2.3.2-001	-	SYS	A, D	Φ3	S
4.2.3.2-003	Mean proportion of wave-offs	2	R	4.2.3.2-001	-	SYS	A, D	Φ3	S
4.2.3.2-004	Vehicle dynamic performance	1	R	4.1-002 4.1-003 4.1-010	4.2.3.2-005, 4.2.3.2-009 - 4.2.3.2-014, 4.2.3.2-018, 4.2.3.2-021, 4.2.3.2-022	SYS	A, D	Φ3	S
4.2.3.2-005	Nominal line velocity	2	R	4.2.3.2-004	4.2.3.2-006	SYS	A, D	Φ3	S

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4.2.3.2-006	Provide capability to limit vehicle speeds	3	R	4.2.3.2-005	-	SYS	A, D	Φ3	S
4.2.3.2-007	Normal vehicle acceleration and deceleration limits	3	R	4.2.3.2-005	-	SYS	A, D	Φ3	S
4.2.3.2-008	Emergency braking deceleration	3	R	4.2.3.2-005	-	SYS	A, D	Φ3	S
4.2.3.2-009	Autonomous operation at 6 second headways	2	R	4.2.3.2-004	-	SYS	A, D	Φ3	S
4.2.3.2-010	Operate at nominal line speed on curves	2	R	4.2.3.2-004	-	SYS	D	Φ3	S
4.2.3.2-011	Nominal operation on ascending grades	2	R	4.2.3.2-004	-	SYS	D	Φ3	S
4.2.3.2-012	Nominal operation on descending grades	2	R	4.2.3.2-004	-	SYS	D	Φ3	S
4.2.3.2-013	Nominal operation on all guideway elevations	2	R	4.2.3.2-004	-	SYS	D	Φ3	S
4.2.3.2-014	Meet ride quality standards at nominal line speed	2	R	4.2.3.2-004	4.2.3.2-015, 4.2.3.2-016, 4.2.3.2-017	SYS	D	Φ3	S
4.2.3.2-015	Comply with accepted ride roughness limits	3	R	4.2.3.2-014	-	SYS	A, T	Φ3	S
4.2.3.2-016	Comply with accepted whole body vibration limits	3	R	4.2.3.2-014	-	SYS	A, T	Φ3	S
4.2.3.2-017	Comply with ride quality standards for vehicle motion	3	R	4.2.3.2-014	-	SYS	A, T	Φ3	S
4.2.3.2-018	Operate within vehicle noise level limits	2	R	4.2.3.2-004	4.2.3.2-019, 4.2.3.2-020	SYS	T	Φ3	S
4.2.3.2-019	Operate within interior noise level limits	3	R	4.2.3.2-018	-	SYS	T	Φ3	S
4.2.3.2-020	Operate within exterior noise level limits	3	R	4.2.3.2-018	-	SYS	T	Φ3	S
4.2.3.2-021	Guideway switching mechanism cycle time	2	R	4.2.3.2-004	-	SYS	T	Φ3	S
4.2.3.2-022	Accurately maintain vehicle position, velocity and heading	2	R	4.2.3.2-004	4.2.3.2-023 - 4.2.3.2-027	SYS	T	Φ3	S
4.2.3.2-023	Maintain longitudinal positioning	3	R	4.2.3.2-022	-	SYS	T	Φ3	S
4.2.3.2-024	Maintain lateral positioning	3	R	4.2.3.2-022	-	SYS	T	Φ3	S
4.2.3.2-025	Maintain accurate velocity	3	R	4.2.3.2-022	-	SYS	T	Φ3	S
4.2.3.2-026	Determine and maintain accurate heading	3	R	4.2.3.2-022	-	SYS	T	Φ3	S
4.2.3.2-027	Control loop gain and margin	3	R	4.2.3.2-022	-	SYS	T	Φ3	S

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4.2.3.2-028	Detect failures and mitigate anomalous effects	1	R	4.1-002 4.1-010	4.2.3.2-029	SYS	T	Φ3	S
4.2.3.2-029	Detect and react to guideway blockages	2	R	4.2.3.2-028	4.2.3.2-030 - 4.2.3.2-034	SYS	T	Φ3	S
4.2.3.2-030	Communicate emergency stop commands	3	R	4.2.3.2-029	-	SYS	T	Φ3	S
4.2.3.2-031	Reroute vehicles around blocked guideway section	3	R	4.2.3.2-029	-	SYS	T	Φ3	S
4.2.3.2-032	Begin controlled deceleration after blockage detection	3	R	4.2.3.2-029	-	SYS	T	Φ3	S
4.2.3.2-033	Notification after blockage detection by vehicle	3	R	4.2.3.2-029	-	SYS	T	Φ3	S
4.2.3.2-034	Notification after blockage detection by system	3	R	4.2.3.2-029	-	SYS	T	Φ3	S
4.2.3.2-035	Operate within physical clearances of route layout	1	R	4.1-001 4.1-010	4.2.3.2-036, 4.2.3.2-037, 4.2.3.2-038, 4.2.3.2-039	SYS	T	Φ3	S
4.2.3.2-036	Nominal operation within specified side clearances	2	R	4.2.3.2-035	-	SYS	T	Φ3	S
4.2.3.2-037	Nominal operation within specified overhead clearance	2	R	4.2.3.2-035	-	SYS	T	Φ3	S
4.2.3.2-038	Nominal operation within specified clearance below	2	R	4.2.3.2-035	-	SYS	T	Φ3	S
4.2.3.2-039	Nominal operation over unrestricted right of way	2	R	4.2.3.2-035	-	SYS	T	Φ3	S
4.2.3.2-040	Operation in local San José environmental condition	1	R	4.1-001, 4.1-002, 4.1-010	4.2.3.2-041, 4.2.3.2-042, 4.2.3.2-043, 4.2.3.2-044	SYS	D	Φ3	S
4.2.3.2-041	Nominal operations in darkness and fog	2	R	4.2.3.2-040	-	SYS	D	Φ3	S
4.2.3.2-042	Nominal operations in heavy rain	2	R	4.2.3.2-040	-	SYS	D	Φ3	S
4.2.3.2-043	Nominal operation in frost and ice	2	R	4.2.3.2-040	-	SYS	D	Φ3	S
4.2.3.2-044	Nominal operation in windy conditions	2	R	4.2.3.2-040	-	SYS	D	Φ3	S
4.2.3.3	Interoperability Requirements								
4.2.3.3-001	Promote interoperability among system elements	1	R	4.1-002, 4.1-005, 4.1-010	4.2.3.3-002, 4.2.3.3-003, 4.2.3.3-004	SYS	I, A	Φ3	S
4.2.3.3-002	Vehicles compatible with all stations and guideways	2	R	4.2.3.3-001	-	SYS	I, A	Φ3	S
4.2.3.3-003	Define guideway-vehicle	2	R	4.2.3.3-001	-	SYS	I, A	Φ3	S

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	interface specification								
4.2.3.3-004	Define vehicle-guideway interface specification	2	R	4.2.3.3-001	-	SYS	I, A	Φ3	S
4.2.3.4	Flexibility Requirements								
4.2.3.4-001	Accommodate flexible transportation needs	1	R	4.1-002, 4.1-003, 4.1-004, 4.1-005, 4.1-010	4.2.3.4-002, 4.2.3.4-003, 4.2.3.4-004, 4.2.3.4-005	SYS	I, A, D	Φ3	S
4.2.3.4-002	Modular guideway for reconfigurability	2	R	4.2.3.4-001	-	SYS	I, A	Φ3	S
4.2.3.4-003	Scalable control algorithms and software	2	R	4.2.3.4-001	-	SYS	I, A, D	Φ3	S
4.2.3.4-004	Scalable operational monitoring and control	2	R	4.2.3.4-001	-	SYS	I, A, D	Φ3	S
4.2.3.4-005	Accommodate future SJC airport expansion	2	R	4.2.3.4-001	-	SYS	I, A	TBD	S
4.2.3.5	Reliability and Availability Requirements								
4.2.3.5-001	System designed and implemented per reliability engineering analysis	1	R	4.1-002, 4.1-004, 4.1-005, 4.1-010	-	SYS	A	Φ3	S
4.2.3.5-002	Maintain expected transit service availability level	1	R	4.1-002, 4.1-004, 4.1-005, 4.1-010	4.2.3.5-003, 4.2.3.5-004, 4.2.3.5-005	SYS	A	Φ3	S
4.2.3.5-003	Progressively achieve availability targets	2	R	4.2.3.5-002	-	SYS	A	Φ3	S
4.2.3.5-004	Long-term service availability target	2	R	4.2.3.5-002	-	SYS	V	Φ3	S
4.2.3.5-005	Subsystem and component reliability targets	2	R	4.2.3.5-002	4.2.3.5-006 - 4.2.3.5-011	SYS	A	Φ3	S
4.2.3.5-006	Vehicle MTBF	3	R	4.2.3.5-005	-	SYS	A	Φ3	S
4.2.3.5-007	Vehicle MTTR	3	R	4.2.3.5-005	-	SYS	A	Φ3	S
4.2.3.5-008	No drive motor single point of failure	3	R	4.2.3.5-005	-	SYS	A	Φ3	S
4.2.3.5-009	Guideway switching mechanism reliability	3	R	4.2.3.5-005	-	SYS	A	Φ3	S
4.2.3.5-010	Command and control channel availability	3	R	4.2.3.5-005	-	SYS	A	Φ3	S
4.2.3.5-011	Command and control channel BER	3	R	4.2.3.5-005	-	SYS	A	Φ3	S

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4.2.3.6	Safety Requirements								
4.2.3.6-001	Establish and maintain a System Safety Program	1	R	4.1-002, 4.1-010	4.2.3.6-002	SYS	I, D	Φ3	S, B
4.2.3.6-002	Develop System Safety Program Plan	2	R	4.2.3.6-001	-	SYS	I	Φ3	B
4.2.3.6-003	System incorporates safety principles of ASCE standards	1	R	4.1-002, 4.1-010	-	SYS	I, A, D, T	Φ3	S
4.2.3.6-004	Implement Fire Protection program per NFPA 130	1	R	4.1-010	-	SYS	I, T	Φ3	S
4.2.3.6-005	System implemented per fire safety standards	1	R	4.1-010	4.2.3.6-006	SYS	I, T	Φ3	S
4.2.3.6-006	Comply with ASCE APM fire safety provisions	2	R	4.2.3.6-005	4.2.3.6-007, 4.2.3.6-008, 4.2.3.6-009	SYS	I, T	Φ3	S
4.2.3.6-007	Use of flame-retardant materials	3	R	4.2.3.6-006	-	SYS	I, T	Φ3	S
4.2.3.6-008	Thermal protection of electrical components	3	R	4.2.3.6-006	-	SYS	I, T	Φ3	S
4.2.3.6-009	Incorporate smoke/fire detection and suppression	3	R	4.2.3.6-006	-	SYS	I, T	Φ3	S
4.2.3.6-010	Provide passenger controls and egress for safety	1	R	4.1-002 4.1-010	4.2.3.6-011, 4.2.3.6-014, 4.2.3.6-015, 4.2.3.6-020	SYS	I, D	Φ3	S
4.2.3.6-011	Provide for passenger-initiated controlled stop	2	R	4.2.3.6-010	4.2.3.6-012, 4.2.3.6-013	SYS	D	Φ3	S
4.2.3.6-012	Stop control interlock	3	R	4.2.3.6-011	-	SYS	D	Φ3	S
4.2.3.6-013	Default emergency vehicle destination	3	R	4.2.3.6-011	-	SYS	D	Φ3	S
4.2.3.6-014	Automatic door operation only when vehicle stopped	2	R	4.2.3.6-010	-	SYS	D	Φ3	S
4.2.3.6-015	Provide for emergency manual egress	2	R	4.2.3.6-010	4.2.3.6-016, 4.2.3.6-017, 4.2.3.6-018, 4.2.3.6-019	SYS	D	Φ3	S
4.2.3.6-016	Manual egress only from stopped vehicle	3	R	4.2.3.6-015	-	SYS	D	Φ3	S
4.2.3.6-017	Manual egress independent of vehicle power	3	R	4.2.3.6-015	-	SYS	D	Φ3	S
4.2.3.6-018	Manual egress operable by visual and hearing-disabled	3	R	4.2.3.6-015	-	SYS	D	Φ3	S
4.2.3.6-019	Manual egress operable by wheelchair users	3	R	4.2.3.6-015	-	SYS	D	Φ3	S
4.2.3.6-020	Emergency walkways on all elevated guideways	2	R	4.2.3.6-010	4.2.3.6-021, 4.2.3.6-022	SYS	I	Φ3	S

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4.2.3.6-021	Emergency walkway dimensional specifications	3	R	4.2.3.6-020	-	SYS	I	Φ3	S
4.2.3.6-022	ADA compliance for emergency walkways	3	R	4.2.3.6-020	-	SYS	I	Φ3	S
4.2.3.6-023	Stations comply with fire safety standards	1	R	4.1-001, 4.1-010	4.2.3.6-024, 4.2.3.6-027, 4.2.3.6-029	SYS	I, D	Φ3	S
4.2.3.6-024	Stations comply with NFPA 130 evacuation provisions	2	R	4.2.3.6-023	4.2.3.6-025, 4.2.3.6-026	SYS	I, D	Φ3	S
4.2.3.6-025	Maximum emergency egress traversal distance	3	R	4.2.3.6-024	-	SYS	I	Φ3	S
4.2.3.6-026	Evacuation without escalators or elevators	3	R	4.2.3.6-024	-	SYS	I	Φ3	S
4.2.3.6-027	Emergency evacuation path lighting	2	R	4.2.3.6-023	4.2.3.6-028	SYS	I, D	Φ3	S
4.2.3.6-028	Secondary power supply for station emergency lighting	3	R	4.2.3.6-027	-	SYS	I, D	Φ3	S
4.2.3.6-029	Code-compliant fire detection and protection devices	2	R	4.2.3.6-023	4.2.3.6-030, 4.2.3.6-031, 4.2.3.6-032, 4.2.3.6-033	SYS	I, D	Φ3	S
4.2.3.6-030	Automatic fire alarm system	3	R	4.2.3.6-029	-	SYS	I, D	Φ3	S
4.2.3.6-031	Automatic fire sprinkler system	3	R	4.2.3.6-029	-	SYS	I, D	Φ3	S
4.2.3.6-032	Stations equipped with fire hose reel, fire extinguishers	3	R	4.2.3.6-029	-	SYS	I, D	Φ3	S
4.2.3.6-033	Fireman's intercom system	3	R	4.2.3.6-029	-	SYS	I, D	Φ3	S
4.2.3.6-034	Provide operational safety during transit operations	1	R	4.1-001, 4.1-002 4.1-010	4.2.3.6-035, 4.2.3.6-036, 4.2.3.6-038, 4.2.3.6-039, 4.2.3.6-040, 4.2.3.6-043, 4.2.3.6-044, 4.2.3.6-045	SYS	I, A, D, T	Φ3	S
4.2.3.6-035	Prevent passengers from entering/crossing guideways	2	R	4.2.3.6-034	-	SYS	I	Φ3	S
4.2.3.6-036	Detect gross weight overload	2	R	4.2.3.6-034	4.2.3.6-037	SYS	D	Φ3	S
4.2.3.6-037	Disable drive mechanism under overload	3	R	4.2.3.6-036	-	SYS	D	Φ3	S
4.2.3.6-038	Safety interlock between doors and drive motors	2	R	4.2.3.6-034	-	SYS	D	Φ3	S
4.2.3.6-039	Energy absorption for collision safety	2	R	4.2.3.6-034	-	SYS	A, D	Φ3	S

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4.2.3.6-040	Self-propulsion with automatic routing	2	R	4.2.3.6-034	4.2.3.6-041, 4.2.3.6-042	SYS	D	Φ3	S
4.2.3.6-041	System-wide power outage	3	R	4.2.3.6-040	-	SYS	D	Φ3	S
4.2.3.6-042	Primary battery discharge or failure	3	R	4.2.3.6-040	-	SYS	D	Φ3	S
4.2.3.6-043	Safety interlock for guideway switches	2	R	4.2.3.6-034	-	SYS	T	Φ3	S
4.2.3.6-044	Collision rate and passenger injury rate	2	R	4.2.3.6-034	-	SYS	A	Φ3	S
4.2.3.6-045	Protection of public from operational hazards	2	R	4.2.3.6-034	-	SYS	I, D	Φ3	S
4.2.3.7	Security Requirements								
4.2.3.7-001	Establish and maintain a System Security Program	1	R	4.1-002, 4.1-010	4.2.3.7-002, 4.2.3.7-003	SYS	I, D	Φ3	S, B
4.2.3.7-002	Develop System Security Program Plan	2	R	4.2.3.7-001	-	SYS	I	Φ3	B
4.2.3.7-003	Develop and adopt regulatory approval process	2	R	4.2.3.7-001	-	SYS	I	Φ3	B
4.2.3.7-004	Implement security features per ASCE APM standards	1	R	4.1-002, 4.1-010	4.2.3.7-005, 4.2.3.7-006	SYS	I, D	Φ3	S
4.2.3.7-005	Incorporate audio/visual security features	2	R	4.2.3.7-004	-	SYS	I, D	Φ3	S
4.2.3.7-006	Incorporate additional security features	2	R	4.2.3.7-004	-	SYS	I, D	Φ3	S
4.2.4	ATN Operational Requirements								
4.2.4.1	System Operations								
4.2.4.1-001	Operation according to documented plans/processes	1	R	4.1-001, 4.1-010	4.2.4.1-002	OPS	I	Φ3	S
4.2.4.1-002	Develop a System Operations Plan	2	R	4.2.4.1-001	-	OPS	I	Φ3	S
4.2.4.1-003	System operates under 24/7 human supervision	1	R	4.1-010	4.2.4.1-004	OPS	D	Φ3	S
4.2.4.1-004	Procedures for system startup and shutdown	2	R	4.2.4.1-003	4.2.4.1-005 - 4.2.4.1-010	OPS	I, D	Φ3	S
4.2.4.1-005	System startup sequence	3	R	4.2.4.1-004	-	OPS	I, D	Φ3	S
4.2.4.1-006	Manual initiation of startup procedure	3	R	4.2.4.1-004	-	OPS	I, D	Φ3	S
4.2.4.1-007	Startup of control, power and vehicle subsystems	3	R	4.2.4.1-004	-	OPS	I, D	Φ3	S
4.2.4.1-008	System shutdown sequence	3	R	4.2.4.1-004	-	OPS	I, D	Φ3	S

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4.2.4.1-009	Manual initiation of shutdown procedure	3	R	4.2.4.1-004	-	OPS	I, D	Φ3	S
4.2.4.1-010	Automatic distribution of vehicles upon shutdown	3	R	4.2.4.1-004	-	OPS	I, D	Φ3	S
4.2.4.1-011	Operate system for maximum safety and security	1	R	4.1-002, 4.1-010	4.2.4.1-012	OPS	D	Φ3	S
4.2.4.1-012	Operational status change for specifiable portion of system	2	R	4.2.4.1-011	4.2.4.1-013	OPS	D	Φ3	S
4.2.4.1-013	Manually re-route vehicles outside of TSA perimeter	3	R	4.2.4.1-012	-	OPS	D	Φ3	S
4.2.4.1-014	Operate system for maximum efficiency and economy	1	R	4.1-002, 4.1-004, 4.1-005, 4.1-006, 4.1-010	4.2.4.1-015, 4.2.4.1-016	OPS	D	Φ3	S
4.2.4.1-015	Minimize number of in-service vehicles	2	R	4.2.4.1-014	-	OPS	A, D	Φ3	S
4.2.4.1-016	Minimize number of empty vehicles in active circulation	2	R	4.2.4.1-014	-	OPS	A, D	Φ3	S
4.2.4.1-017	Provide manned control center facility	1	R	4.1-002, 4.1-010	4.2.4.1-018, 4.2.4.1-019, 4.2.4.1-020	OPS	D	Φ3	S
4.2.4.1-018	Operator interface for system monitoring functions	2	R	4.2.4.1-017	-	OPS	D	Φ3	S
4.2.4.1-019	Operator interface for system control functions	2	R	4.2.4.1-017	-	OPS	D	Φ3	S
4.2.4.1-020	Operator interface for system communications functions	2	R	4.2.4.1-017	-	OPS	D	Φ3	S
4.2.4.1-021	Develop operational procedures and instructions	1	R	4.1-002, 4.1-004, 4.1-010	4.2.4.1-022	OPS	I	Φ3	S
4.2.4.1-022	Minimum set of operational procedures	2	R	4.2.4.1-021	-	OPS	I	Φ3	S
4.2.4.1-023	Minimum set of failure/ outage response procedures	2	R	4.2.4.1-021	-	OPS	I	Φ3	S
4.2.4.2	Service Operations								
4.2.4.2-001	Provide enterprise services	1	R	4.1-002, 4.1-003, 4.1-004, 4.1-010	4.2.4.2-002, 4.2.4.2-003, 4.2.4.2-004, 4.2.4.2-005	OPS	D	Φ3	S
4.2.4.2-002	Provide Business Service functions	2	R	4.2.4.2-001	-	OPS	D	Φ3	S
4.2.4.2-003	Provide Customer Service functions	2	R	4.2.4.2-001	-	OPS	D	Φ3	S
4.2.4.2-004	Provide Enterprise Analytics functions	2	R	4.2.4.2-001	-	OPS	D	Φ3	S

