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Optimizing Driver-Truck Synergy in Semi-Autonomous Truck Platooning Operations

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Abstract

This paper explores the intersection of human and machine collaboration within the framework of semi-autonomous trucking. The study focuses on enhancing truck platoons' operational efficiency and safety—where multiple trucks travel closely together with the aid of advanced driver-assistance systems (ADAS). By integrating human factors engineering and autonomous technology, the research aims to identify optimal strategies for driver engagement, situational awareness, and workload management. Key objectives include improving human drivers' responsiveness and decision-making capabilities while leveraging automated systems' precision and reliability. The findings are expected to contribute to developing more effective training programs and operational protocols, ultimately leading to safer and more efficient platooning operations.

Keywords: Semi-Autonomous Trucks, Truck Platooning, Driver-Truck Synergy, Human Factors Engineering

1. Introduction

The advent of semi-autonomous technology is revolutionizing the trucking industry, particularly through the implementation of truck platooning operations. Truck platooning involves a convoy of trucks traveling nearby, coordinated by advanced driver-assistance systems (ADAS) that enable precise control and synchronization [1]. For example, a historical data safety assessment method based on Markov processes and deep reinforcement learning offers significant insights into the safety of truck platooning[2]. The semi-autonomous technology promises significant benefits, including improved fuel efficiency, reduced emissions, and enhanced road safety. However, the transition to semi-autonomous truck platooning also presents complex challenges, particularly in the realm of human-machine interaction. Optimizing the synergy between drivers and semi-autonomous trucks is crucial for realizing the full potential of platooning operations. While automation can handle many driving tasks, human drivers remain essential for overseeing operations, making critical decisions, and intervening when necessary. The dynamic interplay between human drivers and automated systems requires careful consideration of human factors, including engagement, situational awareness, and workload management. This paper aims to explore strategies for enhancing driver-truck synergy in semi-autonomous truck platooning [3]. Also, machine learning methods can analyze the reliability of semi-automated systems, offering new perspectives for the feasibility studies of semi-automated truck platooning. By integrating insights from human factors engineering and leveraging cutting-edge technology, we seek to identify best practices that ensure both safety and efficiency. The study's objectives include improving driver engagement, enhancing situational awareness, and developing effective workload management techniques. Ultimately, the goal is to contribute to the development of robust operational protocols and training programs that support the seamless integration of human and machine capabilities in the context of truck platooning [4].

Figure 1, illustrates the high-speed driving environment, most vehicles typically operate close to the maximum permissible speed, except during instances of traffic congestion. The movement of vehicles in such environments is often characterized by monotony, assuming operation on expressways or highways [5]. To facilitate the platooning of smart vehicles, data on speed, acceleration, and relative position of each vehicle must be collected and utilized through vehicle-to-vehicle and vehicle-to-infrastructure communication. Implementing platooning in high-speed environments is anticipated to offer considerable convenience for drivers by optimizing vehicle coordination and efficiency.

