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The Spartan Superway: A Solar-Powered Automated Transportation Network

Burford J. Furman[1]

[1] San José State University, Department of Mechanical Engineering, San José (USA)

Abstract

Since 2012, more than 200 undergraduate and graduate students, mostly from San José State University, but including other domestic and international institutions, have been driving innovation in the development of solar-powered automated transit networks (ATNs) through the Spartan Superway project.

Functional models at full and partial scales of a solar-powered, suspended-vehicle ATN have been constructed and demonstrated in public exhibitions.

Research and development continues toward developing a fully-operational test track as well as planning for implementation in the Silicon Valley.

Keywords: *Automated Transit Networks (ATN), pod cars, solar PV, sustainable transportation, engineering education*

1. Introduction

In 2012, the confluence of a new effort in the Department of Mechanical Engineering at San José State University to address sustainable mobility and a search for an interdisciplinary senior project led to the formation of a team of engineers, business, and urban planning students focused on designing a solar powered automated transit system for the Solar Skyways Challenge (Solar Skyways Challenge, 2010). The Challenge offered a $10k prize for multidisciplinary teams to design, build and improve solar-powered, personalized, Automated Transit Networks (ATN's) and their vehicles (podcars). The students named their effort the 'Spartan Superway', which combines the name of the mascot for SJSU and the elevated, superior features of a new form of sustainable transportation. The project has continued beyond the competition, and the subsequent four and a half years have garnered increasing student interest and involvement as well as international attention. Significant progress has been made toward realizing the goal put forth in the Challenge.

The sections below will describe the features of the Superway system, progress to date, and reflections on involving students in its development.

2. Automated Transit Networks

The concepts embodied in ATN or podcars are not new, but it has only been relatively recently that new design approaches using solar PV for powering the system have been introduced, such as shown in Figure 1 (James, 2004). Donn Fichter, while a transportation graduate student, described the basic ideas of ATN in 1953 and in 1964 published his ideas for a complete automated transportation system integrated into a city (Fichter, 1964, 1968, 1974).

Figure 1: Solar Powered Automated Transit (ATN). Relatively small vehicles traverse a network of exclusive guideways and utilize off-line stations to provide on-demand, non-stop, origin-to-destination mobility. Suspending the ATN vehicle below the guideway makes the upper surface available for PV panels that can power the system. (Jpods system, from (Wilmott, 2015)).

The Advanced Transit Association (ATRA) has provided a widely accepted description of the basic concepts of ATN (ATRA, 2003):

1. Direct origin-to-destination service with no need to transfer or stop at intermediate stations
2. Small vehicles available for the exclusive use of an individual or small group traveling together by choice
3. Service available on demand by the user rather than on fixed schedules
4. Fully automated vehicles (no human drivers) that can be available for use 24 hours a day, seven days a week
5. Vehicles captive to a guideway that is reserved for their exclusive use
6. Small (narrow and light relative to LRT and BRT) guideways usually elevated but also at or near ground level or underground
7. Vehicles able to use all guideways and stations on a fully connected network

Items 1, 5, and 7 deserve additional emphasis. In most depictions (and implementations) of ATN, the guideways are elevated above grade as shown in Figure 1. This is extremely important in that vertical space, as opposed to additional horizontal space, can be utilized to situate an entirely new form of transit in an urban setting without needing additional land. The use of elevated guideways has an important advantage over the current transit paradigm in that transit machines are separated from humans that are not using them, i.e. pedestrians, bicyclists, etc. This results in vastly improved safety and quality of life for urban dwellers. And in contrast to other forms of rail-based transit, ATN uses a network of guideways with off-line stations as opposed to a line corridor where stations are on the line and trains make multiple starts and stops between origins and destinations (see Figure 2). With a network, trips can be diffused throughout an urban area instead of needing to congregate travelers at stations along a single corridor, which adds the need for parking at the station and leads to congestion. With off-line stations, vehicles stop only at origin and destination stations, which leads to savings in energy usage and improved throughput.