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4.2.4.2-005	Provide Product Support functions	2	R	4.2.4.2-001	-	OPS	D	Φ3	S
4.2.4.2-006	Operational monitoring per ACSE APM Standards	1	R	4.1-002, 4.1-003, 4.1-004, 4.1-010	4.2.4.2-007, 4.2.4.2-008	OPS	I, D	Φ3	S
4.2.4.2-007	Annual auditing and reporting	2	R	4.2.4.2-006	-	OPS	I, D	Φ3	S
4.2.4.2-008	Service Level Agreement compliance monitoring	2	R	4.2.4.2-006	-	OPS	A	Φ3	S
4.2.4.3	Maintenance Operations								
4.2.4.3-001	Provide maintenance facilities, processes and services	1	R	4.1-002, 4.1-003, 4.1-004, 4.1-010	4.2.4.3-002, 4.2.4.3-005, 4.2.4.3-006, 4.2.4.3-008, 4.2.4.3-013, 4.2.4.3-014	OPS	I, D	Φ3	S
4.2.4.3-002	Operate vehicle maintenance and repair facility	2	R	4.2.4.3-001	4.2.4.3-003, 4.2.4.3-004	OPS	I, D	Φ3	S
4.2.4.3-003	Provide for vehicle movement to and from repair areas	3	R	4.2.4.3-002	-	OPS	I, D	Φ3	S
4.2.4.3-004	Vehicle control within maintenance facility	3	R	4.2.4.3-002	-	OPS	I, D	Φ3	S
4.2.4.3-005	Operate vehicle cleaning facility	2	R	4.2.4.3-001	-	OPS	I, D	Φ3	S
4.2.4.3-006	Maintenance and Repair Facility tooling, equipment	2	R	4.2.4.3-001	4.2.4.3-007	OPS	I	Φ3	S
4.2.4.3-007	Accessible parts storage	3	R	4.2.4.3-006	-	OPS	I	Φ3	S
4.2.4.3-008	Provide Maintenance and Recovery Vehicle	2	R	4.2.4.3-001	4.2.4.3-009, 4.2.4.3-010, 4.2.4.3-011, 4.2.4.3-012	OPS	I, D	Φ3	S
4.2.4.3-009	MRV is self-powered	3	R	4.2.4.3-008	-	OPS	I, D	Φ3	S
4.2.4.3-010	MRV controllable via manual inputs from central control	3	R	4.2.4.3-008	-	OPS	I, D	Φ3	S
4.2.4.3-011	MRV controllable via manual inputs from inside vehicle	3	R	4.2.4.3-008	-	OPS	I, D	Φ3	S
4.2.4.3-012	MRV immediately deployable	3	R	4.2.4.3-008	-	OPS	I, D	Φ3	S
4.2.4.3-013	Parts stocking and replenishment process	2	R	4.2.4.3-001	-	OPS	I	Φ3	S
4.2.4.3-014	Periodic vehicle inspection process	2	R	4.2.4.3-001	-	OPS	I	Φ3	S
4.2.4.4	Emergency Operations								
4.2.4.4-001	Implement an Emergency Preparedness Program	1	R	4.1-002, 4.1-003,	4.2.4.4-002	OPS	I, D	Φ3	S

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				4.1-004, 4.1-010					
4.2.4.4-002	Develop Emergency Preparedness Program Plan	2	R	4.2.4.4-001	-	OPS	I	Φ3	S
4.2.4.4-003	Develop emergency operations procedures	2	R	4.2.4.4.-001	4.2.4.4-004	OPS	I, D	Φ3	S
4.2.4.4-004	Minimum emergency operations procedure content	3	R	4.2.4.4-003	-	OPS	I, D	Φ3	S
4.2.5	ATN Sustainability Objectives								
4.2.5.1	Energy Efficiency								
4.2.5.1-001	Provide improved energy efficiency	1	R	4.1-006, 4.1-010	4.2.5.1-002, 4.2.5.1-003	SUS	A	Φ3	S
4.2.5.1-002	Energy efficiency better than private auto	2	R	4.2.5.1-001	-	SUS	A	Φ3	S
4.2.5.1-003	Lower energy consumption than other transit modes	2	R	4.2.5.1-001	4.2.5.1-004	SUS	A	Φ3	S
4.2.5.1-004	Incorporate energy-saving design techniques	3	R	4.2.5.1-003	4.2.5.1-005, 4.2.5.1-006	SUS	I, A	Φ3	S
4.2.5.1-005	Vehicle coefficient of drag target	4	R	4.2.5.1-004	-	SUS	I, A	Φ3	S
4.2.5.1-006	Vehicle translational resistance target	4	R	4.2.5.1-004	-	SUS	I, A	Φ3	S
4.2.5.2	Energy Sources								
4.2.5.2-001	Maximum utilization of renewable energy	1	R	4.1-006, 4.1-010	4.2.5.2-002, 4.2.5.2-003, 4.2.5.2-004	SUS	I, A	Φ3	S
4.2.5.2-002	Vehicles utilize non-fossil fuel sources	2	R	4.2.5.2-001	-	SUS	I	Φ3	S
4.2.5.2-003	Maximum use of renewable sources at point of generation	2	R	4.2.5.2-001	-	SUS	I, A	Φ3	S
4.2.5.2-004	Stations utilize non-fossil fuel sources	2	R	4.2.5.2-001	4.2.5.2-005	SUS	I, A	Φ3	S
4.2.5.2-005	Stations incorporate solar power generation	3	R	4.2.5.2-004	-	SUS	I	Φ3	S
4.2.5.3	Environmental Compliance								
4.2.5.3-001	Operate in compliance with San José Green Vision	1	R	4.1-006, 4.1-010	4.2.5.3-002	SUS	I, A	Φ3	S
4.2.5.3-002	Minimum GHG emissions	2	R	4.2.5.3-001	4.2.5.3-003, 4.2.5.3-004	SUS	A	Φ3	S
4.2.5.3-003	No direct vehicle GHG emissions	3	R	4.2.5.3-002	-	SUS	A	Φ3	S
4.2.5.3-004	Minimum indirect GHG	3	R	4.2.5.3-002	-	SUS	A	Φ3	S

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	emissions								
4.2.5.3-005	Environmental compliance with regulations and goals	1	R	4.1-006, 4.1-010	4.2.5.3-006, 4.2.5.3-008, 4.2.5.3-009, 4.2.5.3-010, 4.2.5.3-011	SUS	I, A, T	Φ3	S
4.2.5.3-006	Operate within community noise standards	2	R	4.2.5.3-005	4.2.5.3-007	SUS	A, T	Φ3	S
4.2.5.3-007	Procedure for mitigating noise and vibration issues	3	R	4.2.5.3-006	-	SUS	A, T	Φ3	S
4.2.5.3-008	Comply with water runoff regulations	2	R	4.2.5.3-005	-	SUS	I, A	Φ3	S
4.2.5.3-009	Comply with community aesthetic standards	2	R	4.2.5.3-005	-	SUS	I, A	Φ3	S
4.2.5.3-010	Comply with electromagnetic emission regulations	2	R	4.2.5.3-005	-	SUS	A, T	Φ3	S
4.2.5.3-011	Protect environmentally sensitive areas	2	R	4.2.5.3-005	-	SUS	I, A	Φ3	S
4.2.5.4	Materials and Recyclability								
4.2.5.4-001	Minimize environmental impacts from materials use	1	R	4.1-006, 4.1-010	4.2.5.4-002, 4.2.5.4-006, 4.2.5.4-007	SUS	I, A, D, T	Φ3	S
4.2.5.4-002	Minimize use of hazardous materials and supplies	2	R	4.2.5.4-001	4.2.5.4-003, 4.2.5.4-004, 4.2.5.4-005	SUS	I, A	Φ3	S
4.2.5.4-003	Storage battery mercury and cadmium limits	3	R	4.2.5.4-002	-	SUS	A, T	Φ3	S
4.2.5.4-004	Battery and waste product recycling	3	R	4.2.5.4-002	-	SUS	I, D	Φ3	S
4.2.5.4-005	Recycling plan for accountable disposal	3	R	4.2.5.4-002	-	SUS	I, A	Φ3	S
4.2.5.4-006	Maintain ATN with minimum material/energy waste	2	R	4.2.5.4-001	-	SUS	I, A	Φ3	S
4.2.5.4-007	Design for easy deconstruction	2	R	4.2.5.4-001	-	SUS	I, D	Φ3	S
4.2.6	ATN Economic Objectives								
4.2.6.1	Investment Constraints								
4.2.6.1-001	Implement ATN within defined cost and schedule	1	R	4.1-004, 4.1-010	4.2.6.1-002, 4.2.6.1-003	ECN	A, V	Φ3	S
4.2.6.1-002	Per-mile capital investment target	2	R	4.2.6.1-001	-	ECN	A	Φ3	S
4.2.6.1-003	Annual operations and maintenance budget target	2	R	4.2.6.1-001	-	ECN	A	Φ3	S
4.2.6.1-004	"Cost per Unit Service" target	1	R	4.1-004,	-	ECN	A, V	Φ3	S

Req't ID	Short Title	Tier	R/O	↑ Trace	↓ Trace	Cat.	VM	Eff.	Alloc.
				4.1-010					
4.2.6.2	Airport Revenue Objectives								
4.2.6.2-001	Enhance SJC revenue stream	1	R	4.1-002, 4.1-003, 4.1-004, 4.1-010	-	ECN	V	Φ3	S
4.2.6.2-002	Encourage additional use of SJC and its facilities	1	R	4.1-002, 4.1-003, 4.1-005, 4.1-006	4.2.6.2-003, 4.2.6.2-004, 4.2.6.2-005	ECN	V	Φ3	S
4.2.6.2-003	Improve access for the economically disadvantaged	2	R	4.2.6.2-002	-	ECN	V	Φ3	S
4.2.6.2-004	No fare required for Airport connections	2	R	4.2.6.2-002	-	ECN	D	Φ3	S
4.2.6.2-005	No detriment to existing revenue sources	2	R	4.2.6.2-002	-	ECN	V	Φ3	S
4.2.6.3	Land Use / TOD Objectives								
4.2.6.3-001	Promote efficient land use	1	R	4.1-006, 4.1-009	-	ECN	V	Φ3	S, B
4.2.6.3-002	Facilitate opportunities for TOD	1	R	4.1-002, 4.1-005, 4.1-009	-	ECN	V	Φ3	S, B
4.2.6.4	Economic Opportunity Objectives								
4.2.6.4-001	Enhance San José presence in ATN industry	1	R	4.1-006, 4.1-007	-	ECN	V	Φ3	S, B
4.2.6.4-002	Enhance number and quality of employment opportunities	1	R	4.1-006, 4.1-008, 4.1-009	-	ECN	V	Φ3	S, B
4.2.7	ATN Acquisition and Delivery Requirements								
4.2.7.1	Financing Objective								
4.2.7.1-001	Alternative financing options	1	R	4.1-001, 4.1-010	-	ACQ	A	Φ3	B
4.2.7.2	Funding Objective								
4.2.7.2-001	Funding resource assessment	1	R	4.1-001, 4.1-004, 4.1-010	4.2.7.2-002	ACQ	A	Φ3	B
4.2.7.2-002	Funding plan in place prior to procurement	2	R	4.2.7.2-001	4.2.7.2-003	ACQ	A	Φ3	B
4.2.7.2-003	Investigate funding source options	3	O	4.2.7.2-002	-	ACQ	A	Φ3	B
4.2.7.3	Value for Money Objective								
4.2.7.3-001	"Value for Money" analysis	1	R	4.1-001, 4.1-004,	-	ACQ	A	Φ3	B

Req't ID	Short Title	Tier	R/O	↑ Trace	↓ Trace	Cat.	VM	Eff.	Alloc.
				4.1-007, 4.1-008, 4.1-009, 4.1-010					
4.2.7.4	Risk Transfer Objective								
4.2.7.4-001	Provide effective risk transfer	1	R	4.1-010	-	ACQ	A	Φ3	B
4.2.7.5	Cost and Schedule Certainty Objective								
4.2.7.5-001	Cost and schedule certainty	1	R	4.1-010	4.2.7.5-002, 4.2.7.5-004, 4.2.7.5-005, 4.2.7.5-006	ACQ	A	Φ3	B
4.2.7.5-002	Estimate costs using FTA standard cost categories	2	R	4.2.7.5-001	4.2.7.5-003	ACQ	A	Φ3	B
4.2.7.5-003	Separate estimate of development costs	3	R	4.2.7.5-002	-	ACQ	A	Φ3	B
4.2.7.5-004	Schedule estimates per FTA acquisition phases	2	R	4.2.7.5-001	-	ACQ	A	Φ3	B
4.2.7.5-005	Incorporate uncertainty into estimation models	2	R	4.2.7.5-001	-	ACQ	A	Φ3	B
4.2.7.5-006	Cost and schedule commitments	2	R	4.2.7.5-001	4.2.7.5-007	ACQ	A	Φ3	S
4.2.7.5-007	Offer selective ontractor incentives	3	R	4.2.7.5-006	-	ACQ	A	Φ3	B
4.2.7.6	Operations and Maintenance Investment Objective								
4.2.7.6-001	Perform analysis to determine optimum O&M level	1	R	4.1-004, 4.1-010	-	ACQ	A	Φ3	B
4.2.7.7	Revenue Objective								
4.2.7.7-001	Perform analysis to determine optimum revenue strategy	1	R	4.1-004, 4.1-005 4.1-010	-	ACQ	A	Φ3	B
4.2.7.8	Service Quality Objectives								
4.2.7.8-001	Perform analysis of optimum level of service quality	1	R	4.1-002, 4.1-004, 4.1-010	-	ACQ	A	Φ3	B
4.2.7.9	Acquisition Roles and Responsibilities								
4.2.7.9-001	Procure per established roles and responsibilities	1	R	4.1-001, 4.1-010	4.2.7.9-002	ACQ	I	Φ3	S, B
4.2.7.9-002	Roles of public and private entities	2	R	4.2.7.9-001	4.2.7.9-003, 4.2.7.9-004, 4.2.7.9-005	ACQ	I	Φ3	S, B
4.2.7.9-003	Role of independent consultants	3	R	4.2.7.9-002	-	ACQ	A	Φ3	B

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4.2.7.9-004	Role of independent system integration contractor	3	R	4.2.7.9-002	-	ACQ	A	Φ3	B
4.2.7.9-005	Responsibility for establishing requirements	3	R	4.2.7.9-002	-	ACQ	A	Φ3	B
4.2.7.10	Procurement Integrity								
4.2.7.10-001	Procure to highest standards of procurement integrity	1	R	4.1-001, 4.1-010	4.2.7.10-002, 4.2.7.10-005	ACQ	I, A, D	Φ3	B
4.2.7.10-002	Procure per public transit regulations and codes	2	R	4.2.7.10-001	4.2.7.10-003, 4.2.7.10-004	ACQ	A	Φ3	B
4.2.7.10-003	Specific procurement regulations	3	R	4.2.7.10-002	-	ACQ	I	Φ3	B
4.2.7.10-004	Ensure open, transparent competition	3	R	4.2.7.10-002	-	ACQ	D	Φ3	B
4.2.7.10-005	Protection of public interest	2	R	4.2.7.10-001	4.2.7.10-006	ACQ	D	Φ3	B
4.2.7.10-006	Compliance with auditing and accounting standards	2	R	4.2.7.10-005	-	ACQ	D	Φ3	B
4.2.8	ATN Project Management Requirements								
4.2.8.1	Project Management Process								
4.2.8.1-001	Execute procurement per Project Management Plan	1	R	4.1-001, 4.1-010	4.2.8.1-002 - 4.2.8.1-006	PRJ	V	Φ3	B, S
4.2.8.1-002	Develop Work Breakdown Structure	2	R	4.2.8.1-001	-	PRJ	I	Φ3	B
4.2.8.1-003	Develop Contract Data Requirements List	2	R	4.2.8.1-001	-	PRJ	I	Φ3	B
4.2.8.1-004	Institute Master Project Scheduling system	2	R	4.2.8.1-001	-	PRJ	I	Φ3	B
4.2.8.1-005	Establish progress review schedule	2	R	4.2.8.1-001	-	PRJ	I	Φ3	B
4.2.8.1-006	Establish integrated project review process	2	R	4.2.8.1-001	-	PRJ	I	Φ3	B, S
4.2.8.2	Risk Management								
4.2.8.2-001	Establish ongoing Risk Management program	1	R	4.1-001, 4.1-010	4.2.8.2-002	PRJ	V	Φ3	B
4.2.8.2-002	Implement Risk Management System	2	R	4.2.8.2-001	4.2.8.2-003 - 4.2.8.2-007	PRJ	D	Φ3	B
4.2.8.2-003	Perform ongoing threat and mitigation identification	3	R	4.2.8.2-002	-	PRJ	D	Φ3	B, S
4.2.8.2-004	Calculate risk impact	3	R	4.2.8.2-002	-	PRJ	D	Φ3	B, S
4.2.8.2-005	Identify risk mitigation plans	3	O	4.2.8.2-002	-	PRJ	D	Φ3	B, S
4.2.8.2-006	Periodically re-assess threats	3	R	4.2.8.2-002	-	PRJ	D	Φ3	B, S

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	and mitigation opportunities								
4.2.8.2-007	Conversion of threats to liens	3	R	4.2.8.2-002	-	PRJ	D	Φ3	B
4.2.8.3	Systems Engineering and Integration								
4.2.8.3-001	Define and conduct SE activities per SEMP	1	R	4.1-010	-	PRJ	V	Φ3	B, S
4.2.8.3-002	Perform system analysis and planning prior to design	1	R	4.1-010	4.2.8.3-003, 4.2.8.3-004, 4.2.8.3-005, 4.2.8.3-006	PRJ	D	Φ3	S
4.2.8.3-003	Define external requirements and constraints	2	R	4.2.8.3-002	-	PRJ	I	Φ3	B
4.2.8.3-004	Define regulatory approval and certification requirements	2	R	4.2.8.3-002	-	PRJ	I	Φ3	B
4.2.8.3-005	Develop Operational Concept and reference drawings	2	R	4.2.8.3-002	-	PRJ	I	Φ3	B
4.2.8.3-006	Establish Software Development Plan	2	R	4.2.8.3-002	4.2.8.3-007	PRJ	I	Φ3	B
4.2.8.3-007	Software development process maturity level	3	R	4.2.8.3-006	-	PRJ	I	Φ3	B
4.2.8.3-008	Establish and conduct Requirements Management process	1	R	4.1-010	4.2.8.3-009 - 4.2.8.3-013	PRJ	V	Φ3	B, S
4.2.8.3-009	Utilize RM process to define Project requirements	2	R	4.2.8.3-001	-	PRJ	I	Φ3	B
4.2.8.3-010	Conduct requirement analysis and reconciliation	2	R	4.2.8.3-001	-	PRJ	I, D	Φ3	S, B
4.2.8.3-011	Provide baseline management and change control	2	R	4.2.8.3-001	-	PRJ	I, D	Φ3	B
4.2.8.3-012	Operate jointly with Project change control process	2	R	4.2.8.3-001	-	PRJ	D	Φ3	S, B
4.2.8.3-013	Institute waiver and variance processes	2	R	4.2.8.3-001	-	PRJ	I	Φ3	B
4.2.8.3-014	System design per industry SDLC processes	1	R	4.1-010	4.2.8.3-015	PRJ	I, D	Φ3	S, B
4.2.8.3-015	Conduct progressive design reviews	2	R	4.2.8.3-014	4.2.8.3-016	PRJ	D	Φ3	S, B
4.2.8.3-016	Approval of each DR baseline	3	R	4.2.8.3-015	-	PRJ	D	Φ3	B
4.2.8.3-017	Establish and conduct System Interface Management process	1	R	4.1-010	4.2.8.3-018, 4.2.8.3-021	PRJ	V	Φ3	B, S
4.2.8.3-018	Define Interface Control Documents	2	R	4.2.8.3-017	4.2.8.3-019, 4.2.8.3-020	PRJ	I	Φ3	B, S
4.2.8.3-019	ICDs between system and	3	R	4.2.8.3-018	-	PRJ	I	Φ3	B, S

