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Abstract: Eco-friendly vehicles are being developed to reduce carbon emissions and address global warming. The solar powered automated rapid transit ascendant network (SPARTAN) Superway project at San José State

University focuses on an automated transit network (ATN) powered by solar energy. ATN vehicles, with a unique cabin-below-track configuration and distinct steering system, face dynamic challenges, particularly at Y-junctions and curved guideways. This study employs multi-body dynamic simulation to analyse the behaviour of a prototype ATN vehicle under these conditions. Significant lateral forces and reaction spikes at Y-junctions were identified as risks to stability and passenger safety. A design improvement adding a rear bogie steering mechanism is proposed, effectively mitigating impact loads and stabilising lateral accelerations. Consequently, this study underscores the need for tailored dynamic analyses for structurally unique systems like ATN vehicles, ensuring safety, improving reliability, and advancing sustainable urban transit networks.

Keywords: ATN; automated transit network; curved guideway; multi-body dynamics simulation; vehicle dynamics; Y-junction.

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Andries Louw is Founder and Director of Futran System Group of Companies. Futran System develops and implements low-cost, automated public transportation solutions using elevated tracks and automated pods, enhancing efficiency, safety, and convenience in urban areas, especially in developing regions.

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1 Introduction

To prevent the acceleration of global warming around the world, research on alternative energy and renewable energy is being conducted to reduce carbon emissions. Accordingly, academic and technical research on eco-friendly vehicles is also being actively pursued. For example, eco-friendly vehicles such as electric vehicles and hybrid vehicles are being developed to reduce carbon emissions, and autonomous vehicles that provide convenience to drivers and passengers are being studied. As such, future vehicles are becoming eco-friendly, convenient for passengers, and fully automated.

Solar powered automated rapid transit ascendant network (SPARTAN) Superway is a research project of San Jose State University that is developing a transportation system with significant advantages over current transportation methods. The project involves the platform, track, and vehicle design for the establishment of an automated transit network (ATN). Vehicles designed for such systems operate as traffic systems above the road. For example, San Jose State University has developed vehicles to build ATN systems, as shown in Figure 1 (https://www.sjsu.edu/smssv/; Furman, 2016; Furman et al., 2014).

Figure 1 A prototype of ATN vehicle developed in SPARTAN Superway Project (see online version for colours)

As shown in Figure 1, the ATN vehicle exhibits unique characteristics compared to general vehicles, with the cabin and bogie positioned at the bottom and top of the track, respectively. Changes in the vehicle structure also induce changes in dynamic characteristics, necessitating specific studies. The ATN vehicle poses potential safety risks due to its unusual dynamic characteristics. For instance, at Y-junctions, the vehicle is guided by steering wheels in contact with the upper track, which determines the guideway. Unlike conventional vehicles, this unique steering and guiding system may introduce safety concerns. Conducting real-world driving experiments to evaluate safety performance can be hazardous and costly in terms of time and resources. Therefore, it is essential to simulate the vehicle's behaviour in a virtual environment to analyse its dynamic characteristics while ensuring safety and cost efficiency.

This study employs multi-body dynamic simulation to analyse the dynamic behaviour of ATN vehicles. Similar studies have focused on modelling and validating various vehicles and components using multi-body dynamics. For example, Maciel and Barbosa introduced a method for modelling a straddle-type monorail vehicle, highlighting the influence of tyre models on vehicle dynamics (Maciel and Barbosa, 2016). Another study utilised multi-body dynamics software to analyse the ride comfort of a vehicle (Padhi et al., 2022). Andrea et al. modelled and validated a tracked robot through multi-body dynamics simulations (Grazioso et al., 2023). These studies provided methodologies for accurately modelling ATN vehicles in multi-body dynamic simulations.