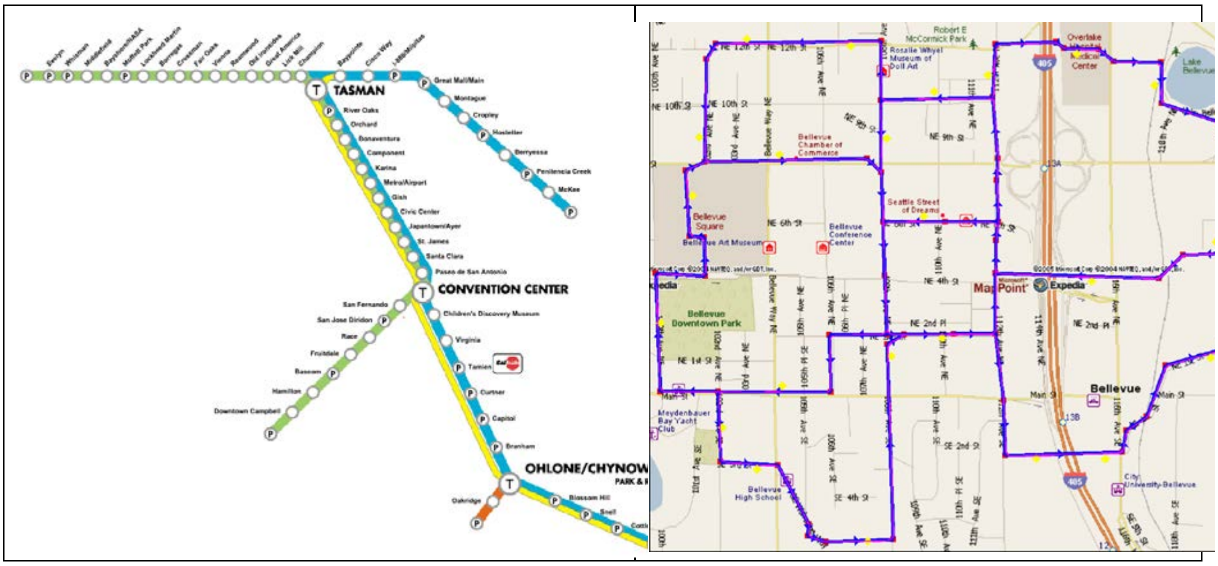

Figure 2: Line haul vs. ATN transit. Conventional rail-based systems have stops arranged along corridors, which requires travelers to get to the corridor to initiate a trip. ATN uses a network and can diffuse travel throughout an area. (Light rail map from http://www.vta.org/getting-around/interactive-light-rail-map and ATN network from (Schneider and Raney, 2005)

There are about five systems throughout the world that qualify as ATNs (Furman, et. al., 2014):

- The Morgantown PRT at West Virginia University (1975)
- The Parkshuttle Rivium metro-feeder outside Rotterdam (1999)
- The Masdar City PRT in Abu Dhabi (2010)
- The Terminal 5 shuttle at London Heathrow Airport (2011)
- The nature park shuttle in Suncheon Bay, South Korea (2014)

(The dates in parenthesis indicate when the systems began carrying passengers.)

Despite the fact that the concept of ATN has been around for more than 50 years and that several systems are in operation, there is only what can be described as a 'proto-market' for such systems and a relatively small number of suppliers who are capable of delivering a modest system of somewhere between 5 to 20 stations within two to three years from the start of construction (Furman, et. al., 2014). There are a variety of reasons for the current 'stalemate', one of which pertains to the state of design of ATN systems. One can liken the situation to the state of wireless communication before the iPhone – a compelling design case has yet to emerge that will spark widespread adoption of ATN and lead to sustainable urban transportation. The Spartan Superway is a more compelling design case for sustainable transportation and is progressing by engaging students to lead the way.