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	external infrastructure								
4.2.8.3-020	ICDs between major ATN elements/subsystems	3	R	4.2.8.3-018	-	PRJ	I	Φ3	B, S
4.2.8.3-021	Establish an ongoing Interface Control process	2	R	4.2.8.3-017	-	PRJ	I, D	Φ3	B, S
4.2.8.3-022	Establish and conduct System Implementation Management process	1	R	4.1-010	4.2.8.3-023, 4.2.8.3-024, 4.2.8.3-025, 4.2.8.3-026	PRJ	V	Φ3	B, S
4.2.8.3-023	Establish oversight process for development/installation	2	R	4.2.8.3-022	-	PRJ	I	Φ3	B
4.2.8.3-024	Establish work site coordination process	2	R	4.2.8.3-022	-	PRJ	I	Φ3	B, S
4.2.8.3-025	Establish Project Site Safety Plan	2	R	4.2.8.3-022	-	PRJ	I	Φ3	B
4.2.8.3-026	Establish construction review/ inspection process	2	R	4.2.8.3-022	-	PRJ	I	Φ3	B, S
4.2.8.4	Service Integration								
4.2.8.4-001	Conduct integration of system and support functions per Service Integration Plan	1	R	4.1-010	-	PRJ	V	Φ3	B, S
4.2.8.5	System Configuration Management/Change Control								
4.2.8.5-001	Establish and conduct Configuration and Data Management processes	1	R	4.1-010	4.2.8.5-002, 4.2.8.5-003	PRJ	V	Φ3	B
4.2.8.5-002	Establish System Config. Management Plan	2	R	4.2.8.5-001	-	PRJ	I	Φ3	B
4.2.8.5-003	Establish Project Data Management system	2	R	4.2.8.5-001	-	PRJ	I	Φ3	B
4.2.8.5-004	Establish and conduct a Change Control process	1	R	4.1-010	-	PRJ	V	Φ3	B, S
4.2.8.6	System Verification and Demonstration								
4.2.8.6-001	Conduct System Verification and Demonstration process per ASCE APM Standards	1	R	4.1-010	4.2.8.6-002 - 4.2.8.6-006	PRJ	D	Φ3	B, S
4.2.8.6-002	Establish System Verification Plan	2	R	4.2.8.6-001	-	PRJ	I	Φ3	B, S
4.2.8.6-003	Establish System Verification procedures	2	R	4.2.8.6-001	-	PRJ	I	Φ3	S
4.2.8.6-004	Conduct QA-witnessed tests	2	R	4.2.8.6-001	-	PRJ	D	Φ3	B, S
4.2.8.6-005	Document and report test results	2	R	4.2.8.6-001	-	PRJ	D	Φ3	S

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4.2.8.6-006	Generate verification liens and workoff plans	2	R	4.2.8.6-001	-	PRJ	D	Φ3	S
4.2.8.7	System Acceptance								
4.2.8.7-001	Establish and conduct System Acceptance process per ASCE APM Standards	1	R	4.1-010	-	PRJ	D	Φ3	B, S
4.2.8.8	Quality Assurance								
4.2.8.8-001	Establish ISO-compliant QA program	1	R	4.1-010	4.2.8.8-002, 4.2.8.8-003	PRJ	V	Φ3	B
4.2.8.8-002	Develop and comply with QA Plan	2	R	4.2.8.8-001	-	PRJ	V	Φ3	B, S
4.2.8.8-003	Implement Quality Management System	2	R	4.2.8.8-001	-	PRJ	I	Φ3	S
4.2.9	Additional ATN Requirements								
4.2.9.1	Legal Requirements								
4.2.9.1-001	Protection of proprietary information	1	R	4.1-010	-	ADL	I, A	Φ3	B
4.2.9.2	Indemnification Requirements								
4.2.9.2-001	Develop strategy for managing liability	1	R	4.1-010	-	ADL	I	Φ3	B
4.2.9.3	Promotion of Industry Standards								
4.2.9.3-001	Participate in industry standards definition	1	R	4.1-010	-	ADL	D	Φ3	B, S
4.2.9.4	Support for Regulatory Requirements Definition								
4.2.9.4-001	Participate in regulatory requirements definition	1	R	4.1-010	-	ADL	D	Φ3	B, S
4.2.9.5	Miscellaneous Requirements								
[TBD]									

(a) Tier 0 requirement 4.1-001 traces downward to the following Tier 1 requirements:

4.2.1.1-001	4.2.3.1-001	4.2.7.9-001
4.2.2.1-001	4.2.3.1-003	4.2.7.10-001
4.2.2.1-007	4.2.3.1-016	4.2.8.1-001
4.2.2.2-008	4.2.3.1-044	4.2.8.2-001
4.2.2.3-001	4.2.3.1-069	
4.2.2.3-004	4.2.3.1-077	
4.2.2.3-021	4.2.3.2-035	
4.2.2.3-026	4.2.3.2-040	
4.2.2.3-044	4.2.3.6-023	

4.2.2.4-001	4.2.3.6-034
4.2.2.7-001	4.2.4.1-001
4.2.2.8-001	4.2.7.1-001
4.2.2.9-001	4.2.7.2-001
4.2.2.9-006	4.2.7.3-001

(b) Tier 0 requirement 4.1-002 traces downward to the following Tier 1 requirements:

4.2.1.1-013	4.2.3.3-001
4.2.1.1-015	4.2.3.4-001
4.2.1.2-001	4.2.3.5-001
4.2.1.3-001	4.2.3.5-002
4.2.1.3-004	4.2.3.6-001
4.2.1.4-001	4.2.3.6-003
4.2.1.4-007	4.2.3.6-010
4.2.1.4-019	4.2.3.6-034
4.2.2.1-021	4.2.3.7-001
4.2.2.3-001	4.2.3.7-004
4.2.2.3-004	4.2.4.1-001
4.2.2.3-044	4.2.4.1-011
4.2.2.4-001	4.2.4.1-014
4.2.2.10-001	4.2.4.1-017
4.2.3.1-001	4.2.4.1-021
4.2.3.1-003	4.2.4.2-001
4.2.3.1-069	4.2.4.2-006
4.2.3.1-077	4.2.4.3-001
4.2.3.1-087	4.2.4.4-001
4.2.3.2-001	4.2.6.2-001
4.2.3.2-004	4.2.6.2-002
4.2.3.2-028	4.2.6.2-002
4.2.3.2-040	4.2.7.8-001

(c) Tier 0 requirement 4.1-003 traces downward to the following Tier 1 requirements:

4.2.1.3-001
4.2.1.3-004
4.2.1.4-001
4.2.1.4-007
4.2.1.4-019
4.2.2.1-021
4.2.3.1-069
4.2.3.1-087
4.2.3.2-001
4.2.3.2-004
4.2.3.4-001

(d) Tier 0 requirement 4.1-004 traces downward to the following Tier 1 requirements:

4.2.1.4-013	4.2.4.2-006
4.2.2.1-001	4.2.4.3-001
4.2.2.2-009	4.2.4.4-001
4.2.3.1-001	4.2.6.1-001
4.2.3.1-003	4.2.6.1-004
4.2.3.4-001	4.2.6.2-001

4.2.3.5-001	4.2.7.2-001
4.2.3.5-002	4.2.7.3-001
4.2.4.1-014	4.2.7.6-001
4.2.4.1-021	4.2.7.7-001
4.2.4.2-001	4.2.7.8-001

(e) Tier 0 requirement 4.1-005 traces downward to the following Tier 1 requirements:

4.2.1.1-015
4.2.3.3-001
4.2.3.4-001
4.2.3.5-001
4.2.3.5-002
4.2.4.1-014
4.2.6.2-002
4.2.6.3-002
4.2.7.7-001

(f) Tier 0 requirement 4.1-006 traces downward to the following Tier 1 requirements:

4.2.2.3-029
4.2.4.1-014
4.2.5.1-001
4.2.5.2-001
4.2.5.3-001
4.2.5.3-005
4.2.5.4-001
4.2.6.2-002
4.2.6.3-001
4.2.6.4-001
4.2.6.4-002

(g) Tier 0 requirement 4.1-007 traces downward to the following Tier 1 requirements:

4.2.6.4-001
4.2.7.3-001

(h) Tier 0 requirement 4.1-008 traces downward to the following Tier 1 requirements:

4.2.6.4-002
4.2.7.3-001

(i) Tier 0 requirement 4.1-009 traces downward to the following Tier 1 requirements:

4.2.1.1-015

4.2.2.3-029

4.2.6.3-001

4.2.6.3-002

4.2.6.4-002

4.2.7.3-001

(j) Tier 0 requirement 4.1-010 traces downward to the following Tier 1 requirements:

4.2.2.1-026
4.2.2.1-033
4.2.2.1-036
4.2.2.2-001
4.2.2.2-003
4.2.2.2-008
4.2.2.3-001
4.2.2.3-004
4.2.2.3-006
4.2.2.3-016
4.2.2.3-021
4.2.2.3-026
4.2.2.3-044
4.2.2.4-001
4.2.2.5-001
4.2.2.6-001
4.2.2.7-001
4.2.2.8-001
4.2.2.9-001
4.2.2.9-006
4.2.2.10-001
4.2.3.1-001
4.2.3.1-003
4.2.3.1-016
4.2.3.1-044
4.2.3.1-077
4.2.3.1-087
4.2.3.2-001
4.2.3.2-004
4.2.3.2-028
4.2.3.2-035
4.2.3.2-040
4.2.3.3-001
4.2.3.4-001
4.2.3.5-001
4.2.3.5-002
4.2.3.6-001
4.2.3.6-003
4.2.3.6-004
4.2.3.6-005
4.2.3.6-010
4.2.3.6-023
4.2.3.6-034
4.2.3.7-001
4.2.3.7-004
4.2.4.1-001
4.2.4.1-003
4.2.4.1-011
4.2.4.1-014
4.2.4.1-017
4.2.4.1-021
4.2.4.2-001
4.2.4.2-006
4.2.4.3-001
4.2.4.4-001
4.2.5.1-001
4.2.5.2-001
4.2.5.3-001
4.2.5.3-005
4.2.5.4-001
4.2.6.1-001
4.2.6.1-004
4.2.6.2-001
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4.2.7.9-001
4.2.7.10-001
4.2.8.1-001
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4.2.8.3-022
4.2.8.4-001
4.2.8.5-001
4.2.8.5-004
4.2.8.6-001
4.2.8.7-001
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d. ANSI/ACSE/TD&I 21.2-08, Automated People Mover Standards, Part 2: Vehicles, Propulsion and Braking

e. ANSI/ACSE/TD&I 21.3-08, Automated People Mover Standards, Part 3: Electrical, Stations and Guideways

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Appendix B. Request for Information

This appendix contains the response guidelines and detailed requests for technical and programmatic information contained in a Request for Information issued by the City of San José on 18 January 2011. Background summary and legal sections have been omitted for clarity. The remaining sections below have been renumbered from the original.

INFORMATION GUIDELINES

Please provide the requested information formatted in accordance with the following outline:

1. Cover Letter and/or Executive Summary
2. General Description
3. Technical
    a. Vehicle, Power and Propulsion
    b. Guidance, Control and Communications
    c. Guideway, Station, Support Facilities and Operations
    d. Safety, Security and Reliability
    e. Standards and Processes
4. Programmatic
    a. Company Structure and Staffing
    b. Manufacturing/Supply Chain Management
    c. Projects Structure and Management
    d. Projects Workplans and Schedule Estimates
    e. Capital Cost Estimates
    f. Operations and Maintenance Cost Estimates
    g. Non-Technical Risk Identification and Management
5. Key Technical Specifications

The following sections and subsections list specific information requested corresponding to the above categories and additional subcategories. The listed items are intended to provide guidance for your response, indicating to you the type and level of detail of information the City will find useful. They are not meant as a checklist requiring complete individual responses. Please respond as completely as possible within time and budgetary constraints by providing analytical results, engineering drawings and test data, as well as written descriptions, diagrams, illustrations, photos or other representations as you deem appropriate.

For most categories, the request consists of a.) an overall description of subsystem design and/or operations, b.) the design criteria on which the design is based and associated performance margins/operational limits (see note), and c.) a description of the subsystem's interfaces with adjacent subsystems. Potential design features, design criteria and interfaces are suggested parenthetically within these three requests, respectively, to guide your response. These are followed by several specific requests for which a direct response is requested.

Note: A compiled list of such information requested in Section 2e may be referenced.

The last section of the request consists of a table of specifications representing key data that will be used to construct independent performance models required to ascertain feasibility. Please provide any additional parameters and corresponding values utilized in your analyses and suggest as being useful with respect the City's feasibility evaluation.

Of particular importance is a discussion of the level of design maturity and verification. Please indicate in both your responses to individual sections and subsections and in the specification table, the basis of your performance claims – design specification/goal, analytical estimate or verification by test.

Requested Information

1.1 General Description

Please provide a general description of your system or subsystem design, performance and operations, including environmental limits of operation and a brief discussion of the technical and operational tradeoffs considered in arriving at your design. A system-level functional block diagram or other representation may be presented to illustrate overall system layout and interfaces.

You may use the above technical outline as a guide. If offering a specific technology or service, select only those sections that apply and provide detail in the applicable data request sections that follow.

1.2 Technical

1.2.1 Vehicle, Power and Propulsion

1.2.1.1 Vehicle Design

1.2.1.1.1 General Layout

a. Description of overall design and key components and materials
b. Design criteria and operational limits (external ambient temperature, solar load, passenger capacity, etc.)
c. Description of interfaces to adjacent subsystems (suspension, propulsion, cabin environmental control, etc.)
d. Dimensions and mass properties (in spec table)
e. Passenger capacity and seating arrangement
f. Number, size and location of doors and windows; door actuation
g. Accommodations for luggage, bicycles, child strollers, etc.
h. Accommodations for the elderly, the disabled and children
i. Structural arrangement
j. Passenger safety and security accommodations, including discussion of crashworthiness
k. Description of power, propulsion, communications, and control system interfaces, including a listing and location of on-board sensors and electronics
l. Description of vehicle interface with sidings and platforms
m. Environmental design criteria and limits (max passenger load, crosswind thresholds, resistance to electrical disturbances, etc.)
n. Other relevant factors

1.2.1.1.2 Cabin Environment and Human Factors Design

a. Description of overall cabin climate control design, performance capabilities and key components and materials
b. Design criteria and operational limits (external ambient temperature, solar load, etc.)
c. Description of interfaces to adjacent subsystems (vehicle structure, power, etc.)
d. Emergency ventilation provisions
e. Interior acoustic spectrum and sound pressure levels (in spec table) and noise abatement provisions

f. Passenger control and information access capabilities and interface (destination selection/modification, climate and lighting control, system and travel status, emergency or informational communications, etc.)
g. Ergonomic and human response design features (seating, headrests, grab-bars, visibility, lighting, to/from vehicle privacy provisions, etc.)
h. Additional standard or optional passenger amenities, if any

1.2.1.2 Suspension

a. Description of overall design, performance capabilities and key components and materials
b. Design criteria and operational limits (max laden weight, crosswinds, guideway irregularity and flexibility, acceleration/deceleration, lateral loads in turns, etc.)
c. Description of interfaces to adjacent subsystems (vehicle structure, guideway and propulsion), in particular the dimensional tolerances and wear points
d. Active control elements, if applicable, and failsafe provisions
e. Suspension compliance and natural frequencies
f. Vehicle dynamic response characteristics and dynamic envelope as determined by the suspension system under worst case design conditions, particularly with respect to ride quality, including allowable shock, sway, and vibration thresholds and dynamic coupling with guideway
g. Turning radius, if applicable
h. Other relevant factors

1.2.1.3 Propulsion

a. Description of overall design, performance capabilities and key components and materials
b. Design criteria and operational limits (max laden weight, max acceleration/deceleration, maximum angles of inclination/declination, adverse weather performance, etc.)
c. Description of interfaces to adjacent subsystems (power, control, suspension)
d. Propulsion capacity (thrust force), modulation, traction control and transmission efficiencies
e. Additional modes of operation (e.g. manual override, reverse)
f. Maximum sustained and "sprint" mode vehicle speed (in spec table)
g. Regenerative braking capabilities (if applicable), including maximum energy dump or conversion
h. Failsafe, redundancy and backup provisions
i. Forward compatibility (i.e. the ability to accommodate evolving technologies with minimal vehicle/guideway modification)
j. Other relevant factors

1.2.1.4 Braking

a. Description of overall design, performance capabilities and key components and materials
b. Design criteria and operational limits (max laden weight, max acceleration/deceleration, maximum angles of guideway inclination/declination, adverse weather performance, etc.)
c. Description of interfaces to adjacent subsystems (power, control, suspension)
d. Braking capacity (thrust force), modulation, skid and fade resistance
e. Failsafe, redundancy and backup provisions
f. Forward compatibility (i.e. the ability to accommodate evolving technologies with minimal vehicle/guideway modification)
g. Other relevant factors

1.2.1.5 Power

a. Description of overall power supply system layout/design, performance capabilities and key components and materials
b. Design criteria and operational limits (propulsion, cabin environment and ancillary systems requirements, etc.)
c. Description of interfaces to adjacent subsystems (propulsion, control, ancillary equipment, external power supply, etc.)
d. Voltage, current and power conditioning requirements as a function of system capacity and utilization for propulsion, cabin environment and ancillary systems
e. Nominal power requirements per vehicle at nominal operating speed and conditions
f. Worst case power requirements per vehicle: max laden weight, max cabin environmental control demand, max acceleration and/or incline, max aerodynamic load, max frictional resistance due to wear, motor/drive inefficiency at max thermal load, etc.
g. Description of system and/or vehicle backup power provisions
h. Ability to accommodate (interface & control) distributed alternative/renewable energy sources
i. On-vehicle battery physical, electrical and energy storage specifications (capacity, depth-of-discharge, etc.)
j. On-vehicle battery recharging requirements (where, when and how often recharging takes place, typical recharge time and voltage/current supply requirements)
k. Other relevant factors

1.2.2 Guidance, Control and Communications

a. Description of control system layout/design, performance capabilities and key components and materials.
b. Design criteria and operational limits (vehicle number, speed and headway, station number and capacity, etc.)
c. Description of interfaces to adjacent subsystems (power, propulsion, ancillary equipment, etc.)
d. Description of control methodology (synchronous, asynchronous, hybrid) and operations re: vehicle routing, acceleration/deceleration, speed, position, headway, non-uniformity of speed such as through turns, and the degree to which sensing and control hardware/software/logic is centralized and/or distributed
e. Description of empty vehicle management method and staging during peak, steady state and quiescent traffic periods, including expected proportion of empty vehicles typically remaining in circulation vs. those held at stations or other off-line facilities
f. The extent, if any, that maintenance activities (such as vehicle cleaning, repair, battery charging, etc.) are integrated into the empty vehicle management concept
g. Description of sensors (laser, magnetic pickup, mechanical, etc.) for vehicle longitudinal and lateral position, speed, acceleration and headway
h. The method (RF, fiber optic or metallic conductor data bus, etc.) by which vehicles communicate with control system elements, such as a centralized controller, distributed controllers, or other vehicles, including, as applicable, RF frequencies and data/control signal communications protocols, data rates and typical/maximum actuation delays for propulsion, braking and guidance maneuvers and redundancy or fail-safe protocols
i. Description of control methods and actuators for switching and merging/de-merging between guideway routes and transitions to/from off-line stations.
j. The method of managing control functions under special or anomalous conditions (e.g., guideway obstruction, adverse weather conditions, vehicle congestion), including manual intervention/override.