Despite these advancements, there remains a gap in the analysis of ATN vehicles, particularly those with SPARTAN's unique structure, when navigating curved guideways and Y-junctions. As a similar research case, Pombo et al. analysed the wear characteristics of wheels based on the dynamic simulation analysis of trains in 2010 (Pombo et al., 2010), and Cai et al. analysed the dynamics of suspension-type monorails (Cai et al., 2019). Schindler et al. described and analysed the dynamic behaviour of a vibration tamper by multi-body dynamics (Schindler et al., 2012). Other studies had research on handling characteristics of a SAE race car, virtual dynamic analysis on dump truck (Balena et al., 2021; Li and Frimpong, 2008). Martinod et al. studied the dynamic characteristic of car body-bogie coupling system when it is under curve driving conditions (Martinod et al., 2014). As such, as an existing research case, it has been conducted based on multi-body dynamics analysis for the analysis of dynamic behaviour of the vehicle and safety performance such as overturning for vehicles such as trains and monorails (Fan et al., 2018; Kozłowski et al., 2015; Lee et al., 2005; Shabana et al., 2007; Xin et al., 2021; Wickens, 1976; Cai et al., 2012; Park et al., 2022; Han and Kim, 2016).

Unlike the vehicles covered in the above research cases, SPARTAN Superway vehicles have a cabin positioned below the track and are designed to operate autonomously without a driver. This unique configuration necessitates accurate dynamic characteristic analysis to ensure the safety of passengers and cargo. As shown in Figure 1, in ATN vehicles, the bogie is located at the bottom of the track. Safety concerns such as the risk of overturning and challenges at crossroads, particularly at Y-junctions where driving routes are converted, must be carefully considered. However, existing studies on the dynamic characteristics of such systems remain insufficient. The studies usually target on the common vehicles or monorail systems that the bogie is located on the same side of the car body.

This study aims to address the gap of existing studies by analysing the dynamic characteristics of ATN vehicles, which are being designed and developed as a representative example of eco-friendly transportation. A multi-body dynamic simulation program, ANSYS Motion 2022 R2, was employed to evaluate the unique structural influences on the dynamic behaviour of ATN vehicles. In particular, the study focuses on identifying and addressing vulnerabilities in the vehicle's performance on curves and at Y-junctions, providing insights into areas where these vehicles differ from conventional systems. Through this analysis, the study not only highlights critical safety considerations but also proposes potential improvements to enhance the stability and safety of ATN vehicles. Also, this study emphasises the necessity of safety analysis for ATN vehicle systems, which have not been thoroughly examined in previous research, using multi-body dynamic simulation in a virtual environment. It highlights that such analysis can be effectively conducted in a virtual setting, minimising real-world risks and costs.

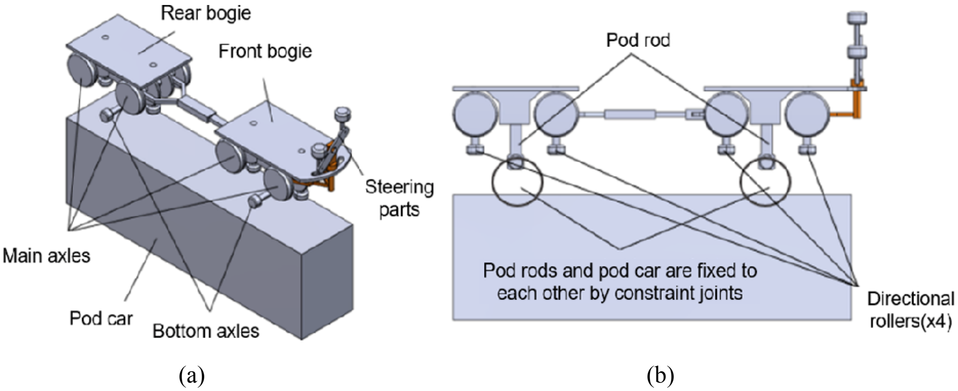
2 Design of ATN vehicle and theoretical approach

2.1 Background of design of ATN vehicle

As an example of an ATN system vehicle, the SPARTAN Superway vehicle, currently under development, is being designed in collaboration with other entities. Similarly, the initial design of the Futran bogie was developed in cooperation with Futran System, which specialises in ATN systems. To evaluate the dynamic characteristics of the vehicle, multi-body simulation analysis was employed.