3. Features of the Spartan Superway

The Superway system features vehicles suspended from a relatively slim guideway, which will carry approximately four to six passengers. The suspended approach , in contrast to the more common supported approach (where vehicles ride like a car in a single lane with lateral curbs) is superior from a design standpoint in many aspects, however it is more difficult to implement (see Figure 3). For example, suspending the vehicle from the guideway enables the bogie (the propulsive assembly that rides along the guideway and connects to the vehicle) to be enclosed by the guideway and therefore be protected from accumulating debris, snow, or ice. Dynamically, the ability of a suspended vehicle to swing outward like a pendulum when traversing a curve means that passengers will experience greater ride comfort than would be experience in a supported vehicle where corning results in the passenger being pressed against the side of the vehicle. As mentioned earlier, by suspending the vehicle below the guideway, the surface above the guideway is available for mounting PV panels. The guideway and bogie designs for Superway follow the lead of Bengt Gustafsson, CEO of Beamways, A.B., a Swedish ATN developer. Bengt patented an idea for the track and bogie that elegantly solves problems that are inherent in other suspended design approaches and leads to a guideway that is smaller in cross section, lighter, and consequently less costly (Gustafsson, 2014).

Figure 3: Supported vs. Suspended ATN vehicles. The Morgantown PRT on the left is a 'supported' system, where vehicles ride on top of the guideway and are supported by it. The Beamways system on the right depicts a suspended system where the vehicle hangs beneath the guideway. (Morgantown photo from http://www.progressiveengineer.com/PEWebBackissues2002/PEWeb%2024%20Mar%2002-2/24photos/PRT1.jpg. Suspended vehicle rendering from Beamways, http://www.beamways.com/wp-content/uploads/beamways_system_en.pdf)

Figure 4 shows prototype demonstration models of the Superway bogie and guideway. A common feature in all ATN vehicles (whether supported or suspended) is that the steering mechanics are part of the bogie/vehicle and the guideways have no moving elements. This is in contrast to common rail transit and monorails where switching from one track to another is accomplished by movement of a track element. ATN vehicles can thus accomplish a switching maneuver more rapidly than common rail vehicles, and can therefore operate at shorter 'headways' (vehicle separations), which improves vehicle throughput.

Figure. 4: Full-scale demonstration models of the Superway guideway and bogie. The photo on the left (from Maker Faire 2014) shows the bogie supporting a mock (not full-scale) vehicle on a short length of straight guideway. The photo on the right shows the bogie and steering mechanisms on a section of guideway that includes a 'Y' switching section. The model on the right, from the exhibit shown at Maker Faire in 2015, demonstrated the steering mechanism and the ability for the bogie to navigate both directions of the 'Y'.

Solar PV mounted on the guideway and tied to the utility electrical power grid makes it feasible to collect all the energy needed to power the system for 24/7 operation. For example, students from Uppsala University studied the feasibility of solar-powered ATN for a 3.8 km network having 10 stations in the city of Uppsala, Sweden. They found that even at that relatively northern latitude (60° ≡ Anchorage Alaska!) a 2420 kWp system consisting of 17,384 m^2 of PV approximately 7 m wide would be sufficient to provide all the power needed by the system over a year. Preliminary results from our research on a proposed 14 km guideway network in San José shows that a monocrystalline PV canopy approximately two to three meters wide above the guideway would be sufficient to provide net-zero metered 24/7 operation averaged over the year (conservatively) for 1,440 passengers per hour (assuming 2 passengers per vehicle and 5 second headway between vehicles). Figure 5 shows the proposed network. Details of the analysis are given in Branco, et. al., 2016.