k. Description of system startup/shutdown design features and methods
l. Other relevant factors

1.2.2.1 Control Software Design

a. Description of control system software layout/design, performance capabilities and key functional components.
b. Design criteria and operational limits (vehicle number, routing, guidance and control, station design, programming flexibility, etc.)
c. Description of interfaces within or to adjacent subsystems (distributed logic, etc.)
d. Actual/projected lines of code, proportion of custom development to commercial off-the-shelf software packages
e. Degree of independence of the control system software from other system aspects such as specific power and propulsion technologies, vehicle designs, and guideway configurations
f. Method for accommodating newly-introduced physical configurations and/or controllable elements in the software (e.g. reprogramming, database changes, etc.) and who performs this function as the system evolves
g. Control system performance modeling and simulation tools or methods suitable for design and/or verification purposes
h. Control system issues related to the scalability of ATC connectivity and performance, including expansion of routes and stations to wider areas, increasing line speeds, reducing headways, and related factors.
i. Other relevant factors

1.2.3 Guideway, Stations, Support Facilities and Operations

1.2.3.1 Guideway Design

a. Description of overall design (e.g., supported vs. suspended; elevated vs. at-grade) and key components and materials
b. Design criteria and operational limits (thermal, vehicle dynamic and seismic loads, adverse weather, minimum horizontal and vertical radii of curvature, etc.)
c. Description of interfaces to and integration with adjacent subsystems (power, propulsion, control, communications, vehicle suspension, etc.)
d. Structural properties, including cross-sectional dimensions and area properties (area, moments of inertia, etc.), lineal weight and average coefficient of thermal expansion (in spec table)
e. Maximum span length (in spec table)
f. Support column footprint (in spec table)
g. Description of guideway segment joint design
h. Techniques for managing thermal expansion, fatigue, corrosion, adverse weather and vibration/resonances
i. Manufacturing, installation and settling tolerances
j. Recommended horizontal and vertical clearance of combined vehicle/guideway from adjacent structures, including vehicle dynamic envelope (in spec table)
k. Passenger safety design features for emergency conditions (seismic events, vehicle/system failure, etc.)
l. Turn radius/bank angle as a function of vehicle speed; bank angle at nominal vehicle speed for coordinated turning (in spec table)
m. Maximum incline (ascending and descending) (in spec table)
n. Minimum vertical curvature at transitions to inclines (in spec table)
o. Limits, if any, on compound curvature of guideway sections
p. External lighting provisions

q. Exterior acoustic spectrum and sound pressure levels (in spec table) and noise abatement provisions
r. Manufacturing and installation methods (on- or off-site, site preparation, shipping, handling and staging, etc.)
s. Capability for modular construction and system expandability
t. Provisions for forward compatibility with respect to evolving vehicle, propulsion and control/communication subsystem designs
u. Other relevant factors

1.2.3.2 Station Design and Operation

a. Description of overall design and operations (vehicle berthing and passenger platform arrangement and location with respect to main line, passenger ticketing, guidance, circulation and queuing, passenger vehicle ingress/egress management, length of acceleration/deceleration segments and vehicle staging areas (if applicable), adverse weather protection, etc.)
b. Design criteria and operational limits (passenger volume, ticketing and guidance, wait times, adverse weather, etc.)
c. Description of interfaces to and integration with adjacent subsystems (guideway, control, communications, external power, etc.)
d. Description of operational performance models and parameters including passenger interactions and flow from station entry/departure to vehicle ingress/egress, and vehicle management (mainline entry/exit and merging/demerging, berthing maneuvers, platooning vs. independence of movement, staging, and response of arriving vehicles to fully occupied entrance queues or berths.)
e. Statistical estimates of times required for the execution of specific functions used as parameters in operational models: ticketing, passenger movement to vehicle berths, vehicle ingress/egress, prep time in vehicle, etc.
f. Estimate of overall station dimensions as a function of required passenger throughput
g. Number (as a function of station size) and qualifications of staff
h. Discussion of passenger security, safety and interaction/guidance features
i. Discussion of accessibility and usability requirements (ADA/ADAAG) in the station design and as part of the operations concept, including specific design features such as use of "low floor" level boarding platforms, height adjustment controls ("kneeling"), conveyances (elevators, escalators, etc.), signage, and other assistive technology/devices
j. Discussion of integration with existing or proposed passenger stations serving complementary transit systems, e.g. light rail, high-speed rail, conventional bus service, bus rapid transit.
k. Discussion of concepts for increasing capacity of existing stations
l. Other relevant factors

1.2.3.3 Support Facilities Design and Operation

a. Description of overall layout/design, functionality and operations of control, vehicle maintenance/staging/storage or other ancillary facilities. (data processing elements, console and information displays, distributed components (cameras, sensors, etc.), control data and communications links, system redundancy/backup, etc.)
b. Design criteria and operational limits (system monitoring and control elements as a function of system size, number of vehicles and maintenance requirements, manual overrides, emergency response, interface with airport security, local fire protection and law enforcement agencies, etc.)
c. Description of interfaces to adjacent subsystems (guideway, control, communications, external power, etc.)

d. Facility size (as a function of system size) and location relative to system
e. Description of organizational structure, roles and responsibilities, including incorporation and interface with municipal personnel, regulatory authorities and third-party service providers
f. Description of technical system and business/legal operations relatedness (time and manner of ticketing and relationship to vehicle scheduling, routing, system security and passenger privacy (e.g. anonymous vs. credentialed (personally identifiable) ticketing and/or advanced ticketing (via web/phone, etc.) with respect to legitimate vs. malicious vehicle demand requests), cost and effectiveness analysis, (user satisfaction measurement and response), third-party services management, technical performance monitoring and upgrade/evolution, etc.)
g. Number (as a function of system size) and qualifications of staff
h. Methods of detection and procedures for response to anomalous occurrences and emergencies
i. Extent to which the system's automated control features can be manually adjusted or overridden
j. The planned approach for operational procedures development and update, staff training and evaluation
k. Other relevant factors

1.2.4 Security, Safety and Reliability

1.2.4.1 Passenger Security and Safety

a. Description of overall layout/design, functionality and operations of control, vehicle maintenance/staging/storage or other ancillary facilities. (data processing elements, console and information displays, distributed components (cameras, sensors, etc.), control data and communications links, system redundancy/backup, etc.)
b. Design criteria and operational limits (system monitoring and control elements as a function of system size, number of vehicles and maintenance requirements, manual overrides, emergency response, interface with airport security, local fire protection and law enforcement agencies, etc.)
c. Description of interfaces to adjacent subsystems (guideway, control, communications, external power, etc.)
d. The standard passenger safety provisions, including but not necessarily limited to safety interlocks, passenger restraints, impact protection features, fire/smoke detection and suppression capabilities, emergency vehicle stop/re-routing controls available to passengers, and passenger audio/video links to safety/security authorities
e. Vehicle failure response and emergency operations concepts
f. Emergency exit design, passenger egress and rescue approaches if a vehicle is stopped on any portion of the guideway (elevated portions in particular)
g. Disabled vehicle removal procedure
h. Specific approaches for physical security at stations, during vehicle boarding/de-boarding, and vehicle operations
i. The status and availability of scenarios or use cases describing how safety events are to be handled operationally
j. Approach for developing, documenting, training and revision of ATC safety and security procedures
k. Other relevant factors

1.2.4.2 System Security

a. Description of the technical means and operational plans for the physical and electronic protection of system elements from inadvertent or malicious tampering

b. Design criteria and operational limits (system monitoring and control elements as a function of system size and number of vehicles, threat analysis, etc.)
c. Description of interfaces to adjacent subsystems (guideway, control, communications, external power and data/communications links, etc.)
d. "Hardening" of the control and communications systems from unauthorized penetration, jamming, hacking, etc.
e. Information systems security
f. Prevention, observation, detection and response to physical threats and vandalism of vehicles, stations, guideways and support facilities
g. Workforce screening and integrity procedures
h. Discussion of system security technical means and operations with respect to passenger privacy
i. Other relevant factors

1.2.4.3 Reliability, Maintainability and Availability

a. Description of the design and operational approach towards, reliability, system availability, maintenance and repair (Failure Modes and Effects/Criticality Analyses (FMECA) or equivalent assessments, "failure management" scenarios or use cases, maintenance and repair of all system elements, automated health-monitoring systems, vehicle recovery and guideway inspection/repair mobile services, etc.)
b. Design criteria and operational limits (system monitoring and control elements as a function of system size and number of vehicles, system availability, system, subsystem and component reliability targets, wait times, etc.)
c. Description of incorporation within subsystems and interface to adjacent subsystems (vehicle, guideway, power, communications, etc.)
d. System availability models and/or measurements
e. Measured or projected vehicle reliability (Mean Time Between Failure (MTBF))
f. Measured or projected other subsystem MTBF
g. Component-level reliability estimates used to develop MTBF projections, to the extent available, including basis in test or heritage
h. Projected lifespan (Mean Time To Replacement/Repair (MTTR)) and maintenance/service schedules/projections of subsystems; key maintenance/wear components (motors, brakes, batteries, etc.)
i. Estimated process times for subsystem and key maintenance/wear component maintenance/repair
j. Provisioning plan for spare vehicles, parts, materials, supplies, and consumables
k. Approach for environmental compliance of maintenance processes (battery recycling, noise, etc.)
l. Other relevant factors

1.2.5 Standards and Processes

1.2.5.1 Systems Engineering

a. Description of standards, processes and policies/procedures for requirements, data, interface, configuration and risk identification and management.
b. System Functional Block Diagram
c. Specific discussion of the processes utilized for the definition, allocation, implementation and verification/validation of component, subsystem and integrated system functional, performance and design requirements

d. Specific discussion of operational control system software configuration management processes
e. Specific discussion of technical and organizational interface/integration management throughout design, installation and operations
f. Specific process to be used for transition from system integration and test to service operations
g. Other relevant factors

1.2.5.2 Design, Manufacturing and Quality Assurance

a. Listing of standards, criteria, processes, regulatory requirements and policies/procedures utilized in component, subsystem and integrated system design, specification, manufacturing and operations, whether internal, required or adopted:

    i. Structural, electrical, etc. standards and criteria
    ii. Materials and manufacturing processes
    iii. Civil infrastructure codes and standards, including for seismic design
    iv. Software design and development (CMMI maturity level or analogous process certification)
    v. Manufacturing quality assurance
    vi. Human factors, including user experience surveys and trials
    vii. Ride quality
    viii. Reliability and maintainability
    ix. Forward compatibility
    x. Transit system design and safety
    xi. Other relevant standards, etc.

b. Discussion of requirements and plans for certification of compliance with applicable U.S. and California State regulations

1.2.5.3 Verification and Validation

a. Listing and description of all work done and planned to verify component, subsystem and integrated system performance claims (test regimen, test data, anomaly resolutions, analyses, etc.)

    i. Component heritage
    ii. Accelerated environmental testing
    iii. Analytical use-case and/or hardware-in-the-loop software simulations
    iv. Analyses
    v. User trials
    vi. Independent verification
    vii. Other relevant verification work

b. Description (e.g. test plans) of verification criteria/levels (qualification, acceptance, etc.), test configurations and procedures
c. Listing and discussion of demonstrated performance margins/factors of safety of key performance parameters, including basis of estimate (analysis, test, heritage, etc.)

1.3 Programmatic

Please provide plans and programmatic estimates of sufficient detail to develop Rough Order of Magnitude (ROM) estimates of overall project cost/schedule/risk estimates as a function of system size, including the basis of estimates and confidence level and/or range of estimate. Plans and estimates provided in this section will be used exclusively for the evaluation of industry readiness in the aggregate; they will not be interpreted or used as offers or commitments or for comparative purposes.

1.3.1 Company Structure and Staffing

a. Description of company structure and staffing for design, manufacturing and verification operations (org chart, bios of key personnel, staffing levels, etc.)
b. Other relevant information

1.3.2 Manufacturing/Supply Chain Management

a. Description of design and manufacturing supply chain and its management (Enterprise Resource Planning (ERP), Product Data Management (PDM), scheduling and procurement management systems and expertise, local content, licensing, etc.)
b. Other relevant information

1.3.3 Projects Structure and Staffing

a. Description of anticipated project (i.e. on-site implementations) organizational structure management (Work Breakdown Structure (WBS) including system integrator and subcontractors, organizational interfaces, roles and responsibilities, local content, licensing, relationship to system size, etc.)
b. Other relevant information

1.3.4 Projects Workplans and Schedule Estimates

a. Description of anticipated project workplans (site surveys and preparation, requirements, design, fabrication and verification processes (milestone design and readiness reviews, etc.) and timelines as a function of system size (route mileage, number of stations, support facilities, etc.). *Include the basis of schedule estimates for each activity and relationship to existing schedule models.*
b. Discussion of schedule issues such as long-lead items procurement, anticipated certification cycle times, schedule dependencies, etc.

1.3.5 Capital Cost Estimates

a. Estimate, in FY11 dollars, of capital costs and billing milestones as a function of system size (route mileage, number and capacity of stations, support facilities, etc.)
b. Description of cost breakdown by primary system element (e.g. vehicles, guideway, stations, support facilities, etc.). *Include the basis of cost estimates for each cost element and relationship to existing cost models.*

1.3.6 Operations and Maintenance Cost Estimates

a. Estimate, in FY11 dollars, of recurring annual costs for operations and maintenance.
b. Description of cost breakdown by operational activity and category (labor, power usage and other consumables, maintenance parts and labor, etc.). Include the basis for estimation of these costs.

1.3.7 Non-Technical Risk Identification and Management

a. Discussion of non-technical risk and risk management methods, including case studies if available (supply chain and subcontractor interfaces, strategic materials, import/export issues, contingency planning, etc.)

1.3.7.1 Key Technical Specifications

BOE = Basis of Estimate (D = Design Specification, A = Analytical Estimate, T = Verified by Test)

Parameter	Value	Units	BOE	Guidance/Comments
Vehicle				
exterior dimensions (LxWxH)				
empty weight				
laden weight (max)				or max load capacity
center of gravity (empty)				height above guideway reference
center of gravity (max laden)				height above guideway reference
passenger capacity				
door location				left, right, both
turning radius				if applicable
interior acoustic spectrum and levels				SPL vs. frequency
min/max controlled cabin temperature				@ max ambient thermal load
min/max controlled cabin temperature				@ min ambient thermal load
reverse drive capability				yes, no
nominal/max (sustained/sprint) forward speed				empty @ level
				empty @ max incline
				max laden @ level
				max laden @ max incline
max acceleration				empty
				@ max laden weight
max deceleration				empty
				@ max laden weight
Power & Propulsion				
nominal/max forward thrust				
nominal/max reverse thrust				
system supply voltage & frequency				
vehicle supply voltage & frequency				
power/current draws:				
vehicle propulsion				empty, stationary
				empty @ level, nominal speed
				empty @ level, max speed
				empty @ max incline, nominal

Parameter	Value	Units	BOE	Guidance/Comments
				speed
				empty @ max incline, max speed
				empty @ max acceleration
				max laden, stationary
				max laden @ level, nominal speed
				max laden @ level, max speed
				max laden @ max incline, nominal speed
				max laden @ max incline, max speed
				max laden @ max acceleration
vehicle cabin environmental control				@ max rated operating thermal load
				@ min rated operating thermal load
vehicle ancillary equipment				
station & support facilities				per unit area
vehicle battery voltage				
vehicle battery power/current capacity				@ min operational ambient temp
				@ max operational ambient temp
vehicle battery recharge rate				@ recommended voltage/current
vehicle battery charge cycles				max allowable
Guidance, Communications & Control				
min headway				
signal, processing & actuation latency				all commanded maneuvers
guideway switch max actuation rate				if applicable
speed/acceleration control accuracy				all conditions
communications data rate, frequency and bandwidth				
control signal data demand				number of on-board control sensors x sampling rate x word length
control link data rate				
nominal line capacity				
Guideway				
cross-sectional dimensions (WxH)				

Parameter	Value	Units	BOE	Guidance/Comments
cross-sectional moment of inertia (I_{xx})				
cross-sectional moment of inertia (I_{yy})				
torsional constant (J)				
lineal weight				
max span length				
min horizontal radius of curvature				@ centerline
min vertical radius of curvature				@ transitions to incline/decline
bank angle in curves				nominal or as function of vehicle speed, lading
max incline				
max decline				
allowable flexure				@ midspan
allowable settling				@ supports
exterior acoustic spectrum and level				from vehicle as source
Station				
max passenger throughput				per seat-berth
average wait time				mean and distribution per unit demand and seat-berth
assumed load factor				mean and distribution of occupied seats
vehicle ingress time				mean and distribution per passenger
vehicle egress time				mean and distribution per passenger
ticketing time				mean and distribution
length of acceleration/deceleration segments				
vehicle merge maneuver time				from stationary at berth to nominal speed on main line
vehicle demerge maneuver time				from nominal speed on main line to stationary at berth