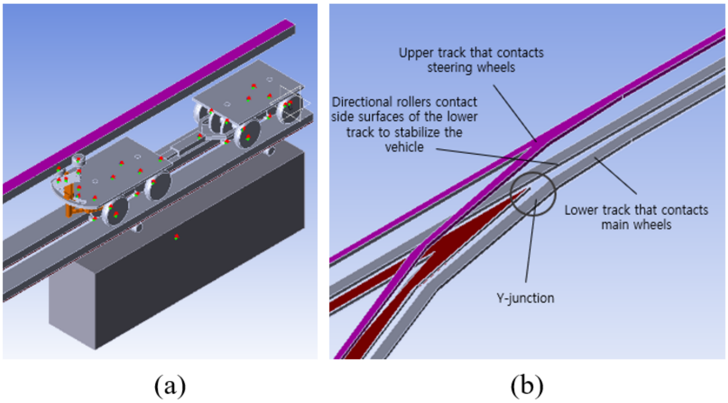
Figure 2 illustrates the 3D model of the ATN vehicle conceptualised by Futran System, where Figure 2(a) presents the conformal view and Figure 2(b) shows the side profile. Figure 3 depicts the vehicle and track models used in the multi-body dynamics simulation. Figure 3(a) shows the vehicle on a straight track, while Figure 3(b) illustrates the track at a Y-junction. The ATN vehicle features a bogie positioned at the top of the track and a passenger compartment suspended below it. A steering mechanism located at the top of the bogie is used to set the driving path by the contact of the wheels, as shown in Figure 3. Additionally, a directional roller is installed to prevent the vehicle from deviating laterally from the track.

Figure 2 3D model of ATN vehicle concepted by Futran system (see online version for colours)



(a) (b)

Figure 3 Simulation model: (a) Futran Bogie and (b) guideway with Y-junction (see online version for colours)

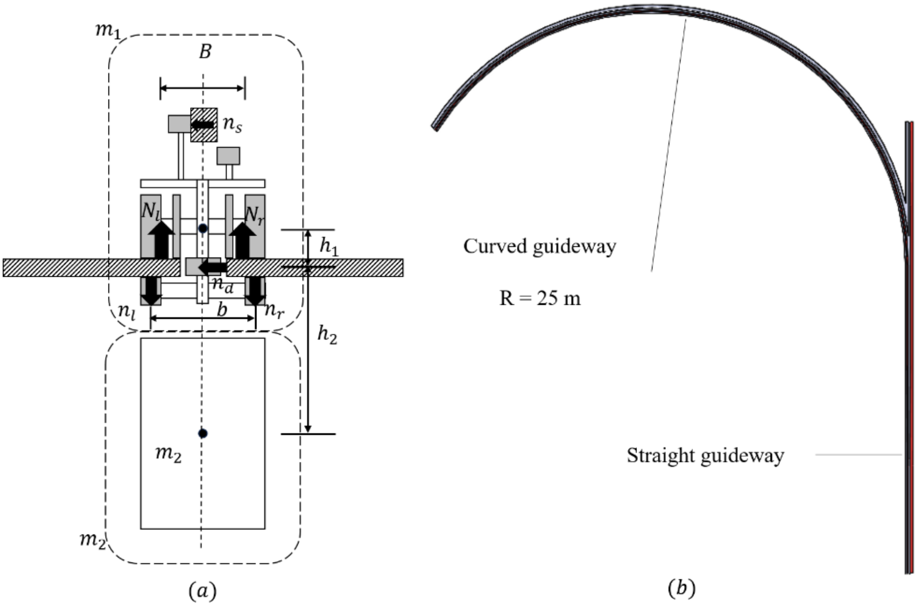


(a) (b)

2.2 Theoretical dynamic property of ATN vehicle

The most important factors analysed in this study are the transverse motion and dynamic behaviour of ATN vehicles at Y-junctions during curved track driving. Figure 4 illustrates the 2D simplified structure of the ATN vehicle in the Futran system, where Figure 4(a) depicts the front view of the vehicle, and Figure 4(b) provides an example of the overall designed track.

Figure 4 2D model of Futran Bogie vehicle and track: (a) front view of the vehicle and (b) track model (see online version for colours)



Assuming that the track is parallel to the ground and neglecting changes in the vehicle's posture during curved driving and friction caused by slip, the vehicle's motion can be described using equations (1)–(3). Here, equation (1) represents the vertical force balance, equation (2) represents the horizontal force balance, and equation (3) describes the moment balance. It is also assumed that the vehicle moves on the left side of the guideway during turning.

$$N_l + N_r - n_l - n_r = \left(m_1 + m_2\right) g \tag{1}$$

$$\left(m_1 + m_2\right) a_x = \mu\left(N_l + N_r - n_l - n_r\right) - n_s - n_d \tag{2}$$

$$\left(m_1 h_1 - m_2 h_2\right) a_x = \frac{N_l - N_r}{2} B - \frac{n_l - n_r}{2} b - n_s h_s - n_d h_d \tag{3}$$

As described above, unlike conventional vehicles, the direction of the moment generated by the cabin in ATN vehicles is reversed due to the positional difference between the cabin and the bogie (the bogies are located above the guideway, while the cabin is suspended below it).