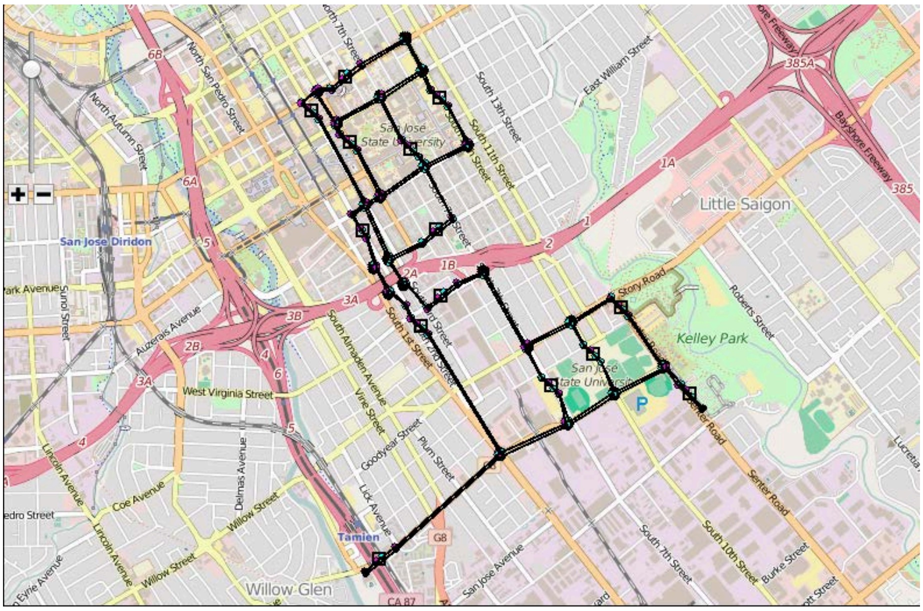

Figure. 5: Proposed guideway placement for the Superway in San José. The layout of guideways and stations connects the south and north parts of San José State University and the Tamien Caltrain/Light Rail stations. The total length of the guideway is about 14 km. A canopy of monocrystalline PV approximately two to three meters wide above the guideway would be sufficient to power the system. (Route map made using RouteTime software from Jpods (http://www.jpods.com/tools)

The vehicles in the Superway will pick up power from wayside power rails mounted within the guideway and will only carry relatively small batteries for emergency needs.

4. Progress in Development

The following provides a summary of the development of the Spartan Superway since 2012.

<u>2012-2013</u>

In this inaugural year, the team consisted of 11 mechanical, 4 computer, 3 business, and 1 urban planning student (See Figure 6). In addition to winning First Place in the Solar Skyways Challenge prize for its entry, the team designed and fabricated a 1/12 scale model test track, control system, and articulated transit supportive land use metrics and land use entitlements process for implementing ATN. More information on the development from this year can be found in Kipping (2013).

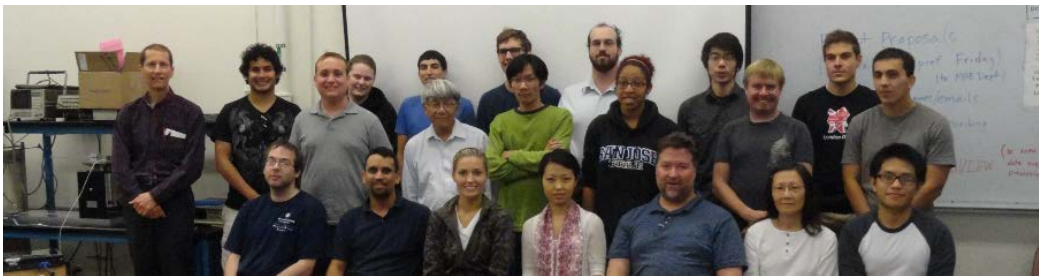

Figure. 6: Year 1 (2012-2013) team.