Appendix C. Reference Design Guideway Segment Definition

		Segment ID	Type	Entrance Radius (ft)	Exit Radius (ft)	Θ (deg)		Length (ft)		Low Performance Length (ft)	Low Performance Entry Speed (mi/hr)	Low Performance Exit Speed (mi/hr)	Low Performance TOS (sec)		Mid Performance Length (ft)	Mid Performance Entry Speed (mi/hr)	Mid Performance Exit Speed (mi/hr)	Mid Performance TOS (sec)		High Performance Length (ft)	High Performance Entry Speed (mi/hr)	High Performance Exit Speed (mi/hr)	High Performance TOS (sec)
	Turnaround	1_01	LC	49	49	284.95		244.746		244.746	6.783	6.8	24.60		244.746	9.6	9.6	17.40		244.746	13.6	13.6	12.30
		1_02	LC	49	49	55.88		47.995		47.995	6.8	6.8	4.82		47.995	9.6	9.6	3.41		47.995	13.6	13.6	2.41
		1_03a	LS					188.490	188.490	157.208	6.8	17.5	8.82	188.490	164.588	9.6	24.8	6.53	188.490	188.490	13.6	35.0	4.91
		1_03b	LS							31.282	17.5	17.5	1.22		23.902	24.8	24.8	0.66		0.000	35.0	35.0	0.00
		1_03											**10.04**					**7.19**					**4.91**
		1_04	LS					423.092		423.092	17.5	17.5	16.47		423.092	24.8	24.8	11.65		423.092	35.0	35.0	8.24
		1_05	LC	328	328	90.63		518.813		518.813	17.5	17.5	20.20		518.813	24.8	24.8	14.28		518.813	35.0	35.0	10.11
	SJC Drop	1_06	LS					216.610		216.610	17.5	17.5	8.43		216.610	24.8	24.8	5.96		216.610	35.0	35.0	4.22
		1_07	LC	1018	1018	17.81		316.395		316.395	17.5	17.5	12.32		316.395	24.8	24.8	8.71		316.395	35.0	35.0	6.16
		1_08	LC	340	340	88.92		527.652		527.652	17.5	17.5	20.55		527.652	24.8	24.8	14.53		527.652	35.0	35.0	10.28
		1_09	LS					478.198		478.198	17.5	17.5	18.62		478.198	24.8	24.8	13.17		478.198	35.0	35.0	9.32
		1_10	LC	1356	1356	2.17		51.463		51.463	17.5	17.5	2.00		51.463	24.8	24.8	1.42		51.463	35.0	35.0	1.00
		1_11	LS					158.117		158.117	17.5	17.5	6.16		158.117	24.8	24.8	4.35		158.117	35.0	35.0	3.08
		1_12	LS					243.550		243.550	17.5	17.5	9.48		243.550	24.8	24.8	6.71		243.550	35.0	35.0	4.74
		1_13	LC	328	328	110.76		634.085		634.085	17.5	17.5	24.69		634.085	24.8	24.8	17.46		634.085	35.0	35.0	12.352
		1_14	LC	328	328	103.60		593.061		593.061	17.5	17.5	23.09		593.061	24.8	24.8	16.33		593.061	35.0	35.0	11.55
		1_15	LS					240.590		240.590	17.5	17.5	9.37		240.590	24.8	24.8	6.62		240.590	35.0	35.0	4.69
		1_16	LS					158.116		158.116	17.5	17.5	6.16		158.116	24.8	24.8	4.35		158.116	35.0	35.0	3.08
		1_17	LC	1356	1356	2.17		51.463		51.463	17.5	17.5	2.00		51.463	24.8	24.8	1.42		51.463	35.0	35.0	1.00
	SJC Return	1_18	LS					478.198		478.198	17.5	17.5	18.62		478.198	24.8	24.8	13.17		478.198	35.0	35.0	9.32
		1_19	LC	328	328	88.92		509.029		509.029	17.5	17.5	19.82		509.029	24.8	24.8	14.02		509.029	35.0	35.0	9.92
		1_20	LC	1006	1006	17.81		312.666		312.666	17.5	17.5	12.17		312.666	24.8	24.8	8.61		312.666	35.0	35.0	6.09
		1_21	LS					216.610		216.610	17.5	17.5	8.43		216.610	24.8	24.8	5.96		216.610	35.0	35.0	4.22
		1_22	LC	340	340	90.63		537.794		537.794	17.5	17.5	20.94		537.794	24.8	24.8	14.81		537.794	35.0	35.0	10.48
		1_23	LS					270.848		270.848	17.5	17.5	10.55		270.848	24.8	24.8	7.46		270.848	35.0	35.0	5.276
		1_S1_01a	LT					189.754	189.754	167.136	17.5	5.0	10.12	189.754	179.141	24.8	5.0	8.21	189.754	189.754	35.0	5.0	6.47
		1_S1_01b	LT							22.618	5.0	5.0	3.08		10.613	5.0	5.0	1.45		0	5.0	5.0	0.00
Loop 1 (VTA)		1_S1_01					Decelerate to Queue Slot 2						**13.21**					**9.65**					**6.47**
		1_S1_02a	SS					26.702	26.702	9.664	5.0	5.0	1.32	26.702	16.349	5.0	5.0	2.23	26.702	19.7	5.0	5.0	2.69
	VTA Arrival	1_S1_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		1_S1_02c	SS							17.038	0.0	5.0	4.65		10.353	0.0	5.0	2.82		7.002	0.0	5.0	1.91
		1_S1_02d	SS				Advance from Queue Slot 2 to Berth 2	72.794	72.794	38.717	5.0	5.0	5.28	72.794	52.089	5.0	5.0	7.10	72.794	58.79	5.0	5.0	8.02
		1_S1_02e	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		1_S1_02_A											**20.54**					**17.80**					**16.43**
		1_S1_02a	SS							17.038	0.0	5.0	4.65		10.353	0.0	5.0	2.82		7.002	0.0	5.0	1.91
		1_S1_02b	SS				Back Out	38.245	38.245	4.168	5.0	5.0	0.57	38.245	17.540	5.0	5.0	2.39	38.245	24.241	5.0	5.0	3.31
		1_S1_02c	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		1_S1_02d	SS							17.038	0.0	5.0	4.65		10.353	0.0	5.0	2.82		7.002	0.0	5.0	1.91
		1_S1_02e	SS				Advance to Queue Slot 2	61.830	61.830	27.753	5.0	5.0	3.78	61.830	41.125	5.0	5.0	5.61	61.830	47.826	5.0	5.0	6.52
	VTA Departure	1_S1_02f	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		1_S1_02_D											**22.94**					**19.29**					**17.47**
		1_S1_03a	LS					34.710	34.710	29.580	0.0	6.8	5.95	34.710	31.641	0.0	9.6	4.50	34.710	34.710	0.0	13.6	3.47
		1_S1_03b	LS							5.130	6.8	6.8	0.52		3.069	9.6	9.6	0.22		0.000	13.6	13.6	0.00
		1_S1_03											**6.46**					**4.72**					**3.47**
		1_S1_04	LC	49	49	49.07		42.820		42.820	6.8	6.8	4.30		42.820	9.6	9.6	3.04		42.820	13.6	13.6	2.15
		1_24	LS					166.024		166.024	17.5	17.5	6.46		166.024	24.8	24.8	4.57		166.024	35.0	35.0	3.23
		1_25a	LS					174.812	174.812	157.208	17.5	6.8	8.82	174.812	164.588	24.8	9.6	6.53	174.812	174.812	35.0	13.6	4.91
	VTA Bypass	1_25b	LS							17.603	6.8	6.8	1.77		10.224	9.6	9.6	0.73		0.000	13.6	13.6	0.00
		1_25											**10.59**					**7.26**					**4.91**
		1_26						34.710		34.710	6.8	6.8	3.49		34.710	9.6	9.6	2.47		34.710	13.6	13.6	1.74
		1_27	LC	49	49	55.88		47.995		47.995	6.8	6.8	4.82		47.995	9.6	9.6	3.41		47.995	13.6	13.6	2.41

Loop 2 (Main)	Loop Begin	2_01	LS					69.340		69.340	17.5	17.5	2.70		69.340	24.8	24.8	1.91		69.340	35.0	35.0	1.35
		2_02	LC	2015	2015	8.95		314.715		314.715	17.5	17.5	12.25		314.715	24.8	24.8	8.67		314.715	35.0	35.0	6.13
		2_03	LS					338.514		338.514	17.5	17.5	13.18		338.514	24.8	24.8	9.32		338.514	35.0	35.0	6.59
		2_04	LS					238.288		238.288	17.5	17.5	9.28		238.288	24.8	24.8	6.56		238.288	35.0	35.0	4.64
		2_05	LC	328	328	64.34		368.335		368.335	17.5	17.5	14.34		368.335	24.8	24.8	10.14		368.335	35.0	35.0	7.18
		2_06	LC	328	328	30.75		176.057		176.057	17.5	17.5	6.86		176.057	24.8	24.8	4.85		176.057	35.0	35.0	3.43
	EL S1 Arrival	2_S1_01a	LC	320	320	33.92	Decelerate to Queue Slot 2	272.159	272.159	20.209	17.5	17.3	0.79	272.159	27.865	24.8	24.5	0.67	272.159	27.865	35.0	34.6	0.55
		2_S1_01b	LC	320	320					66.260	17.3	17.3	2.61		58.603	24.5	24.5	1.63		58.603	34.6	34.6	1.16
		2_S1_01c	LC	320	320					185.691	17.3	5.0	9.97		185.691	24.5	5.0	8.10		185.691	34.6	5.0	6.40
		2_S1_01											**13.37**					**10.40**					**8.10**
		2_S1_02a	SS					26.702	26.702	9.664	5.0	5.0	1.32	26.702	16.349	5.0	5.0	2.23	26.702	19.7	5.0	5.0	2.69
		2_S1_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S1_02c	SS				Advance from Queue Slot 2 to Berth 2	72.794	72.794	17.038	0.0	5.0	4.65	72.794	10.353	0.0	5.0	2.82	72.794	7.002	0.0	5.0	1.91
		2_S1_02d	SS							38.717	5.0	5.0	5.28		52.089	5.0	5.0	7.10		58.79	5.0	5.0	8.02
		2_S1_02e	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S1_02_A											**20.54**					**17.80**					**16.43**
	EL S1 Departure	2_S1_02a	SS				Back Out	38.245	38.245	17.038	0.0	5.0	4.65	38.245	10.353	0.0	5.0	2.82	38.245	7.002	0.0	5.0	1.91
		2_S1_02b	SS							4.168	5.0	5.0	0.57		17.540	5.0	5.0	2.39		24.241	5.0	5.0	3.31
		2_S1_02c	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S1_02d	SS				Advance to Queue Slot 2	61.830	61.830	17.038	0.0	5.0	4.65	61.830	10.353	0.0	5.0	2.82	61.830	7.002	0.0	5.0	1.91
		2_S1_02e	SS							27.753	5.0	5.0	3.78		41.125	5.0	5.0	5.61		47.826	5.0	5.0	6.52
		2_S1_02f	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S1_02_D											**22.94**					**19.29**					**17.47**
		2_S1_03a	LS					233.150	233.150	176.841	0.0	17.5	13.77	233.150	182.160	0.0	24.8	10.03	233.150	189.470	0.0	35.0	7.38
		2_S1_03b	LS							56.309	17.5	17.5	2.19		50.990	24.8	24.8	1.40		43.680	35.0	35.0	0.85
		2_S1_03											**15.96**					**11.43**					**8.23**
	Low Speed Interconnect	2_SE_01	LS					232.919		232.919	5.0	5.0	31.76		232.919	5.0	5.0	31.76		232.919	5.0	5.0	31.76
	EL S2 Arrival	2_S2_01a	LT				Decelerate to Queue Slot 2	233.150	233.150	66.014	17.5	17.5	2.57	233.15	54.009	24.8	24.8	1.19	233.15	43.356	35.0	35.0	0.84
		2_S2_01b	LT							167.136	17.5	5.0	10.12		179.141	24.8	5.0	8.21		189.794	35.0	5.0	6.47
		2_S2_01											**12.70**					**9.40**					**7.31**
		2_S2_02a	SS					26.702	26.702	9.664	5.0	5.0	1.32	26.702	16.349	5.0	5.0	2.23	26.702	19.7	5.0	5.0	2.69
		2_S2_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S2_02c	SS				Advance from Queue Slot 2 to Berth 2	72.794	72.794	17.038	0.0	5.0	4.65	72.794	10.353	0.0	5.0	2.82	72.794	7.002	0.0	5.0	1.91
		2_S2_02d	SS							38.717	5.0	5.0	5.28		52.089	5.0	5.0	7.10		58.79	5.0	5.0	8.02
		2_S2_02e	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S2_02_A											**20.54**					**17.80**					**16.43**
	EL S2 Departure	2_S2_02a	SS				Back Out	38.245	38.245	17.038	0.0	5.0	4.65	38.245	10.353	0.0	5.0	2.82	38.245	7.002	0.0	5.0	1.91
		2_S2_02b	SS							4.168	5.0	5.0	0.57		17.540	5.0	5.0	2.39		24.241	5.0	5.0	3.31
		2_S2_02c	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S2_02d	SS				Advance to Queue Slot 2	61.83	61.830	17.038	0.0	5.0	4.65	61.830	10.353	0.0	5.0	2.82	61.830	7.002	0.0	5.0	1.91
		2_S2_02e	SS							27.753	5.0	5.0	3.78		41.125	5.0	5.0	5.61		47.826	5.0	5.0	6.52
		2_S2_02f	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S2_02_D											**22.94**					**19.29**					**17.47**
		2_S2_03a	LT					233.15	233.150	176.841	0.0	17.5	13.77	233.150	182.160	0.0	24.8	10.03	233.150	189.470	0.0	35.0	7.38
		2_S2_03b	LT							56.309	17.5	17.5	2.19		50.990	24.8	24.8	1.40		43.680	35.0	35.0	0.85
		2_S2_03											**15.96**					**11.43**					**8.23**
	Low Speed Interconnect	2_SE_02	LS					232.905		232.905	5.0	5.0	31.76		232.905	5.0	5.0	31.76		232.905	5.0	5.0	31.76

Loop 2 (Main)	EL S3 Arrival	2_S3_01a	LT				Decelerate to Queue Slot 2	233.150	233.150	66.014	17.5	17.5	2.57	233.150	54.009	24.8	24.8	1.49	233.15	43.356	35.0	35.0	0.84
		2_S3_01b	LT							167.136	17.5	5.0	10.12		179.141	24.8	5.0	8.21		189.794	35.0	5.0	6.47
		2_S3_01											**12.70**					**9.69**					**7.31**
		2_S3_02a	SS					26.702	26.702	9.664	5.0	5.0	1.32	26.702	16.349	5.0	5.0	2.23	26.702	19.7	5.0	5.0	2.69
		2_S3_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S3_02c	SS				Advance from Queue Slot 2 to Berth 2	72.794	72.794	17.038	0.0	5.0	4.65	72.794	10.353	0.0	5.0	2.82	72.794	7.002	0.0	5.0	1.91
		2_S3_02d	SS							38.717	5.0	5.0	5.28		52.089	5.0	5.0	7.10		58.79	5.0	5.0	8.02
		2_S3_02e	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S3_02_A											**20.54**					**17.80**					**16.43**
	EL S3 Departure	2_S3_02a	SS				Back Out	38.245	38.245	17.038	0.0	5.0	4.65	38.245	10.353	0.0	5.0	2.82	38.245	7.002	0.0	5.0	1.91
		2_S3_02b	SS							4.168	5.0	5.0	0.57		17.540	5.0	5.0	2.39		24.241	5.0	5.0	3.31
		2_S3_02c	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S3_02d	SS				Advance to Queue Slot 2	61.830	61.830	17.038	0.0	5.0	4.65	61.830	10.353	0.0	5.0	2.82	61.830	7.002	0.0	5.0	1.91
		2_S3_02e	SS							27.753	5.0	5.0	3.78		41.125	5.0	5.0	5.61		47.826	5.0	5.0	6.52
		2_S3_02f	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S3_02_D											**22.94**					**19.29**					**17.47**
		2_S3_03a	LT					233.15	233.150	176.841	0.0	17.5	13.77	233.150	182.160	0.0	24.8	10.03	233.150	189.470	0.0	35.0	7.38
		2_S3_03b	LT							56.309	17.5	17.5	2.19		50.990	24.8	24.8	1.40		43.680	35.0	35.0	0.85
		2_S3_03											**15.96**					**11.43**					**8.23**
	Economy Lot Bypass	2_07	LC	328	328	55.41		317.178		317.178	17.5	17.5	12.35		317.178	24.8	24.8	8.73		317.178	35.0	35.0	6.18
		2_08	LS					83.029		83.029	17.5	17.5	3.23		83.029	24.8	24.8	2.29		83.029	35.0	35.0	1.62
		2_09	LS					232.907		232.907	17.5	17.5	9.07		232.907	24.8	24.8	6.41		232.907	35.0	35.0	4.54
		2_10	LS					123.093		123.093	17.5	17.5	4.79		123.093	24.8	24.8	3.39		123.093	35.0	35.0	2.40
		2_11	LS					232.907		232.907	17.5	17.5	9.07		232.907	24.8	24.8	6.41		232.907	35.0	35.0	4.54
		2_12	LS					149.817		149.817	17.5	17.5	5.83		149.817	24.8	24.8	4.12		149.817	35.0	35.0	2.92
		2_13	LC	328	328	37.08		212.249		212.249	17.5	17.5	8.26		212.249	24.8	24.8	5.84		212.249	35.0	35.0	4.13
	Main Line Entry	2_14	LC	328	328	57.70		330.310		330.310	17.5	17.5	12.86		330.310	24.8	24.8	9.09		330.310	35.0	35.0	6.43
		2_15	LC	328	328	129.97		744.016		744.016	17.5	17.5	28.97		744.016	24.8	24.8	20.49		744.016	35.0	35.0	14.49
	Main Line	2_16	LC	906	906	24.15		381.825		381.825	17.5	17.5	14.87		381.825	24.8	24.8	10.51		381.825	35.0	35.0	7.44
		2_17	LS					246.291		246.291	17.5	17.5	9.59		246.291	24.8	24.8	6.78		246.291	35.0	35.0	4.80
		2_18	LC	906	906	27.15		429.245		429.245	17.5	17.5	16.71		429.245	24.8	24.8	11.82		429.245	35.0	35.0	8.36
		2_19	LS					111.500		111.500	17.5	17.5	4.34		111.500	24.8	24.8	3.07		111.500	35.0	35.0	2.17
		2_20	LC	627	627	5.40		59.072		59.072	17.5	17.5	2.30		59.072	24.8	24.8	1.63		59.072	35.0	35.0	1.15
	2 - 3 Transition	T23_01	LC	627	627	11.02		122.55		122.550	17.5	17.5	4.77		122.550	24.8	24.8	3.37		122.550	35.0	35.0	2.39
		T23_02a	LC	627	627	11.79		128.942	128.942	31.168	17.5	17.5	1.21	128.942	21.942	24.8	24.8	0.60	128.942	0.000	35.0	35.0	0.00
		T23_02b	LC	627	627	11.79				97.774	17.5	12.9	4.39		107.000	24.8	18.2	3.40		128.942	35.0	25.7	2.69
		T23_02											**5.60**					**4.00**					**2.69**
	Main Line	2_21	LC	750	750	21.12		276.47		276.470	17.5	17.5	10.77		276.470	24.8	24.8	7.61		276.470	35.0	35.0	5.39
		2_22	LC	726	726	9.59		121.532		121.532	17.5	17.5	4.73		121.532	24.8	24.8	3.35		121.532	35.0	35.0	2.37
		2_23	LC	726	726	4.44		56.312		56.312	17.5	17.5	2.19		56.312	24.8	24.8	1.55		56.312	35.0	35.0	1.10
		2_24	LS					454.815		454.815	17.5	17.5	17.71		454.815	24.8	24.8	12.52		454.815	35.0	35.0	8.86
		2_25	LS					269.694		269.694	17.5	17.5	10.50		269.694	24.8	24.8	7.43		269.694	35.0	35.0	5.25
		2_26	LC	1368	1368	3.05		72.915		72.915	17.5	17.5	2.84		72.915	24.8	24.8	2.01		72.915	35.0	35.0	1.42
		2_27	LS					348.971		348.971	17.5	17.5	13.59		348.971	24.8	24.8	9.61		348.971	35.0	35.0	6.80
		2_28	LC	1356	1356	8.79		207.979		207.979	17.5	17.5	8.10		207.979	24.8	24.8	5.73		207.979	35.0	35.0	4.05
		2_29	LS					560.837		560.837	17.5	17.5	21.84		560.837	24.8	24.8	15.44		560.837	35.0	35.0	10.93
		T25_01	LT					186.888		186.888	17.5	17.5	7.28		186.888	24.8	24.8	5.15		186.888	35.0	35.0	3.64
		2_30	LS					186.32		186.32	17.5	17.5	7.25		186.32	24.8	24.8	5.13		186.32	35.0	35.0	3.63
		2_31	LC	1368	1368	5.83		139.157		139.157	17.5	17.5	5.42		139.157	24.8	24.8	3.83		139.157	35.0	35.0	2.71