When the bogie passes through a Y-junction, some contact motion is absent on the wheels inside the Y-junction, as shown in Figure 3(b). Consequently, the equilibrium equation for three degrees of freedom contains four or more unknowns, making it impossible to derive an exact solution. However, the dynamic characteristics of the ATN vehicle can be explained based on the equation as follows:

As the mass of the cabin and bogie increases, the vertical load on the vehicle increases proportionally. However, the impact on overturning varies due to the difference in moment direction. In a general vehicle, during a left turn (Figure 4), the entire mass of the vehicle is above the track, causing the reaction force on the left wheel to decrease, leading to overturning to the right according to D'Alembert's principle. In contrast, for ATN vehicles, while the bogie experiences a similar effect, the cabin generates a moment in the opposite direction, as shown in equation (3). If the moments from the cabin and bogie counterbalance each other, the lateral acceleration does not produce a net overturning moment, reducing the risk of overturning.

ATN vehicles are equipped with wheels at the bottom of the track to prevent structural rollover. If the vehicle tips to the right, the reaction force on the top-left wheel diminishes, while no reaction force is generated on the bottom-left wheel.

The actual lateral friction force generated by the wheels is caused by slip (Park et al., 2022; Han and Kim, 2016). In ATN vehicles, the slip angle remains constant because the structural steering mechanism determines the vehicle's driving direction during curved motion. According to studies such as Pacejka's Magic Formula, the lateral friction force increases with the reaction force on the wheels.

When the vehicle enters a Y-junction, some right wheels lose their reaction force, while the steering wheel comes into contact to determine the direction. In this case, lateral motion remains unchanged at constant driving speeds, as shown in equations (1)–(3). However, the lateral acceleration may vary due to the reaction forces exerted by the steering wheel and directional roller.

To validate these predicted dynamic characteristics, a multi-body dynamic simulation analysis was conducted. This analysis included creating detailed 3D models, defining constraints, and other necessary parameters (Pacejka and Bakker, 1992; Maclaurin, 2011).

3 Multi-body dynamics analysis

To analyse the Y-junction behaviour of the ATN vehicle, a simulation was conducted with the vehicle's mass defined as $m_1 = 614$ kg and $m_2 = 940$ kg as shown in Table 1. Since m_1 represents a smaller mass compared to m_2, it can be predicted, based on equation (3), that the vehicle will experience a tendency to roll over to the left during a left turn. This rollover effect increases the reaction force on the left wheel while decreasing the reaction force on the right wheel.

The ATN vehicle, as defined, was modelled in a multi-body dynamic simulation program and driven with the wheel speed as an input parameter. The simulation focused on analysing the dynamic characteristics of the vehicle in response to variations in speed and mass, which were identified as key parameters. For the simulation, a curved driving radius of 25 m was used as a defining condition. The vehicle and track model employed in the multi-body dynamic simulation are shown in Figure 3.