<u>2013-2014</u>

The team expanded to 15 mechanical, three electrical, two civil, two urban planning, and also several dozen industrial design students through the DSID 125 and DSID 131 classes (See Figure 7). The engineers designed and constructed a 4.9 m section of guideway at full scale with a movable bogie (See Figure 4, left side) and improved the 1/12 scale model with more reliable and more sophisticated vehicles. The guideway, bogie, and 1/12th scale model were demonstrated at Maker Faire Bay Area 2014 and InterSolar 2014. The industrial design students in DSID 125 made full scale mockups to explore what a transit vehicle and ATN station *could* look like, and those in DSID 131 researched use cases and designed smart phone user interfaces (UIs) for transit users. More information on the development from this year can be found in Cowley, et. al., (2014).

Figure. 7: Year 2 (2013-2014) (mechanical) team.

2014-2015

The team continued to expand this year with 26 mechanical, two computer, and one civil engineering student(s) (See Figure 8). Notable accomplishments this year included a full-scale guideway with an operational switch and motorized bogie, which was able to autonomously demonstrate the switching action of the bogie between two guideway paths; a new 1/12th scale model that more closely matched the guideway and bogie of the full-scale than the previous year's design; and a full-scale mockup of a cabin (lower-half); and revised solar PV on the full-scale guideway. The models were shown at the Maker Faire Bay Area 2015 and the S.T.E.A.M. Fest 2015 (1/12 scale only) in San José. In the summer of 2015, our summer intern program expanded greatly with seven students from Brazil, four from Sweden, six from South Korea, two from France, and six from the U.S. (See Figure 9). More information on the development from this year can be found in Ornellas, et. al., (2015).

Figure. 8: Year 3 (2014-2015) (mechanical) team.

Figure. 9: Superway Summer 2015. Students from the U.S., South Korea, France, Brazil, and Sweden participated.

2015-2016

This past year saw the largest team so far with 42 mechanical, three electrical, two MS mechanical, and two MS software engineers (See Figure 10). Nine sub-teams completed: a 1/2-scale guideway and bogie; significant expansion and improvement of the 1/12 scale model and vehicles; a 1/2-scale cabin model and small scale cabin interior model; and made a start at validating finite element analysis of the guideway with physical torsion testing. The two MS software engineers worked on a functional user interface for a smart phone app for a user to schedule and pay for a trip on Superway. The 1/2-scale model was notable in that it demonstrated a switch and had a section of guideway that would enable the vehicle to come down to ground-level by traversing guideway slopes of 17°. The 1/2-scale cabin was suspended from the bogie with an active suspension, which was designed by one of the sub-teams. More information on the development from this year can be found in Alvarez et. al., (2016).

Figure. 10: Year 4 team (2015-2016) (mechanical and electrical teams).

Summer 2016

This summer we have about 30 interns from Brazil, France, South Korea, and SJSU working on improvements to the bogie from Year 4; site planning for a full-speed test track; route planning for actual implementations of Superway at the south campus of SJSU and network routes that would connect the north and south campuses; and PV sizing analysis for the test track and north-south networks (See Figure 11). Also, related work is being done under the umbrella of the SJSU Center for Service Systems Engineering

(CSSEI) to investigate the impact Superway could have on reducing automobile trips in Silicon Valley. More information on CSSE is available at: http://cssei.com/

Figure. 11: Summer 2016 intern team (partial).

5. The Superway as a Student Project

Students have a unique and effective role to play in bringing solar-powered automated transit into widespread use. As mentioned earlier, the Superway project has continued for the last four and a half years as an interdisciplinary senior project. There have also been a handful of graduate students who have done their MS project/thesis on topics that have advanced Superway technology, and we have run a summer research internship program since 2014 with international and domestic students. Some things we have observed over the years in working with students:

- Students resonate with the goals of solar-powered ATN and its interdisciplinary nature

Students understand the mess we are in when it comes to transportation issues, climate change, and environmental impacts, and they are motivated to do something to solve the problems. They also enjoy working with and learning from peers in other disciplines as these bring different perspectives and different skills to the party.