Loop 2 (Main)	2 - 4 Transition	T24_01a	LT					140.754	140.754	96.146	17.5	17.5	3.74	140.754	65.500	24.8	24.8	1.80	140.754	0.000	35.0	35.0	0.00
		T24_01b	LT							44.608	17.5	11.6	5.31		75.254	24.8	16.4	4.05		140.754	35.0	23.2	3.15
		T24_01											**9.05**					**5.85**					**3.15**
	Main Line	2_32	LS					321.706		321.706	17.5	17.5	12.53		321.706	24.8	24.8	8.86		321.706	35.0	35.0	6.27
		2_33	LS					447.327		447.327	17.5	17.5	17.42		447.327	24.8	24.8	12.32		447.327	35.0	35.0	8.71
	2 - 4 Transition	T24_02a	LT					109.075	109.074803	70.947	17.5	17.5	2.76	109.075	44.952	24.8	24.8	1.24	109.075	0.000	35.0	35.0	0.00
		T24_02b	LT							38.128	17.5	13.7	3.77		64.123	24.8	19.4	2.96		109.0748	35.0	27.4	2.38
		T24_02											**6.54**					**4.20**					**2.38**
	Main Line	2_34	LC	328	328	4.56		26.109		26.109	17.5	17.5	1.02		26.109	24.8	24.8	0.72		26.109	35.0	35.0	0.51
		2_35	LS					1119.785		1119.785	17.5	17.5	43.60		1119.785	24.8	24.8	30.83		1119.785	35.0	35.0	21.81
	Lot 4 Approach	2_36a	LS					135.600	135.600	20.840	17.5	17.5	0.81	135.600	12.033	24.8	24.8	0.33	135.600	0.000	35.0	35.0	0.00
		2_36b	LS							114.760	17.5	11.5	5.40		123.567	24.8	11.5	5.84		135.600	35.0	23.0	3.20
		2_36											**6.21**					**6.18**					**3.20**
		2_37	LC	141	141	172.68		424.682		424.682	11.5	11.5	25.22		424.682	11.5	11.5	25.22		424.682	23.0	23.0	12.61
	L4 S1 Arrival	2_S4_01	LT					111.630		111.63	11.5	11.5	6.63		111.63	11.5	11.5	6.63		111.63	23.0	23.0	3.31
		2_S4_02a	LS				Decelerate to Queue Slot 2	87.600	87.6	18.386	11.5	11.5	1.09	87.600	8.213	11.5	11.5	0.49	87.600	0.000	23.0	23.0	0.00
		2_S4_02b	LS							69.214	11.5	5.0	5.73		79.387	11.5	5.0	3.36		87.600	23.0	5.0	4.28
		2_S4_02											**6.82**					**3.85**					**4.28**
		2_S4_03a	SS					26.702	26.702	9.664	5.0	5.0	1.32	26.702	16.349	5.0	5.0	2.23	26.702	19.7	5.0	5.0	2.69
		2_S4_03b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S4_03c	SS				Advance from Queue Slot 2 to Berth 2	72.794	72.794	17.038	0.0	5.0	4.65	72.794	10.353	0.0	5.0	2.82	72.794	7.002	0.0	5.0	1.91
		2_S4_03d	SS							38.717	5.0	5.0	5.28		52.089	5.0	5.0	7.10		58.79	5.0	5.0	8.02
		2_S4_03e	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S4_03_A											**20.54**					**17.80**					**16.43**
	L4 S1 Departure	2_S4_03a	SS				Back Out	38.245	38.245	17.038	0.0	5.0	4.65	38.245	10.353	0.0	5.0	2.82	38.245	7.002	0.0	5.0	1.91
		2_S4_03b	SS							4.168	5.0	5.0	0.57		17.540	5.0	5.0	2.39		24.241	5.0	5.0	3.31
		2_S4_03c	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S4_03d	SS				Advance to Queue Slot 2	61.830	61.830	17.038	0.0	5.0	4.65	61.830	10.353	0.0	5.0	2.82	61.830	7.002	0.0	5.0	1.91
		2_S4_03e	SS							27.753	5.0	5.0	3.78		41.125	5.0	5.0	5.61		47.826	5.0	5.0	6.52
		2_S4_03f	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S4_03_D											**22.94**					**19.29**					**17.47**
		2_S4_04a	LT					233.15	233.15	176.841	0.0	17.5	13.77	233.150	182.160	0.0	24.8	10.03	233.15	189.470	0.0	35.0	7.38
		2_S4_04b	LT							56.309	17.5	17.5	2.19		50.990	24.8	24.8	1.40		43.680	35.0	35.0	0.85
		2_S4_04											**15.96**					**11.43**					**8.23**

Loop 2 (Main)	Low Speed Interconnect	2_SE_03	LS					118.352		118.352	5.0	5.0	16.14		118.352	5.0	5.0	16.14		118.352	5.0	5.0	16.14
	L4 S2 Arrival	2_S5_01a	LT				Decelerate to Queue Slot 2	233.15	233.15	66.014	17.5	17.5	2.57	233.150	54.009	24.8	24.8	1.49	233.15	43.356	35.0	35.0	0.84
		2_S5_01b	LT							167.136	17.5	5.0	10.12		179.141	24.8	5.0	8.21		189.794	35.0	5.0	6.47
		2_S5_01											**12.70**					**9.69**					**7.31**
		2_S5_02a	SS					26.702	26.702	9.664	5.0	5.0	1.32	26.702	16.349	5.0	5.0	2.23	26.702	19.7	5.0	5.0	2.69
		2_S5_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S5_02c	SS				Advance from Queue Slot 2 to Berth 2	72.794	72.794	17.038	0.0	5.0	4.65	72.794	10.353	0.0	5.0	2.82	72.794	7.002	0.0	5.0	1.91
		2_S5_02d	SS							38.717	5.0	5.0	5.28		52.089	5.0	5.0	7.10		58.79	5.0	5.0	8.02
		2_S5_02e	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S5_02_A											**20.54**					**17.80**					**16.43**
	L4 S2 Departure	2_S5_02a	SS				Back Out	38.245	38.245	17.038	0.0	5.0	4.65	38.245	10.353	0.0	5.0	2.82	38.245	7.002	0.0	5.0	1.91
		2_S5_02b	SS							4.168	5.0	5.0	0.57		17.540	5.0	5.0	2.39		24.241	5.0	5.0	3.31
		2_S5_02c	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S5_02d	SS				Advance to Queue Slot 2	61.830	61.830	17.038	0.0	5.0	4.65	61.830	10.353	0.0	5.0	2.82	61.830	7.002	0.0	5.0	1.91
		2_S5_02e	SS							27.753	5.0	5.0	3.78		41.125	5.0	5.0	5.61		47.826	5.0	5.0	6.52
		2_S5_02f	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		2_S5_02_D											**22.94**					**19.29**					**17.47**
		2_S5_03a	LT					233.150	233.150	176.841	0.0	17.5	13.77	233.150	182.160	0.0	24.8	10.03	233.15	189.470	0.0	35.0	7.38
		2_S5_03b	LT							56.309	17.5	17.5	2.19		50.990	24.8	24.8	1.40		43.680	35.0	35.0	0.85
		2_S5_03											**15.96**					**11.43**					**8.23**
	Lot 4 Bypass	2_38a	LS					135.600	135.600	114.760	11.5	17.5	5.40	135.600	123.567	11.5	24.8	5.84	135.6	135.600	23.0	35.0	3.20
		2_38b	LS							20.840	17.5	17.5	0.81		12.033	24.8	24.8	0.33		0.000	35.0	35.0	0.00
		2_38											**6.21**					**6.18**					**3.20**
		2_39	LS					186.225		186.225	17.5	17.5	7.25		186.225	24.8	24.8	5.13		186.225	35.0	35.0	3.63
		2_40	LS					232.909		232.909	17.5	17.5	9.07		232.909	24.8	24.8	6.41		232.909	35.0	35.0	4.54
		2_41	LS					356.010		356.010	17.5	17.5	13.86		356.010	24.8	24.8	9.80		356.010	35.0	35.0	6.94
	Loop End	2_42	LS					122.006		122.006	17.5	17.5	4.75		122.006	24.8	24.8	3.36		122.006	35.0	35.0	2.38
		2_43	LC	2015	2015	9.22		324.234		324.234	17.5	17.5	12.62		324.234	24.8	24.8	8.93		324.234	35.0	35.0	6.32
		2_44	LC	2035	2035	19.97		709.221		709.221	17.5	17.5	27.62		709.221	24.8	24.8	19.53		709.221	35.0	35.0	13.82
		2_45	LC	5021	5021	3.30		289.081		289.081	17.5	17.5	11.26		289.081	24.8	24.8	7.96		289.081	35.0	35.0	5.63
		2_46	LC	1347	1347	12.07		283.733		283.733	17.5	17.5	11.05		283.733	24.8	24.8	7.81		283.733	35.0	35.0	5.53
		2_47	LS					248.631		248.631	17.5	17.5	9.68		248.631	24.8	24.8	6.85		248.631	35.0	35.0	4.84
		2_48	LC	645	645	23.75		267.322		267.322	17.5	17.5	10.41		267.322	24.8	24.8	7.36		267.322	35.0	35.0	5.21
		2_49	LS					82.754		82.754	17.5	17.5	3.22		82.754	24.8	24.8	2.28		82.754	35.0	35.0	1.61

Loop 3 (Terminal A)		3_01	LS					222.603		222.603	11.8	11.8	12.81		222.603	16.8	16.8	9.06		222.603	23.7	23.7	6.40
		3_02	LC	150	150	178.41		471.817		471.817	11.8	11.8	27.15		471.817	16.8	16.8	19.20		471.817	23.7	23.7	13.57
		3_03a	LT					142.64	142.640	110.438	11.8	17.5	5.13	142.640	119.356	16.8	24.8	3.92	142.640	131.757	23.7	35.0	3.06
		3_03b	LT							32.202	17.5	17.5	1.25		23.284	24.8	24.8	0.64		10.883	35.0	35.0	0.21
		3_03											**6.38**					**4.56**					**3.27**
		3_04	LC	1506	1506	14.24		374.187		374.187	17.5	17.5	14.57		374.187	24.8	24.8	10.30		374.187	35.0	35.0	7.29
		3_05a	LC	1506	1506	4.57		119.989	119.989	22.215	17.5	17.5	0.87	119.989	12.989	24.8	24.8	0.36	119.989	0.153	35.0	35.0	0.00
		3_05b	LC	1506	1506	4.57				97.774	17.5	12.9	4.39		107.000	24.8	18.2	3.40		119.836	35.0	25.7	2.69
		3_05											**5.25**					**3.75**					**2.69**
		3_06	LC	177	177	183.13		565.733		565.733	12.9	12.9	29.99		565.733	18.2	18.2	21.20		565.733	25.7	25.7	14.99
	3 - 2 Transition	T32_01/2a	LC			11.46		146.397	146.397	97.774	12.9	17.5	4.39	146.397	107.000	18.2	24.8	3.40	146.397	119.8364	25.7	35.0	2.69
		T32_01/2b	LC			11.46				48.623	17.5	17.5	1.89		39.397	24.8	24.8	1.08		26.561	35.0	35.0	0.52
		T32_01											**6.28**					**4.48**					**3.21**
		3_07	LC	735	735	11.46		71.611		71.611	12.9	12.9	3.80		71.611	18.2	18.2	2.68		71.611	25.7	25.7	1.90
	TA Arrival	3_S1_01a	LC					107.690	107.690	19.462	12.9	12.9	1.03	107.690	8.869	18.2	18.2	0.33	107.690	0.000	25.7	25.7	0.00
		3_S1_01b	LC							88.228	12.9	5.0	6.74		98.821	18.2	5.0	5.81		107.690	25.7	5.0	4.78
		3_S1_01											**7.77**					**6.14**					**4.78**
	TA IB NB Arrival	3_S1_02a	SS				Decelerate to Queue Slot 3	40.500	40.500	23.462	5.0	5.0	3.20	40.500	30.147	5.0	5.0	4.11	40.500	33.498	5.0	5.0	4.57
		3_S1_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		3_S1_02c	SS				Advance from Queue Slot 3 to Berth 3	67.5	67.500	17.038	0.0	5.0	4.65	67.500	10.353	0.0	5.0	2.82	67.500	7.002	0.0	5.0	1.91
		3_S1_02d	SS							33.424	5.0	5.0	4.56		46.795	5.0	5.0	6.38		53.496	5.0	5.0	7.29
		3_S1_02e	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		3_S1_02_NB_A											**21.70**					**18.96**					**17.59**
	TA IB NB Departure thru SB	3_S1_02a	SS				Advance from Berth 3 to Queue Slot 3	155.000	47.000	17.038	0.0	5.0	4.65	47.000	10.353	0.0	5.0	2.82	47.000	7.002	0.0	5.0	1.91
		3_S1_02b	SS							29.962	5.0	5.0	4.09		36.647	5.0	5.0	5.00		39.998	5.0	5.0	5.45
		3_S1_02_NB_D											**8.73**					**7.82**					**7.36**
		3_S2_01a	SS							40.500	5.0	5.0	5.52		40.500	5.0	5.0	5.52		40.500	5.0	5.0	5.52
		3_S2_01b	SS						67.500	50.462	5.0	5.0	6.88	67.500	57.147	5.0	5.0	7.79	67.500	60.498	5.0	5.0	8.25
		3_S2_01c	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		3_S2_01d	SS				Accelerate from Queue Slot 3	27.000	27.000	17.038	0.0	5.0	4.65	27.000	10.353	0.0	5.0	2.82	27.000	7.002	0.0	5.0	1.91
		3_S2_01e	SS							9.962	5.0	5.0	1.36		16.647	5.0	5.0	2.27		19.998	5.0	5.0	2.73
		3_S2_01_NB_D											**23.06**					**21.23**					**20.32**
	TA IB SB Arrival thru NB	3_S1_02a	SS				Decelerate to Queue Slot 3	40.500	40.500	23.462	5.0	5.0	3.20	40.500	30.147	5.0	5.0	4.11	40.500	33.498	5.0	5.0	4.57
		3_S1_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		3_S1_02c	SS				Advance from Queue Slot 3 to Berth 3	155.000	67.500	17.038	0.0	5.0	4.65	67.500	10.353	0.0	5.0	2.82	67.500	7.002	0.0	5.0	1.91
		3_S1_02d	SS							50.462	5.0	5.0	6.88		57.147	5.0	5.0	7.79		60.498	5.0	5.0	8.25
		3_S1_02e	SS							47.000	5.0	5.0	6.41		47.000	5.0	5.0	6.41		47.000	5.0	5.0	6.41
		3_S1_02_SB_A											**25.78**					**23.96**					**23.05**
		3_S2_01a	SS						40.500	23.462	5.0	5.0	3.20	40.500	30.147	5.0	5.0	4.11	40.500	33.498	5.0	5.0	4.57
		3_S2_01b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		3_S2_01_SB_A											**7.85**					**6.93**					**6.48**
	TA IB SB Departure	3_S2_01a	SS				Advance from Berth 3 to Queue Slot 3	27.000	27.000	17.038	0.0	5.0	4.65	27.000	10.353	0.0	5.0	2.82	27.000	7.002	0.0	5.0	1.91
		3_S2_01b	SS							9.962	5.0	5.0	1.36		16.647	5.0	5.0	2.27		19.998	5.0	5.0	2.73
		3_S2_01c	SS					40.500	40.500	23.462	5.0	5.0	3.20	40.500	30.147	5.0	5.0	4.11	40.500	33.498	5.0	5.0	4.57
		3_S2_01d	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		3_S2_01e	SS				Accelerate from Queue Slot 3	27.000	27.000	17.038	0.0	5.0	4.65	27.000	10.353	0.0	5.0	2.82	27.000	7.002	0.0	5.0	1.91
		3_S2_01f	SS							9.962	5.0	5.0	1.36		16.647	5.0	5.0	2.27		19.998	5.0	5.0	2.73
		3_S2_01_SB_D											**19.86**					**17.12**					**15.75**
		3_S2_02a	LS					92.368	92.368	74.076	5.0	11.8	6.00	92.368	84.36103	5.0	16.8	5.29	92.368	92.368	5.0	23.7	4.41
		3_S2_02b	LS							18.292	11.8	11.8	1.05		8.007	16.8	16.8	0.33		0.000	23.7	23.7	0.00
		3_S2_02											**7.05**					**5.61**					**4.41**
	3 - 2 Transition	T32_03a	LT					189.794	189.794	167.136	5.0	17.5	10.12	189.794	179.141	5.0	24.8	8.21	189.794	189.794	5.0	35.0	6.47
		T32_03b	LT							22.658	17.5	17.5	0.88		10.653	24.8	24.8	0.29		0.000	35.0	35.0	0.00
		T32_03											**11.01**					**8.50**					**6.47**

Loop 4 (Terminal B)		4_01	LS					208.843		208.843	13.7	13.7	10.39		208.843	19.4	19.4	7.35		208.843	27.4	27.4	5.19
		4_02	LC	201	201	173.02		606.956		606.956	13.7	13.7	30.19		606.956	19.4	19.4	21.35		606.956	27.4	27.4	15.10
		4_03a	LT					152.154	152.154	86.393	13.7	17.5	3.77	152.154	95.876	19.4	24.8	2.96	152.154	109.075	27.4	35.0	2.38
		4_03b	LT							65.761	17.5	17.5	2.56		56.278	24.8	24.8	1.55		43.079	35.0	35.0	0.84
		4_03											6.33					4.51					3.22
		4_04a	LT					143.003	143.003	98.395	17.5	17.5	3.83	143.003	20.810	24.8	24.8	0.57	143.003	8.516	35.0	35.0	0.17
		4_04b	LT							44.61	17.5	11.6	5.31		122.19	24.8	16.4	4.05		134.487	35.0	23.2	3.15
		4_04											9.14					4.62					3.32
		4_05	LC	144	144	162.00		407.138		407.138	11.6	11.6	23.93		407.138	16.4	16.4	16.92		407.138	23.2	23.2	11.96
		4_06	LS					174.41		174.41	11.6	11.6	10.25		174.41	16.4	16.4	7.25		174.41	23.2	23.2	5.12
		4_07	LS					44.096		44.096	11.6	11.6	2.59		44.096	16.4	16.4	1.83		44.096	23.2	23.2	1.30
		4_08	LS					104.265		104.265	11.6	11.6	6.13		104.265	16.4	16.4	4.33		104.265	23.2	23.2	3.06
	4 - 2 Transition	T42_01a	LT					140.754	140.754	113.34934	11.6	17.5	5.31	140.754	122.19252	16.4	24.8	4.05	140.754	134.487	23.2	35.0	3.15
		T42_01b	LT							27.405	17.5	17.5	1.07		18.561	24.8	24.8	0.51		6.267	35.0	35.0	0.12
		T42_01											6.38					34.89					3.27
	TB Arrival	4_S1_01a	LS					89.340	89.340	18.537	11.6	11.6	1.09	89.340	8.327	16.4	16.4	0.35	89.340	0.000	23.2	23.2	0.00
		4_S1_01b	LS							70.803	11.6	5.0	5.82		81.013	16.4	5.0	5.16		89.340	23.2	5.0	4.32
		4_S1_01											6.90					5.51					4.32
	TB IB NB Arrival	4_S1_02a	SS				Decelerate to Queue Slot 3	40.500	40.500	23.462	5.0	5.0	3.20	40.500	30.147	5.0	5.0	4.11	40.500	33.498	5.0	5.0	4.57
		4_S1_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		4_S1_02c	SS				Advance from Queue Slot 3 to Berth 3	67.500	67.500	17.038	0.0	5.0	4.65	67.500	10.353	0.0	5.0	2.82	67.500	7.002	0.0	5.0	1.91
		4_S1_02d	SS							33.424	5.0	5.0	4.56		46.795	5.0	5.0	6.38		53.496	5.0	5.0	7.29
		4_S1_02e	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		4_S1_02_NB_A											21.70					18.96					17.59
	TB IB NB Departure thru SB	4_S1_02a	SS				Advance from Berth 3 to Queue Slot 3	155.000	47.000	17.038	0.0	5.0	4.65	43.479	10.353	0.0	5.0	2.82	47.000	7.002	0.0	5.0	1.91
		4_S1_02b	SS							29.962	5.0	5.0	4.09		33.126	5.0	5.0	4.52		39.998	5.0	5.0	5.45
		4_S1_02_NB_D											8.73					7.34					7.36
		4_S2_01a	SS							40.500	5.0	5.0	5.52		40.500	5.0	5.0	5.52		40.500	5.0	5.0	5.52
		4_S2_01b	SS						67.500	50.462	5.0	5.0	6.88	67.500	57.147	5.0	5.0	7.79	67.500	60.498	5.0	5.0	8.25
		4_S2_01c	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		4_S2_01d	SS				Accelerate from Queue Slot 3	27.000	27.000	17.038	0.0	5.0	4.65	27.000	10.353	0.0	5.0	2.82	27.000	7.002	0.0	5.0	1.91
		4_S2_01e	SS							9.962	5.0	5.0	1.36		16.647	5.0	5.0	2.27		19.998	5.0	5.0	2.73
		4_S2_01_NB_D											23.06					21.23					20.32
	TB IB SB Arrival thru NB	4_S1_02a	SS				Decelerate to Queue Slot 3	40.500	40.500	23.462	5.0	5.0	3.20	40.500	30.147	5.0	5.0	4.11	40.500	33.498	5.0	5.0	4.57
		4_S1_02b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		4_S1_02c	SS				Advance from Queue Slot 3 to Berth 3	155.000	67.500	17.038	0.0	5.0	4.65	70.751	10.353	0.0	5.0	2.82	67.500	7.002	0.0	5.0	1.91
		4_S1_02d	SS							50.462	5.0	5.0	6.88		60.398	5.0	5.0	8.24		60.498	5.0	5.0	8.25
		4_S1_02e	SS							47.000	5.0	5.0	6.41		43.749	5.0	5.0	5.97		47.000	5.0	5.0	6.41
		4_S1_02_SB_A											25.78					23.96					23.05
		4_S2_01a	SS						40.500	23.462	5.0	5.0	3.20	40.500	30.147	5.0	5.0	4.11	40.500	33.498	5.0	5.0	4.57
		4_S2_01b	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		4_S2_01_SB_A											7.85					6.93					6.48
	TB IB SB Departure	4_S2_01a	SS				Advance from Berth 3 to Queue Slot 3	27.000	27.000	17.038	0.0	5.0	4.65	27.000	10.353	0.0	5.0	2.82	27.000	7.002	0.0	5.0	1.91
		4_S2_01b	SS							9.962	5.0	5.0	1.36		16.647	5.0	5.0	2.27		19.998	5.0	5.0	2.73
		4_S2_01c	SS					40.500	40.500	23.462	5.0	5.0	3.20	40.500	30.147	5.0	5.0	4.11	40.500	33.498	5.0	5.0	4.57
		4_S2_01d	SS							17.038	5.0	0.0	4.65		10.353	5.0	0.0	2.82		7.002	5.0	0.0	1.91
		4_S2_01e	SS				Accelerate from Queue Slot 3	27.000	27.000	17.038	0.0	5.0	4.65	27.000	10.353	0.0	5.0	2.82	27.000	7.002	0.0	5.0	1.91
		4_S2_01f	SS							9.962	5.0	5.0	1.36		16.647	5.0	5.0	2.27		19.998	5.0	5.0	2.73
		4_S2_01_SB_D											19.86					17.12					15.75
	TB Departure	4_S2_02a	LS					120.928	120.928	100.847	5.0	13.7	7.35	120.928	111.697	5.0	19.4	6.25	120.928	120.928	5.0	27.4	5.09
		4_S2_02b	LS							20.081	13.7	13.7	1.00		9.231	19.4	19.4	0.32		0.000	27.4	27.4	0.00
		4_S2_02											8.35					6.57					5.09
	4 - 2 Transition	T42_02a	LT					189.754	189.754	167.136	5.0	17.5	10.12	189.754	179.141	5.0	24.8	8.21	189.754	189.754	5.0	35.0	6.47
		T42_02b	LT							22.618	17.5	17.5	0.88		10.613	24.8	24.8	0.29		0.000	35.0	35.0	0.00
		T42_02											11.01					8.50					6.47