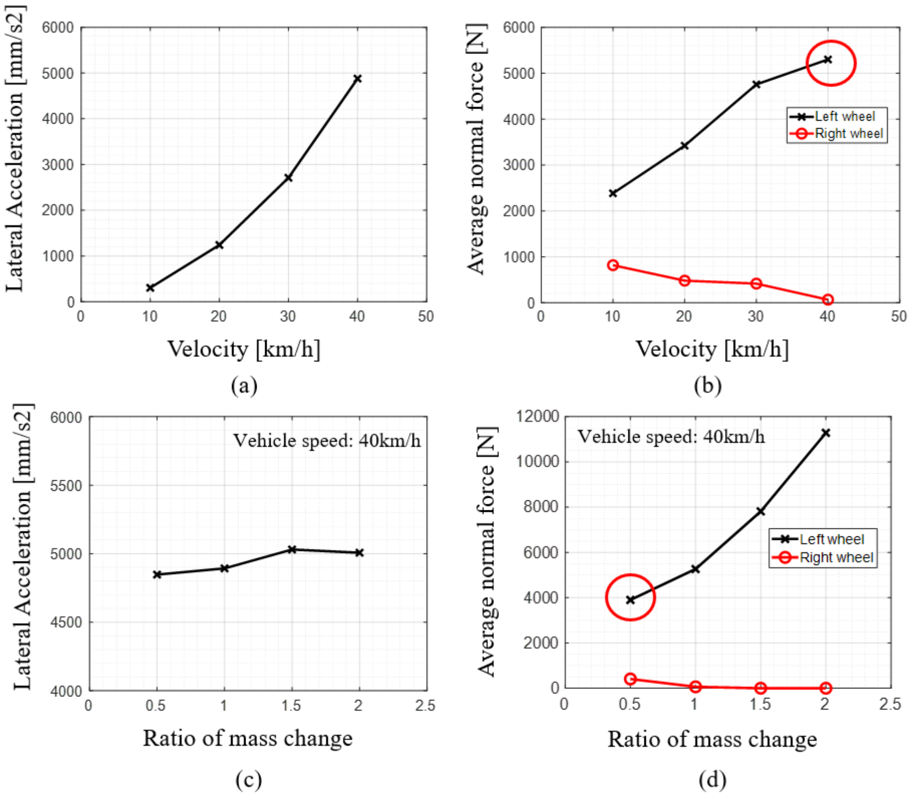
Table 1 Mass properties of the vehicle model

Part name	*Mass* (kg)
Front bogie	253
Rear bogie	130
Pod car	940
Main axles (front bogie)	80
Main axles (rear bogie)	60
Bottom axles	26
Steering parts	65

3.1 Simulation results with variation of vehicle speed and ratio of mass

Figure 5 illustrates the changes in lateral acceleration and wheel reaction force in response to variations in vehicle speed and cabin mass. The analysis results for speeds of 10, 20, 30, and 40 km/h are shown in Figure 5(a) and (b), while Figure 5(c) and (d) present the results when the cabin mass is varied at a constant driving speed of 40 km/h.

Figure 5 Simulation results: (a) lateral acceleration about variation of vehicle speed; (b) normal force on wheels about variation of vehicle speed; (c) lateral acceleration about variation of mass of cabin and (d) normal force on wheels about variation of mass of cabin (see online version for colours)



As shown in Figure 5, the reaction force of the left wheel increases with higher vehicle speeds. This is attributed to the increase in lateral acceleration, which generates a larger moment. When the cabin mass is greater than the bogie mass, the reaction force on the left wheel increases significantly, whereas the reaction force on the right wheel decreases. Furthermore, as the cabin mass increases, the reaction force on the left wheel also increases. Conversely, when the cabin mass is reduced at a constant driving speed of 40 km/h, the reaction force on the left wheel decreases.

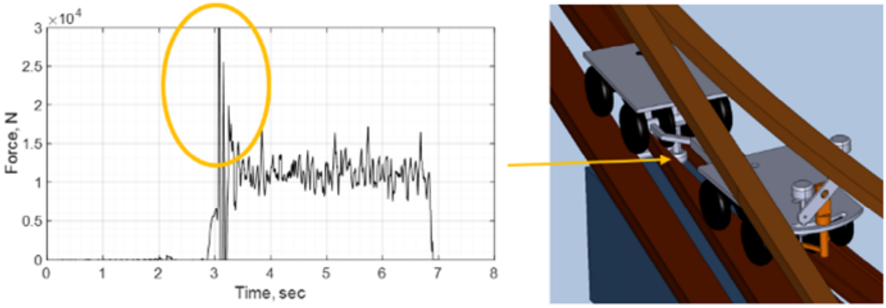
This phenomenon is caused by the opposing moment generated by the cabin, which is positioned below the track, unlike in a conventional vehicle. Additionally, when the inner wheels are assumed not to influence the vehicle's dynamic motion, the effect of the reaction forces on the outer wheels becomes more pronounced.

Therefore, when designing an ATN vehicle with a cabin located below the track, differences in wheel reaction forces may arise even at the same driving speed due to the positional difference between the bogie and the cabin. These differences must be carefully considered to ensure proper wheel contact conditions, lateral safety of the cabin, and to minimise wear and tear on the wheels, particularly at Y-junctions.