- Students bring a fresh perspective to solving problems

Lacking prior experience means that students can bring fresh, unencumbered thinking to solving technical problems. One phrase we often repeat in describing the work we are doing with students on Superway is that we are ‘raising the bar’, which means that if a group of inexperienced students can demonstrate that something can be done, then certainly more experienced professionals or commercial enterprises will need to step up their game and deliver ATN technology that can at least perform as well.

- Students respond to specific challenges

For the past three years we have set the goal for the students to display their work at Maker Faire Bay Area, a weekend festival that celebrates arts, crafts, engineering, science projects, and the Do-It-Yourself (DIY) mindset. More than 50,000 people attend Maker Faire, so the students are motivated by a deadline and to get their design in good shape to show to the public.

- Students can accomplish a lot with a little

On the one hand, having very modest resources is limiting in terms of what can be designed, purchased, and fabricated, however, on the other hand, it provides opportunity to develop resourceful and creative thinking to “do more with less” as the great technology visionary Buckminster Fuller admonished. Having limited resources also provides students the opportunity to learn how to go about finding the resources they need, which is a valuable skill in itself.

- International and summer interns can be very effective

During the regular school terms, the students working on Superway do so as part of a regular, two-semester, three-unit course. Most SJSU students work part-time in addition to going to school full-time, so they have limited time to put toward the project, perhaps 10 hrs/week at best. During the summer, however, through our intern program, participants spend more like 20 – 30 hrs/week, and their work output is much greater. For the last three summers we have had interns from Brazil (through the Brazil Scientific Mobility Program (BSMP)), Sweden, South Korea, and France.

- ATN development can and should engage disciplines outside of engineering

Creating a new paradigm of truly sustainable is not just a task for engineers! Urban planners, business, industrial designers, architects, economists, and many other disciplines are needed to fully realize the goal of solar powered ATN. There is currently a lot of emphasis in academia on providing students with interdisciplinary projects. ATN development is a great way to meet this need.

There are challenges, however, when working with student, and we continue to look for approaches to overcome them. For example:

- It’s hard to maintain continuity from year to year with 100% turnover

One of the most difficult aspects of working with students is that we only have them for a limited time. Every academic year we start with a new group that has only limited, informal connection to the group who came before. Much time is spent at the outset of the year getting the new students ‘up to speed’ and helping them set up organizational and managerial structures under which to carry out their work.

- There is a significant learning curve at the start of the term

Going along with the previous challenge, we find that it takes quite a bit of time at the beginning of the term to get the students oriented to ATN and cognizant of the work of prior teams

- Our teams are composed of students with a range of abilities and work ethics

Unlike a company, which has the luxury to hire employees on the basis of their skills and experience for a specific position, we have little leverage to exclude students who have interest, but may lack the skills and experience that would enable them to be effective early on. Consequently, we usually field a team with a wide range of abilities and work ethics. It is hard to discern at the outset who will be the key contributors, the average, or the slackers, and this causes variability in the quality of the outcome from year to year.

- Knowledge capture, transfer, and progress tracking are tricky

We are making more use of cloud storage, such as Google Drive, to capture and make available knowledge generated by the teams. One rather new practice we’ve employed is the use of team and individual blogs (See: http://spartansuperway.blogspot.com/ and links to student blogs). This has helped us capture knowledge and check on progress of both individuals and sub-teams, which is a challenge when the full team is relatively large. When asked about what would have improved the outcome of the project at the end of the term, we often hear, ‘communication’, from the students. There are significant interdependencies in a project like Superway, and it is hard to coordinate these without a full-time project manager.

6. Conclusions

The Spartan Superway is leading the way toward a new paradigm of urban transportation that is truly sustainable, because it is based on solar power. Students are leading the charge to show what can be done in this regard. Currently, fossil fuel based vehicles all compete for the same constrained space at grade, crash into each other and into people. The current transit paradigm is tired and in need of radical, not incremental, improvement. The Superway is that improvement. It is now time for institutions and individuals who are really serious about sustainability, climate change, breaking our addiction to petroleum, and improving the quality of life in urban areas to step up and support this work.

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