Appendix D. Trip Definitions

Trip ID	Origin	Destination	Segments	Distance	
				(ft)	(mi)
01	VTA	TA IB NB	1.S1.02.D, 1.S1.03 - 01.S1.04, 1.01 - 1.13, 2.01 -2.04, 3.04 - 3.07, 3.S1.01. 3.S1.02.NB.A	6535	1.24
02	VTA	TA IB NB	1.S1.03 - 1.S1.04, 1.01 - 1.13, 2.01 -2.20, T23.01, T23.02, 3.07, 3.S1.01 - 3.S1.02	TBD	TBD
03	TA IB NB	VTA	**3.S1.02, 3.S2.01, T32.02, 2.25 - 2.33, TBD Transition, 4.02 - 03, 2.44 - 2.45, 1.14 - 1.23, 1.S1.01 - 1.S1.02**	TBD	TBD
04	TA IB NB	VTA	3.S1.02.NB.D, 3.S2.01.NB.D, T32.03, 2.25 - 2.33, T24.02, 4.02, 4.03, 2.44, 2.45, 1.14 - 1.23, 1.S1.01, 1.S1.02.A	8451	1.60
05	VTA	TB IB SB	1.S1.02.D, 1.S1.03 - 1.S1.04, 1.01 - 1.13, 2.01 -2.04, 3.04 - 3.06, T32.01, 2.23 - 2.31, T24.01, 4.07 - 4.08, 4.S1.01, 4.S1.02.SB.A, 4.S2.01.SB.A	9265	1.75
06	VTA	TB IB SB	1.S1.03 - 1.S1.04, 1.01 - 1.13, 2.01 -2.31, T24.01, 4.07 - 4.08, 4.S1.01 - 4.S1.03, 4.S2.01	TBD	TBD
07	TB IB SB	VTA	4.S2.01.SB.D, 4.S2.02, 4.01 - 4.03, 2.44, 2.45, 1.14 - 1.23, 1.S1.01, 1.S1.02A	5839	1.11
08	TB IB SB	VTA	4.S2.01, T42.02, 2.34 - 2.45, 1.14 - 1.23, 1.S1.01 - 1.S1.02	TBD	TBD
09	EL S1	TA IB NB	2.S1.02.D, 2.S1.03, 2.10 - 2.20, T23.01 - 02, 3.07, 3.S1.01, 3.S1.02.NB.A	3892	0.74
10	EL S2	TA IB NB	2.S2.02.D, 2.S2.03, 2.12 - 2.20, T23.01 - 02, 3.07, 3.S1.01, 3.S1.02.NB.A	3536	0.67
11	EL S3	TA IB NB	2.S3.02.D, 2.S3.03, 2.14 - 2.20, T23.01 - 02, 3.07, 3.S1.01, 3.S1.02.NB.A	3174	0.60
12	TA IB NB	EL S1	3.S1.02.NB.D, 3.S2.01.NB.D, 3.S2.02, 3.01 - 3.03, 2.04 - 2.06, 2.S1.01, 2.S1.02.A	2266	0.43
13	TA IB NB	EL S2	3.S1.02.NB.D, 3.S2.01.NB.D, 3.S2.02, 3.01 - 3.03, 2.04 - 2.08, 2.S2.01, 2.S2.02.A	2627	0.50
14	TA IB NB	EL S3	3.S1.02.NB.D, 3.S2.01.NB.D, 3.S2.02, 3.01 - 3.03, 2.04 - 2.10, 2.S3.01, 2.S3.02.A	2983	0.56
15	TA IB NB	EL S1	**3.S1.02, 3.S2.01, T32.02, 2.25 - 2.33, TBD Transition, 4.02 - 03, 2.44 - 2.49, 2.01 - 2.06, 2.S1.01 - 2.S1.02**	TBD	TBD
16	TA IB NB	EL S2	**3.S1.02, 3.S2.01, T32.02, 2.25 - 2.33, TBD Transition, 4.02 - 03, 2.44 - 2.49, 2.01 - 2.06, 2.S1.01 - 2.S1.02**	TBD	TBD
17	TA IB NB	EL S3	**3.S1.02, 3.S2.01, T32.02, 2.25 - 2.33, TBD Transition, 4.02 - 03, 2.44 - 2.49, 2.01 - 2.06, 2.S1.01 - 2.S1.02**	TBD	TBD
18	TA IB NB	EL S1	3.S1.02, 3.S2.01, T32.02, 2.25 - 2.49, 2.01 - 2.06, 2.S1.01 - 2.S1.02	TBD	TBD
19	TA IB NB	EL S2	3.S1.02, 3.S2.01, T32.02, 2.25 - 2.49, 2.01 - 2.08, 2.S2.01 - 2.S2.02	TBD	TBD
20	TA IB NB	EL S3	3.S1.02, 3.S2.01, T32.02, 2.25 - 2.49, 2.01 - 2.10, 2.S3.01 - 2.S3.02	TBD	TBD
21	EL S1	TB IB SB	2.S1.02D, 2.S1.03, 2.10 - 2.31, T24.01, 4.07 - 4.08, 4.S1.01, 4.S1.02.SB.A, 4.S2.01.SB.A	6623	1.25
22	EL S2	TB IB SB	2.S2.02D, 2.S2.03, 2.12 - 2.31, T24.01, 4.07 - 4.08, 4.S1.01, 4.S1.02.SB.A, 4.S2.01.SB.A	6267	1.19
23	EL S3	TB IB SB	2.S3.02D, 2.S3.03, 2.14 - 2.31, T24.01, 4.07 - 4.08, 4.S1.01, 4.S1.02.SB.A, 4.S2.01.SB.A	5904	1.12
24	TB IB SB	EL S1	4.S2.01.SB.D, 4.S2.02, 4.01 -4.03, 2.44 -2.49, 2.01 - 2.06, 2.S1.01, 2.S1.02.A	4941	0.94
25	TB IB SB	EL S2	4.S2.01.SB.D, 4.S2.02, 4.01 -4.03, 2.44 -2.49, 2.01 - 2.08, 2.S2.01, 2.S2.02.A	5302	1.00
26	TB IB SB	EL S3	4.S2.01.SB.D, 4.S2.02, 4.01 -4.03, 2.44 -2.49, 2.01 - 2.10, 2.S3.01, 2.S3.02.A	5658	1.07
27	L4 S1	TA IB NB	2.S4.03.D, 2.S4.04, 2.41 - 2.49, 2.01 - 2.04, 3.04 - 3.07, 3.S1.01, 3.S1.02.NB.A	5324	1.01
28	L4 S2	TA IB NB	2.S5.02.D, 2.S5.03, 2.42 - 2.49, 2.01 - 2.04, 3.04 - 3.07, 3.S1.01, 3.S1.02.NB.A	4968	0.94
29	TA IB NB	L4 S1	3.S1.02.NB.D, 3.S2.01.NB.D, T32.03, 2.25 - 2.37, 2.S4.01, 2.S4.02, 2.S4.03.A	4932	0.93
30	TA IB NB	L4 S2	3.S1.02.NB.D, 3.S2.01.NB.D, T32.03, 2.25 - 2.39, 2.S5.01, 2.S5.02.A	5287	1.00
31	L4 S1	TB IB SB	2.S4.03.A, 2.S4.04, 2.41 - 2.44, 4.04 - 4.08, 4.S1.01, 4.S1.02.SB.A, 4.S2.01.SB.A	3002	0.57
32	L4 S2	TB IB SB	2.S5.02.A, 2.S5.03, 2.42 - 2.44, 4.04 - 4.08, 4.S1.01, 4.S1.02.SB.A, 4.S2.01.SB.A	2646	0.50
33	TB IB SB	L4 S1	4.S2.01.SB.D, T42.02, 2.34 - 2.37, 2.S4.01, 2.S4.02, 2.S4.03.A	2289	0.43
34	TB IB SB	L4 S2	4.S2.01.SB.D, T42.02, 2.34 - 2.39, 2.S5.01, 2.S5.02.A	2645	0.50

Appendix E. Vehicle Definitions

Vehicle Definition	Vehicle Weight (lb)	Seats/Vehicle	Frontal Area (ft ^{2})	Propulsion Type (C_{rr})	LF	Passengers per Vehicle
01	1000	1	13.1	0.0050	100%	1
02	1000	1	13.1	0.0100	100%	1
03	1000	2	13.1	0.0050	50%	1
04	1000	2	13.1	0.0050	100%	2
05	1000	2	13.1	0.0100	50%	1
06	1000	2	13.1	0.0100	100%	2
07	1500	2	13.1	0.0050	50%	1
08	1500	2	13.1	0.0050	100%	2
09	1500	2	13.1	0.0100	50%	1
10	1500	2	13.1	0.0100	100%	2
11	1500	4	26.3	0.0050	25%	1
12	1500	4	26.3	0.0050	50%	2
13	1500	4	26.3	0.0050	75%	3
14	1500	4	26.3	0.0050	100%	4
15	1500	4	26.3	0.0100	25%	1
16	1500	4	26.3	0.0100	50%	2
17	1500	4	26.3	0.0100	75%	3
18	1500	4	26.3	0.0100	100%	4
19	2000	4	26.3	0.0050	25%	1
20	2000	4	26.3	0.0050	50%	2
21	2000	4	26.3	0.0050	75%	3
22	2000	4	26.3	0.0050	100%	4
23	2000	4	26.3	0.0100	25%	1
24	2000	4	26.3	0.0100	50%	2
25	2000	4	26.3	0.0100	75%	3
26	2000	4	26.3	0.0100	100%	4
27	2500	4	26.3	0.0050	25%	1
28	2500	4	26.3	0.0050	50%	2
29	2500	4	26.3	0.0050	75%	3
30	2500	4	26.3	0.0050	100%	4
31	2500	4	26.3	0.0100	25%	1
32	2500	4	26.3	0.0100	50%	2
33	2500	4	26.3	0.0100	75%	3
34	2500	4	26.3	0.0100	100%	4
35	3000	4	26.3	0.0050	25%	1
36	3000	4	26.3	0.0050	50%	2
37	3000	4	26.3	0.0050	75%	3
38	3000	4	26.3	0.0050	100%	4
39	3000	4	26.3	0.0100	25%	1
40	3000	4	26.3	0.0100	50%	2
41	3000	4	26.3	0.0100	75%	3
42	3000	4	26.3	0.0100	100%	4
43	3000	6	39.4	0.0050	17%	1
44	3000	6	39.4	0.0050	33%	2
45	3000	6	39.4	0.0050	50%	3
46	3000	6	39.4	0.0050	67%	4
47	3000	6	39.4	0.0050	100%	6
48	3000	6	39.4	0.0100	17%	1
49	3000	6	39.4	0.0100	33%	2
50	3000	6	39.4	0.0100	50%	3
51	3000	6	39.4	0.0100	67%	4
52	3000	6	39.4	0.0100	100%	6
53	3500	6	39.4	0.0050	17%	1
54	3500	6	39.4	0.0050	33%	2
55	3500	6	39.4	0.0050	50%	3
56	3500	6	39.4	0.0050	67%	4
57	3500	6	39.4	0.0050	100%	6
58	3500	6	39.4	0.0100	17%	1
59	3500	6	39.4	0.0100	33%	2
60	3500	6	39.4	0.0100	50%	3
61	3500	6	39.4	0.0100	67%	4
62	3500	6	39.4	0.0100	100%	6

Appendix F. CPUC Regulatory Process and Case Studies

This Appendix briefly outlines the CPUC rulemaking process and describes how it was applied and its results used in two respective case studies. It is impossible to provide a precise estimate of the time and effort that would be required to establish ATN technology as a legitimate transit option form a regulatory perspective, but previous efforts can serve as comparison benchmarks after a rough accounting for obvious differences in scope and complexity.

F.1 General Rulemaking Process Outline

1. Rulemaking actions and investigations may be initiated by the CPUC itself, or upon the filing of an application, petition or complaint by any person, organization or group of organizations

2. Upon initiation, a docket is opened in which a record of the ensuing proceedings and summary references is maintained.

    a. For rulemaking actions, an Order Instituting Rulemaking (OIR) is issued, providing a general description of the topic to be addressed.

    b. A Scoping Memo is developed that details the intent and scope of the rulemaking activity, with a preliminary schedule. The scope of the rulemaking may include one or more existing General Orders, may result in a new General Order, or may culminate in specific decisions, rulings or resolutions that bear on the topic of interest without formal changes to existing General Orders or prevailing rules.

    c. An Administrative Law Judge (ALJ) is assigned to the case and issues a Prehearing Conference Notice.

    d. The Prehearing Conference is held at a publicly announced time and location, allowing interested individuals or organizations to become official parties to the proceeding.

    e. One or more hearings are conducted by the CPUC as needed for introduction of evidence and supporting information for the proceeding.

    f. The ALJ, or an Assigned Commissioner for the proceeding, issues rulings on procedural matters so as to move the proceeding toward an orderly decision.

    g. A Proposed Decision or "draft decision" is issued by the ALJ or Assigned Commissioner.

    h. A Comment period is opened, during which parties have opportunity to provide inputs and reactions to the draft decision. A round of "opening comments" is followed by a round of "reply comments."

    i. A Final Decision is developed and placed on the agenda of a regularly scheduled CPUC meeting for approval, modification or rejection.

    j. Advice Letters (also referred to as "compliance filings") may be required from affected parties to specify to the CPUC how compliance with final rulings will be implemented.

3. The CPUC may also generate and issue Resolutions on related administrative and contractual matters, subject to vote by the full Commission.

The Commission maintains an index of all open proceedings that can be readily referenced online. Documents associated with closed proceedings, such as CPUC decisions, rulings and resolutions, are not generally directly downloadable, but can be requested via an online form.

F.2 Case Studies

The following are several examples of how CPUC rules and associated standards have been revised using the Commission's existing processes. While a direct correlation between these efforts and, due to differences in scope and complexity, that which may be required for ATNs is not easily drawn, these case studies do serve as data points to aid the City in sizing up what would lie ahead should it continue to pursue its interest in ATN Technology.

F2.1 Rulemaking for Modification of General Orders 95 and 128.

This example illustrates the workings of the CPUC rulemaking process for modification of two existing General Orders. While the example is not related to transportation regulations, the general process is quite analogous to what may be expected for modification of transit-related rules.

Background: The CPUC issued an OIR on 2 October 2001 for the purposes of "strengthening General Orders 95 and 128," which govern, respectively, the construction of overhead and underground power and communication lines. The Consumer Protection and Safety Division (CPSD) initiated the proceeding with an offer of 13 proposed rule changes (PRCs), to which "a wide variety of companies and individuals" provided written responds on the filing deadline of 4 December 2001. Comments in reply were made available on 4 February 2002. It is notable that "most of the parties which filed comments requested that a workshop be convened, [to which] the ALJ agreed."

A coalition of industry participants and consultants was thus formed, with the first workshop held on 7 May, 2002. Workshop sessions, generally two to three days in length, were held on a semi-regular basis over the course of 16 months, approximately 50 workshop days in total. It was estimated that twenty to thirty individual participants attended each workshop, representing approximately ten organizations recognized as parties to the proceeding. Over the course of the workshop sessions, as many as 70 individual participants were estimated to have supported at least one session. The workshop sessions were publicly announced, open to anyone, and held in various cities throughout California to facilitate public access.

It is interesting to note that the parties to the proceeding were not all from the same industry. Electric power utilities (both municipal entities and investor-owned companies), cable system operators (actually represented by a cable industry association), major telecommunications firms, labor organizations, and a variety of consultants with an interest in overhead and underground utility installation comprised the workshop group.

Proceedings: The first step taken during the initial workshop session was an agreement to retain the services of a professional facilitator, which entailed costs of approximately $180,000 over the 16-month evaluation period. This fee was paid by the principal stakeholder firms participating in the workshops. The second workshop focused on the protocols for introducing, evaluating and forming consensus positions on the proposed rule changes. Actual discussion of the proposed changes began at the third session.

The evaluation protocol is worthy of additional note. Rather than a simple up-or-down vote on the proposals as they were initially stated, a six-level scoring system was established to provide a finer gradation of the parties' positions on an issue:

The levels of consensus were defined as follows:

1. I am enthusiastic about this decision. I am satisfied that the decision is an expression of the wisdom of the group.

2. I find the decision is the best choice. It is the best of the real options that we have available to us.

3. I can live with the decision; I'm not especially enthusiastic about it.

4. I do not fully agree with the decision and need to register my view about it. However, I do not choose to block the decision and will stand aside. I am willing to support the decision because I trust the wisdom of the group.

5. I do not agree with the decision and I feel the need to block this decision being accepted as consensus.

6. I feel that we have no clear sense of unity in the group. We need to talk more before consensus can be reached.

Consensus was achieved if all the voting parties voted a 1, 2, 3 or 4. A vote of 5 or 6, even if by a single party and even if all other parties voted 1, forced the workshop to continue discussing the proposal. If there appeared to be no possibility of obtaining a consensus, then the group would move the Proposed Rule Change to a Multiple Alternative Proposals (MAP) process.

The protocol also allowed a two-week "go-back" period during which a representative could reconsider their vote and perhaps confer off-line with other individuals from their organization. Votes could be changed during this period, but not after the agenda was set for the next session. Participants were also given the ability to add any "remaining concerns" to the Workshop Report as a means for them to express their position on residual issues on the record. As stated in the Workshop Report for this effort:

> *"It is inevitable that a tiered voting system will result in some parties having misgivings or concerns about proposals for which they nevertheless voted. Regardless of these concerns, all consensus PRCs are [considered to be] supported by all of the parties who voted on them, and the parties request that all of the consensus PRCs be adopted by the Commission."*

Using this method, the parties were able to achieve consensus on most of the proposed rule changes. Only a small percentage of the changes were relegated to the MAP category.

Results: From the rounds of opening and reply comments, as well as ideas introduced in the workshop sessions, the original 13 proposals offered by the CPSD expanded to 63 proposed rule changes or new rules that were explicitly addressed in the Workshop. Based on the results of the discussions and voting protocol, 40 drew a consensus, 8 failed to do so, and 15 were withdrawn.