3.2 *Influence of Y-junction on ATN vehicle*

Figure 6 shows the change in the reaction force on the left wheel when the vehicle is travelling at a speed of 60 km/h. Figure 6(a) shows the reaction force graph for the left wheel, while Figure 6(b) depicts the vehicle's behaviour at the corresponding simulation time in Figure 6(a). As shown in Figure 6(a), a significant spike in the reaction force of the left wheel is observed near the point where the Y-junction begins. This corresponds to the vehicle's position shown in the simulation in Figure 6(b).

Figure 6 Simulation results about 60 km/h of vehicle speed: (a) normal forces on left wheels; (b) vehicle attitude at the indicated simulation time (see online version for colours)



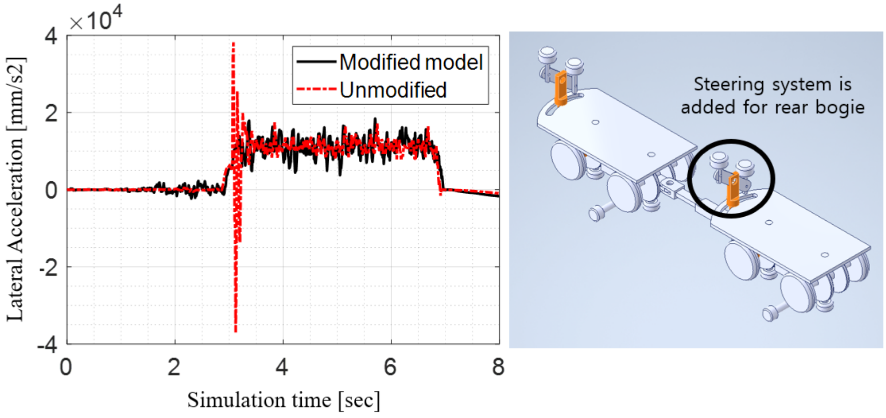
(a) (b)

When the vehicle exceeds a certain speed, a considerable difference occurs in the driving direction between the front and rear bogies. At this point, the directional roller, which is designed to provide lateral safety, is subjected to a substantial impact load from the side. This impact load generates a significant transverse force and moment, resulting in a large lateral acceleration, as described by equations (2) and (3). Such changes pose a considerable risk to the safety of the vehicle and its passengers and must be addressed through design improvements.

The primary cause of this behaviour is the unique steering system of ATN vehicles, where the front bogie's slip angle is controlled by the steering wheel, whereas the rear bogie is guided solely by traction force without any steering mechanism. This difference in steering functionality can lead to impact loads and dynamic instability, particularly at Y-junctions. Consequently, if two or more bogies are required to accommodate a larger cabin, it becomes essential to design a system that prevents structural impact loads. This can be achieved by incorporating a dedicated steering mechanism for each bogie.

Figure 7 shows the changes in lateral acceleration when a steering mechanism is added to the rear bogie. In this figure, Figure 7(a) compares the lateral acceleration before and after the modification, while Figure 7(b) shows the improved model. As shown in Figure 7, the installation of a separate steering mechanism in the rear bogie allows the slip direction of the bogie to align with the curved driving path. This adjustment eliminates the impact load at the Y-junction, significantly enhancing safety. Specifically, Figure 7(a) demonstrates that the lateral acceleration remains stable during curved driving, while the large spike previously observed at the Y-junction is removed.

Figure 7 Simulation results: (a) comparison of the lateral acceleration of the vehicle between the modified and unmodified model and (b) shape of the bogie of the modified model (see online version for colours)



(a) (b)

The results emphasise the critical importance of analysing ATN vehicles' dynamic characteristics, particularly due to their structural and functional differences from conventional systems such as monorails. Unlike monorails, ATN vehicles' unique steering system and cabin-bogie configuration create challenges at Y-junctions, where impact loads and lateral instability can occur. The observed spike in reaction forces is a direct result of these unique characteristics. By addressing these challenges, the study demonstrates the effectiveness of adding steering mechanisms to reduce risks.

In conclusion, the findings emphasise that structurally distinct systems like ATN vehicles require a detailed analysis using multi-body dynamics to ensure safety and stability. Such methods are essential for evaluating the performance of systems that differ from conventional designs. The proposed improvements contribute not only to enhancing the safety of ATN vehicles but also to establishing a framework for analysing structurally unique transportation systems.

4 Conclusion

ATN vehicles represent a futuristic solution to address urban traffic congestion and environmental challenges. Their unique structure, with the bogie positioned above the track and the cabin located below, introduces dynamic characteristics distinct from conventional vehicles, necessitating specialised safety analyses.

This study analysed the dynamic behaviour of ATN vehicles at Y-junctions, focusing on structural and dynamic challenges unique to these systems. Using multi-body dynamics simulation with models designed in collaboration with Futran System and San José State University, the safety and stability of ATN vehicles were thoroughly evaluated. Theoretical predictions showed that the position of the cabin and bogie creates opposing moments during curved driving, which can either mitigate or exacerbate overturning risks depending on the specific conditions. Additionally, the steering mechanism and directional rollers, while designed to ensure lateral safety, were shown to introduce significant reaction forces and lateral accelerations under certain conditions, particularly at Y-junctions.

Simulation results revealed critical insights into the dynamic behaviour of ATN vehicles as follows:

The opposing moments between the cabin and bogie can reduce the risk of overturning under normal conditions, but discrepancies in reaction forces due to speed or mass distribution can still lead to instability.

At higher speeds, the rear bogie's slip angle diverges significantly from the front bogie, causing large impact loads on directional rollers and sudden changes in lateral acceleration and wheel reaction forces.

By implementing an additional steering mechanism for the rear bogie, the safety of the vehicle was improved by aligning the slip direction of both bogies, reducing lateral impact loads and stabilising acceleration and reaction forces.

This study demonstrates the critical importance of using virtual environments and multi-body dynamic simulations for safety analysis of ATN vehicles, as these systems allow for the evaluation of complex scenarios without the risks and costs of physical testing. The findings highlight that structural characteristic, such as the position of the cabin and bogie and the behaviour of steering mechanisms at Y-junctions, significantly affect vehicle stability and safety.

In conclusion, while the structural overturning of ATN vehicles is inherently mitigated by their design, sudden changes in lateral dynamics at Y-junctions remain a safety concern. This study contributes to addressing these challenges by proposing a simulation-based approach to analyse and improve vehicle safety. Future research will focus on refining the vehicle and track models and conducting physical validation tests to enhance the accuracy and reliability of the simulation results. By bridging the gap between simulation and real-world testing, this approach ensures that ATN systems can be developed as safe, efficient, and eco-friendly urban transportation solutions.

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References

Balena, M., Mantriota, G. and Reina, G. (2021) 'Dynamic handling characterization and set-up optimization for a formula SAE race car via multi-body simulation', *Machines*, Vol. 9, No. 6, p.126, https://doi.org/10.3390/machines9060126

Cai, C., He, Q., Zhu, S., Zhai, W. and Wang, M. (2019) 'Dynamic interaction of suspension-type monorail vehicle and bridge: numerical simulation and experiment', *Mechanical Systems and Signal Processing*, Vol. 118, pp.388–407, https://doi.org/10.1016/j.ymssp.2018.08.062

Cai, Q.C., Lee, K.H., Song, W.L., Lee, C.H. and Lee, Y. (2012) 'Simplified dynamics model for axial force in tripod constant velocity joint', *International Journal of Automotive Technology*, Vol. 13, pp.751–757, https://doi.org/10.1007/s12239-012-0074-8

Fan, X., Walker, P.D. and Wang, Q. (2018) 'Modeling and simulation of longitudinal dynamics coupled with clutch engagement dynamics for ground vehicles', *Multi-Body System Dynamics*, Vol. 43, pp.153–174, https://doi.org/10.1007/s11044-017-9592-5

Furman, B. (2016) 'The SPARTAN superway: a solar-powered automated transportation network', *ASES National Solar Conference*, San Francisco, CA.

Furman, B., Fabian, L., Ellis, S., Muller, P. and Swenson, R. (2014) *A Review of the State of the Industry and Prospects for the Future*, CA-MTI-14-1227, MTI Report, pp.12–31.

Grazioso, A., Ugenti, A., Galati, R., Mantriota, G. and Reina, G. (2023) 'Modeling and validation of a novel tracked robot via multibody dynamics', *Robotica*, Vol. 41, No. 10, pp.3211–3232, doi: 10.1017/S0263574723000966.