A quick look at the 63 proposals indicates that they vary significantly in complexity; some very simple, some less so but uncontroversial and requiring only a moderate amount of discussion, and other that were relatively complex with the potential of having significant implications for stakeholders. The latter proposals, of course, required greater and more detailed discussion. The 63 proposed changes were distributed fairly equally into these three "complexity categories." Several examples are given in Table <insert ID>.

PRC Number	General Order/Rule Reference	Proposal Description	"Complexity" Category
3	GO 95, Rule 31.6	Define term "permanently abandoned" lines	Simple
46	GO 95, Rule 54.8-B(3)	Correct reference to incorrect rule	Simple
10	GO 128, Rule 17.8	Add requirement for identification of sub-surface and self-contained surface-mounted equipment enclosures	Moderate
36	GO 95, Rule 22.0-C	Expand definition of pole reinforcement techniques	Moderate
31	GO 95, Rule 92	Revise clearance requirements for communications facilities	Significant
53	GO 95, Rule 87.10	Define requirements for the transition of fiber optic cable facilities between supply levels and transitions to or from the communication level	Significant

Required Resources: Including research, workshop preparation and attendance, inter-party coordination and the preparation of filings and supporting documentation, "several thousand hours of effort" were expended by the parties' representatives over the sixteen-month period for this rulemaking action.

Note that the 16 month period of workshop activity did not represent the entire rulemaking process. A full two years ensued between the issuing of the OIR by the CPSD and the submittal of the Workshop Report. Moreover, additional actions taken by the Commission to issue a final decision on the submitted results and to implement the actual changes required additional time of which no record was found here.

Implications for the City of San José: It is rather easy to envision an analogous effort of significantly larger scope being necessary to address the universe of possible rule changes pertinent to the adoption of ATN technology.

As a rough estimate based on this example, it is not at all unlikely that an ATN rulemaking effort could involve a three to five year cycle, with many thousands of hours of effort required of the parties involved in support. While this would entail considerable expense, it is likely that only a small portion would necessarily be borne by the City itself. The City's efforts would be similar in nature those undertaken in support of this evaluation which, in fact, represents a good deal of the preparatory work that would be required from the City in order to articulate its interests during such proceedings. The majority of the effort would be borne by the remaining collection of private sector suppliers, local public interest groups, trade associations, and other interested parties.

F2.2 Establishing Standards for a New Transit Vehicle Category

The purpose of this example is to illustrate how CPUC regulations as embodied in an existing General Order can be leveraged to revise existing rules to accommodate a new transit technology. Note that it is not being implied here that this in any way compares in scope to what is likely to be required in the case of ATNs, but it does illustrate CPUC rulemaking flexibility and some of the issues and organizations involved in a transit-related topic.

Background: A category of public transit conveyances known as "Historical Trolleys" or "Vintage Trolleys" is enjoying a comeback in a number of urban centers in the U.S. While these are similar in some respects to Light Rail systems in that they are steel wheel on rails and are electrically powered, there are many differences in their system configuration and operation. Even within the category, there is a wide range of vehicle designs. As a result, common regulations and standards for light rail systems did not well accommodate this category.

To address this need, the American Public Transportation Association (APTA) created a Vintage Trolley and Streetcar Task Force (later re-named the Heritage Trolley & Streetcar Subcommittee) in 2000 to “establish appropriate standards for equipping and operating Vintage Trolley vehicles in an urban public transit environment.” In this case, the results of a prior CPUC rulemaking effort were used as the basis for a proposed nationwide standard.

Proceedings: The APTA Task Force first set out to establish a clear understanding of the problem. Among the salient findings from their initial investigations were:

1. Great diversity in implementation and operations: Vehicles of many different physical characteristics, some restored original equipment and some newly built replicas of original designs, were found to operate in varying fleet sizes, route lengths and service frequencies for multiple purposes, ranging from museum exhibits to full-scale public transit.

2. Competing objectives: Vintage systems have parallel needs for accurate historical preservation along with modern expectations for mechanical integrity and safety, which sometimes need to be reconciled, i.e. while the simplicity of the older designs is an appealing factor, it can also mean that extra attention to maintenance is needed to assure safe and sustainable operations.

3. Inconsistent regulations: Rail safety requirements applied to these systems were found to vary on a state-by-state basis, with “few [having] any provision for operation of Vintage Trolleys.”.

4. Forgotten practices: The Task Force discovered that when the widespread use of original rail cars died out, much knowledge about their operation and maintenance was lost.

As a second step, the Task Force compiled a set of reference information pertinent to the category, both historical and contemporary, to use as a starting point:

1. Painstaking effort was undertaken to unearth documentation preserved by historians, museums and private collectors relative to mechanical and electrical maintenance.

2. Consulting its own APTA Rail Transit Standards/Recommended Practices, it was found that a number of provisions, such as periodic inspections, were applicable to any system whether modern or vintage.

3. The “Historical Streetcars” section of CPUC General Order 143-B was evaluated and subsequently selected as a model for adaptation into a set of new APTA Standard for Vintage/Heritage Trolley Vehicle Equipment.

   In its original update to General Order 143, the CPUC had clearly delineated which parts of the General Order pertained to all vehicles, whether vintage or modern. Among these provisions were specifications for basic operational speed control, handles and safety bars, warning devices for stopped vehicles, parking brakes, interior lighting, emergency exits, operating rules, maintenance schedules, inspections and tests.

   GO 143-B went on to recognize the differences between historical trolleys and modern Light Rail technology, and to specify exemptions from numerous Light Rail Vehicle requirements in favor of separate standards for vintage vehicles. These tailored specifications covered numerous topics such as the service braking system, specific operating speeds and conditional operating rules, required stopping distances, exterior lighting, door operation, and windshield and window specifications.

Results: Using the information from these sources as a foundation, the Task Force developed an integrated set of updated Vintage Trolley equipment and operational standards that were organized into three primary areas:

1. Safety-oriented procedures applicable to all vintage systems, including rules for operations, training, and maintenance facilities and procedures.

2. Minimum vehicle equipment requirements.

3. Additional equipment requirements for certain specific operational conditions.

Essentially, the resulting suite of requirements embodied in the new APTA Standard represented an augmentation of the GO 143-B provisions for historical vehicles upon which it was based. Provisions were added to account for the wide variance in original equipment design. As with many standards and regulations, the option of using alternative methods to achieve the original intent of a provision is provided in terms of a systematic request and approval process. An example of this is the requirement for door interlocks, as many vintage vehicles to not have doors as part of their original design.

Additional flexibility was incorporated in the standard to account for varying local ordinances. For example, locally-imposed regulations for safety lighting and audible warnings when approaching at-grade crossings must be observed, but can be problematic and perhaps unnecessary in particular applications. The Standard therefore sets minimum requirements with a proviso that local regulations must also be accommodated.

Certain equipment was specified as unconditional requirements on newly-constructed retro-style vehicles. However, the Standard provides guidance for performing Hazard Analyses to determine the need for conditional retrofitting of older vehicles with additional equipment. Examples in this category include “dead man” controls, low air pressure interlocks, speed monitoring equipment, turn indicators and stop lights, windshield wipers and/or defrosters.

Finally, a set of issues was identified for further consideration on a case-by-case basis in specific applications, depending on proposed vehicle design and concept of operations. For these issues, specific standards are not given. Instead, a general process is recommended for determining how best to meet the intent of the regulations. Among issues of this type are vehicle structural requirements, evacuation means and methods (as for fire safety) and ADA compliance.

As for CPUC rulemaking, the APTA standards development process includes provisions by which revisions to Standard or Recommend Practices can be requested by any interested party. A mailing address to which questions regarding the interpretation of standards or requests for their revision may be directed is provided in the Foreword to the Standard itself.

Required Resources: The APTA Standard for Vintage/Heritage Trolley Vehicle Equipment was initially released on 20 June 2005, about five years after the Task Force was formed. An initial draft was introduced for review by the entire Task Force on 6 June 2003. A number of additional drafts were generated, reviewed and accepted at Task Force sessions held in various locations throughout the U.S. Face-to-face discussions were held with numerous operators of vintage vehicle systems and other interested parties.

The Task Force itself involved the participation of over 100 APTA members. While it is not known how many person-hours of effort went into the entire end-to-end process of developing and approving the Standard, it can be fairly estimated to have totaled in the thousands of hours over the five year span.

Implications for the City of San José: This case study is analogous to the process currently underway to revise the ASCE APM Standards to accommodate the ATN concept. As stated mentioned in the body of this report, standards such as these, while extremely useful, do not carry the force of law. Nevertheless, this case study is also useful for gauging the level of a separate and perhaps completely independent effort for which the CPUC is the authority. Once again, it portends a multi-year time process involving the efforts of a large number of individuals and organizations. And it must also again be cautioned that the scope of an effort to qualify and establish regulations for ATNs is likely to be considerably greater in scope.

Appendix G: Examples of International ATN Regulatory Approaches and Processes

A number of ATN pilot projects and related initiatives are currently being undertaken outside the U.S. A brief look at these activities provides high-level insight into how safety regulators in other countries are addressing the challenges of integrating advanced transit technologies while maintaining acceptable risks to public passengers and operational staff.

While these experiences do not by any means necessarily translate into how the CPUC may choose to authorize initial ATN system implementation and operation in California, they do exemplify the principles of provisional system certification and operational authorization based on the results of formal safety analyses and tests. A primary goal with this approach is to "strike a balance," such that valuable operational experience with ATN technology can be gained in an environment where safety and security risks are reasonably well understood and contained.

United Kingdom. In the U.K., as is the case in California, regulatory responsibility for trams, people movers and automated guideway transit systems resides with the rail safety authority. In 2006, rail safety responsibilities that were previously vested in Her Majesty's Rail Inspectorate (HMRI) and the Health and Safety Executive (HSE) were coalesced in the Office of Railway Regulation (ORR). Extensively documented safety regulations for "Railways and Other Guideway-transport Systems" (ROGS), along with a multi-part set of Railway Safety Principles and Guidance (RSPG) documents, serve as the foundation for establishing safety criteria for rail transit systems and their operation.

Schedule 4 of a "ROGS Guidance on Regulations" document, published in 2006 by ORR, specifies a process for engaging a qualified, independent safety authority ("competent person") to a) evaluate and approve the analytic and empirical safety verification plan for a candidate system, and b) verify the integrity of conduct and adequacy of results of the verification activities.

In operation, a Safety Verification Team consisting of senior experienced leaders from academic, industry and government organizations is appointed to serve as the independent evaluator. A formal risk assessment, comprised of hazard identification and (initially) qualitative risk scoring steps, is conducted, forming the basis for a Quantified Risk Assessment (QRA). The QRA, in turn, documents the assumptions and calculations demonstrating how the design mitigates the hazards to a defined level of acceptability.

While formal risk management and reliability analysis methods such as these have reached a significant level of maturity, it is also widely recognized that they are inherently non-deterministic in any given application, since it can never be guaranteed that all significant hazards and failure modes have been adequately characterized in advance. Moreover, the effects of multiple or cascading failures is generally not well accounted for in typical hazard identification and failure modes/effects analyses, which is a major weakness since it is quite typical for unanticipated interactions between failure points to be at the root of real-world anomalies in complex systems.

In keeping with this factor, a degree of "process uncertainty" is generally accepted even with the most rigorous risk management practices. Accordingly, new-technology systems entering public service are often deliberately constrained to specific operational limits and restrictions, at least on a temporary basis. This allows for actual operational safety and reliability experience to accrue over time, adding confidence to the results of the initial analyses. For ATNs, operational limits on line speed and vehicle separation (headway) may be set to conservative initial levels.

Sweden. The Swedish Rail Agency has been actively involved in ATN system development and certification for a number of years, reflecting the country's longstanding interest in clean, efficient transit systems and significant investment in advanced transit technology research and development. The Agency has overall responsibility for defining applicable system implementation and operational rules, supervising safe operations, ensuring fair service offering, pricing and competition, and issuing safety certificates and authorizations for transit services.

Given its primary role in preventing unsafe and unreliable transportation systems from being put into public service, the Agency has explicitly addressed the question of how safety can be assured for new technology for which "(no) reference system or code of practice (exists)." This issue is certainly relevant for current-generation ATN technology, which has very little in the way of a long-term operational track record.

The strategy used by the Agency in such a situation is to require an applicant for certification to a) demonstrate a thorough understanding of the range of safety risks posed by the new system, b) generate a risk reduction strategy for each identified concern, and c) verify the reduction of risks per "a structured and documented development procedure," which in turn is based on recognized risk management process standards such as IEC 61508[1] or EN 50126 / IEC 62278.[2] The Agency emphasizes the importance of its continuing involvement in the project from inception through approval for service operations.

The methodology specified in these standards provides for quantification of safety per risk levels experienced in comparable systems. The analysis is required to specifically address both random (spurious) and systematic (repeatable) failure events in terms of likelihood and consequences, such that a numeric value of expected casualties can be objectively computed and compared with an acceptable hazard threshold for a particular application, per its "Safety Integrity Level" (level of criticality).

The overall approach for a given application involves generation of a "Safety Case" by the system supplier. The Safety Case is a document which describes the safety management, quality management and technical safety plans and procedures for the system. The Safety Case document is assessed and approved by an Independent Safety Authority assigned for the project, and its prescribed verification activities are subsequently conducted under the ISA's review authority as the implementation progresses.

This process involves extensive definition of safety management plans, hazard identification and risk assessments, Failure Modes, Effects and Criticality Analysis (FMECA) exercises, and Fault Tree generation and analysis. These activities are integrated into the complete Safety Case document pertaining to physical test facilities and, to the greatest extent possible, anticipated general applications. The ACSE APM Standards serve as overarching guidance in system design and operational practice to assure wide acceptability in a variety of applications.

Via a methodology analogous to that previously described for that in the U.K., detailed safety analyses also feed into a QRA. The QRA, in turn, provides a computed passenger safety risk level (expressed in expected fatalities per billion passenger-kilometers). The result of this analysis, when validated by the ISA, forms the baseline against which actual system performance criteria are then

[1] IEC 61508 is an international standard of the International Electrotechnical Commission defining application-independent requirements, methods, tools and techniques for development of safety-critical systems.
[2] EN 50126 and IEC 62278, "Railway Applications - Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)," is a widely-adopted standard within the EU for guidance on public transit system safety analysis and verification.

verified by tests, demonstrations and additional analyses as appropriate. Successful completion of the end-to-end safety requirement compliance process then allows the Swedish Rail Agency to issue a provisional certification for operation of the new-technology system.

Masdar City, Abu Dhabi, U.A.E. The Abu Dhabi Department of Transportation has certified initial operations of a simple ATN system based on a methodology similar in many respects to the prior examples. The approach initially takes into account applicable portions of key industry standards, including the ASCE APM standards and NFPA 130 fire safety code, for general guidance. For specific applications, a customized suite of operational scenarios are defined in order to represent "all the possible and likely interactions of the users and operators, which in turn form the top-level requirements … [for which] validation and verification are defined."

A quantitative expression of the application's safety level is developed from FMECA, Fault Tree and Event Tree analyses. The system's actual response to the safety case scenarios was then demonstrated via verification tests at progressive stages of implementation. The certification by the Abu Dhabi DOT was also supported by results of independent evaluations by an Independent Safety Assessor and an Independent Health Assessor.

CityMobil Project. Vendor-independent efforts to establish a standardized certification process have also been actively pursued in recent years, especially in Europe, and have actually served a role in guiding implementation-specific certification procedures such as those just described. CityMobil, a European research and demonstration project[3] devoted to promoting efficient automated transport systems for urban applications, has developed and presented a proposed European standard process for certification of automated transit systems. This effort was motivated in large part in response to the observation that while there has been extensive movement toward common European safety certifications for automotive products, the extent of commonality across Europe with respect to rail system safety is much more limited, and that a common process for certifying automated transport systems was essentially lacking altogether.

In the proposed procedure, a specific safety level of 3 fatalities per billion passenger-kilometers (twice as stringent as for regular auto traffic) was set as the baseline target. It is then undertaken to conduct a detailed system safety analysis, in accordance with industry-accepted risk management and failure analysis processes, to provide a quantitative determination of the system's expected safety level.

This analysis is then utilized to guide the development of test cases to ensure that the functional specifications upon which the safety analyses are based are appropriately verified. Finally, technical tests, demonstrations and independent analyses are prescribed and conducted to validate the overall safety model. This overall process is keyed to existing European and international standards for risk management and safety analysis to the extent practical.

Discussions have ensued regarding the emphasis in the CityMobil procedure on hardware reliability (the dominant factor in standard automotive technology), whereas ATNs are much more heavily dependent on the operation of complex real time software in myriad real-world situations. However, in response it has also been pointed out that among the problems originally identified as key challenges in tackling this issue were increasing levels of intelligence and complexity in transport systems, and the inability of traditional methods of test and certification to address this trend.

[3] CityMobil is conducted and co-sponsored as part of the European Commission Sixth Framework Programme for Research and Technology Development.

In any case, continuing efforts are being made toward a normalized European safety certification process for this category of advanced transport systems. The extent to which regulatory authorities in individual European nations will adopt the resulting recommendations is not fully known at present.

MODURBAN. The Modular Urban Guided Rail Systems project was a €20 million, 51-month effort devoted to issues of achieving common operational procedures and technical architectures in urban guided transit systems. The effort, begun in January 2005, involved 39 partners from government and industry with a common concern about the inefficiencies and costs of incompatible rail system designs and standards. Six subprojects were defined to look in depth at specific interoperability objectives and technical issues:

- Onboard Intelligent Interfaces (MODONBOARD)
- Wayside Intelligent Interfaces (MODWAYSIDE)
- Communication Systems (MODCOMM)
- Passenger Access (MODACCESS)
- Energy-Related Aspects (MODENERGY)
- System Engineering and Risk Assessment (MODSYSTEM)

While much of the MODURBAN activity was focused on streamlined procurement, operational efficiency and increased interoperability of urban rail systems, a significant degree of attention was given to safety and regulatory compliance as well. This aspect was motivated in part by the belief that common functional requirements, system interfaces, and verification standards contribute to the reduction of risk in introducing new technologies. In particular, "standardized safety certification through risk analysis, safety planning and hazard logs" was promoted as a means not only to enhance operational safety, but also to reduce programmatic costs and risks.

Of the dozens of MODURBAN project deliverables[4] that have been published as public documents, three are especially relevant to the question of system safety certification:

- "Safety Conceptual Approach for Function and Technical Prescriptions," WP23-D86, provides a detailed description and comparison of existing safety and risk management standards and methodologies. It outlines the current practices used by individual countries, notes commonalities and differences among them, and proposes a unified standard safety evaluation process incorporating both qualitative and quantitative hazard identification/risk analysis methods.

- "Conformity Assessment, Guidelines for Functional and Technical Specifications," WP23-D93, identifies a key barrier to widespread adoption of advanced transit technologies in Europe: the lack of standardized procedures for certifying urban guided transport between and even within individual countries. An overview of the existing EU directives regulations, and certification processes in current use is provided, along with the underlying European standards and policies for transit safety. Finally, common elements of the diverse processes are pulled together into a proposed integrated scheme.

[4] Public documents generated as part of the project are freely downloadable at www.modurban.org.

- "Preliminary Safety Plan," WP23-D126, provides a roadmap for integration of safety-related capabilities across the end-to-end life cycle of a transit system. It offers a model description of the necessary roles and responsibilities, applicable safety principles and standards, system safety requirements, conduct of evaluation methodologies, certification and approval procedures, and system demonstration and acceptance criteria.

These and other outputs of the MODURBAN effort provide a solid foundation for further integration of a unified regulatory process for advanced transit applications. Specific efforts along this line, such as the MODSAFE project described below, are currently in progress under European Commission leadership.

MODSAFE. The Modular Urban Transport Safety and Security Analysis (MODSAFE) project was initiated in early 2009 as a follow up to portions of the MODURBAN activity. Like MODURBAN, MODSAFE is being conducted as a cooperative consortium of industrial concerns, research organizations, rail system operators in coordination with the European Commission.[5]

The fundamental precept of MODSAFE is to address the "diversified landscape of safety requirements, safety models, roles and responsibilities, schemes for safety approval, acceptance and certification" of light rail, metro, tram and related transit systems.

[5] MODSAFE Project is formally part of the Seventh Framework Programme of research and development, sponsored by the European Commission.