Han, J.B. and Kim, K.J. (2016) 'Dynamic interaction analysis of maglev and 3 span continuous guideway based on 3D multibody dynamic simulation', *Korean Journal of Computational Design and Engineering*, Vol. 21, No. 4, pp.409–416, https://doi.org/10.7315/CDE.2016.409

Kozłowski, M., Choromański, W. and Kowara, J. (2015) 'Parametric sensitivity analysis of ATN-PRT vehicle (automated transit network – personal rapid transit)', *Journal of Vibroengineering*, Vol. 17, No. 3, pp.1436–1451.

Lee, C.G., Kim, C.W., Kawatani, M., Nishimura, N. and Kamizono, T. (2005) 'Dynamic response analysis of monorail bridges under moving trains and riding comfort of trains', *Engineering Structures*, Vol. 27, No. 14, pp.1999–2013, https://doi.org/10.1016/j.engstruct.2005.06.014

Li, Y. and Frimpong, S. (2008) 'Dynamic modelling and virtual prototype simulation of dump truck-haul road interactions', *International Journal of Heavy Vehicle Systems*, Vol. 15, Nos. 2–4, pp.416–432, https://doi.org/10.1504/IJHVS.2008.022251

Maciel, G.P.R. and Barbosa, R.S. (2016) 'Monorail vehicle model to study influence of tyre modelling on overall dynamics', *International Journal of Heavy Vehicle Systems*, Vol. 23, No. 4, pp.317–332, https://doi.org/10.1504/IJHVS.2016.079270

Maclaurin, B. (2011) 'A skid steering model using the magic formula', *Journal of Terramechanics*, Vol. 48, No. 4, pp.247–263, https://doi.org/10.1016/j.jterra.2011.04.002

Martinod, R.M., Betancur, G.R., Osorio, J.F. and Castañeda, L.F. (2014) 'A study of the effect of the transition curve in the coupling elements between the carbody and the bogie', *International Journal of Heavy Vehicle Systems*, Vol. 21, No. 4, pp.351–363, https://doi.org/10.1504/IJHVS.2014.068113

Pacejka, H.B. and Bakker, E. (1992) 'The magic formula tyre model', *Vehicle System Dynamics*, Vol. 21, No. S1, pp.1–18, https://doi.org/10.1080/00423119208969994

Padhi, S., Patel, Y., Kumar, H. and Rastogi, V. (2022) 'Numerical simulation-based ride comfort analysis of the high-speed train using multibody dynamics', *International Journal of Heavy Vehicle Systems*, Vol. 29, No. 5, pp.441–462, https://doi.org/10.1504/Ijhvs.2022.128923

Park, S., Choi, Y.H. and Lee, C.H. (2022) 'Review of regulation for rollover test and evaluation of safety for buses by using simulation of multi-body dynamics', *Journal of Drive and Control*, Vol. 19, No. 3, pp.39–46, http://dx.doi.org/10.7839/ksfc.2022.19.3.039

Pombo, J., Ambrosio, J., Pereira, M., Lewis, R., Dwyer-Joyce, R., Ariaudo, C. and Kuka, N. (2010) 'A study on wear evaluation of railway wheels based on multi-body dynamics and wear computation', *Multi-Body System Dynamics*, Vol. 24, pp.347–366, https://doi.org/10.1007/s11044-010-9217-8

Schindler, C., Schwickert, M. and Yang, X. (2012) 'Dynamic behaviour of a vibration tamper by multi-body simulation', *International Journal of Heavy Vehicle Systems*, Vol. 19, No. 3, pp.225–243, https://doi.org/10.1504/IJHVS.2012.047914

Shabana, A.A., Zaazaa, K.E. and Sugiyama, H. (2007) *Railroad Vehicle Dynamics: A Computational Approach*, 1st ed., Boca Raton, CRC Press, https://doi.org/10.1201/9781420045857

Wickens, A.H. (1976) 'Steering and dynamic stability of railway vehicles', *Vehicle System Dynamics*, Vol. 5, pp.15–46, https://doi.org/10.1080/00423117508968404

Xin, L., Du, Z., Zhou, J., Yang, Z. and Xu, Z. (2021) 'Study on dynamic response of straddle-type monorail vehicle with single-axle bogie under curve condition', *Mechanika*, Vol. 27, pp.122–129, https://doi.org/10.5755/j02.mech.25319

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