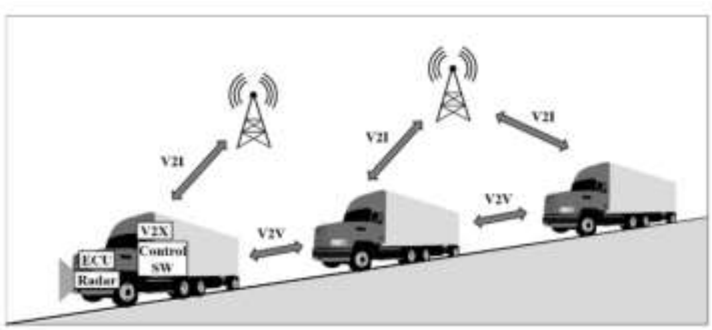

Figure 1: Concept of Platooning

Truck platooning, the concept of multiple trucks traveling near the aid of advanced technology, has gained significant attention in recent years due to its potential to revolutionize freight transportation. The idea is not entirely new, with convoys being used in military operations and racing events for decades. However, advancements in automation and connectivity have made platooning a feasible solution for commercial trucking [6]. For instance, the application of semi-supervised classification techniques in surface defect detection can also be utilized for defect detection and correction in truck platooning[7]. Platooning offers several benefits such as improved fuel efficiency through reduced aerodynamic drag, enhanced traffic flow, and potential reductions in CO2 emissions. Moreover, it addresses the industry's pressing challenges, including driver shortages, rising fuel costs, and the need for sustainable transportation solutions. Semi-autonomous technology in trucking represents a significant evolution in the way goods are transported over long distances. These systems integrate a range of sensors, cameras, and artificial intelligence algorithms to automate certain driving tasks while still requiring human oversight. In the context of truck platooning, semi-autonomous technology enables trucks to communicate with each other and maintain safe distances automatically. This technology also facilitates lane-keeping, adaptive cruise control, and collision avoidance systems, enhancing safety and efficiency on the road. Understanding the capabilities and limitations of semi-autonomous technology is essential for implementing effective truck platooning operations and maximizing their benefits while ensuring safety and regulatory compliance. While semi-autonomous technology offers promising advancements in trucking, optimizing the interaction between drivers and trucks is crucial for the success of platooning operations [8]. Human drivers remain integral for decision-making, handling complex situations, and ensuring overall safety. Therefore, finding the right balance between automated assistance and human intervention is essential. Optimizing driver-truck interaction involves enhancing driver engagement, maintaining situational awareness, and managing driver workload effectively. By improving this interaction, truck platooning operations can achieve higher levels of efficiency, safety, and acceptance within the industry and among the general public. The structure of this paper is as follows: Section 2 offers a comprehensive review of the relevant literature, identifying existing gaps in the research. In Section 3, Driver Engagement in Semi-Autonomous Platooning. Finally, Section 6 concludes the paper by summarizing the findings and case studies and suggesting future research directions to further advance the field.

2. Literature Review

The current state of semi-autonomous truck platooning reflects a promising but evolving landscape. Several trials and pilot programs have demonstrated the feasibility and potential benefits of platooning technology [9]. For example, graphene-based mid-infrared photodetector research has shown the potential of novel plasmonic antennas, which could enhance sensing accuracy in truck platooning[10, 11]. Companies like Peloton Technology, Volvo, and Daimler Trucks have been at the forefront of developing and testing semi-autonomous platooning systems. These systems typically utilize vehicle-to-vehicle (V2V) communication and advanced driver-assistance systems (ADAS) to enable trucks to follow each other at close distances while maintaining safety and efficiency[12]. However, widespread adoption still faces regulatory and infrastructure challenges, limiting the scale of deployment. Nevertheless, ongoing research and industry initiatives continue to push the boundaries of semi-autonomous truck platooning, aiming to address these challenges and unlock its full potential. Human factors play a critical role in the design and implementation of autonomous systems, including semi-autonomous truck platooning. Understanding how drivers interact with technology, perceive information, and make decisions is essential for developing effective and user-friendly systems. Factors such as trust, situation awareness, and workload influence the success and acceptance of autonomous technologies. Human-centered design principles are increasingly being integrated into the development process to ensure that technology complements human capabilities and limitations. This involves considering factors like user interface design, communication protocols, and training programs to optimize human-automation interaction and enhance overall system performance and safety. Numerous studies have investigated driver engagement and workload management in semi-autonomous driving contexts, providing valuable insights into optimizing human-automation interaction [13]. Research has explored various techniques for maintaining driver attention and involvement while automation handles certain driving tasks. Additionally, studies have examined workload factors such as task complexity, time pressure, and environmental conditions to develop strategies for effective workload management. Findings from previous research highlight the importance of designing systems that provide clear feedback to drivers, maintain situational awareness, and dynamically adjust workload allocation based on real-time conditions.

Figure 2, illustrates the basic problem with conventional trucks lies in their inefficiency and environmental impact. Traditional trucks operate with individual drivers and lack advanced technologies for coordination, resulting in high fuel consumption and emissions. Additionally, conventional trucks often travel with significant space, leading to underutilization of cargo capacity and increased transportation costs [14]. Maintenance and downtime also pose challenges, affecting operational reliability and cost-effectiveness. Moreover, safety concerns persist due to human error and fatigue among drivers, contributing to road accidents. Addressing these issues is crucial for improving the sustainability, safety, and efficiency of freight transportation systems.

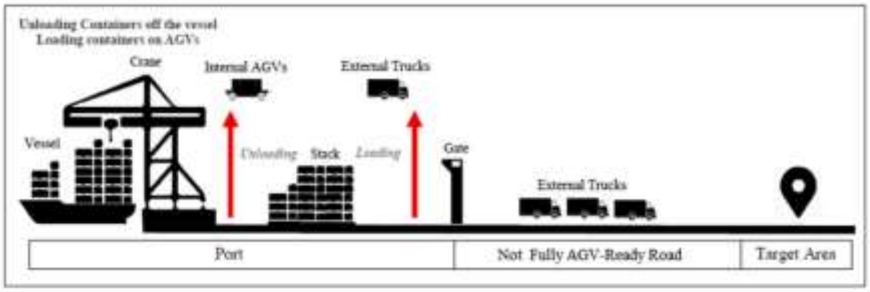

Figure 2: The Basic Problem with conventional Trucks

Numerous studies have delved into methods and algorithms for managing platoons of smart vehicles. These investigations primarily focus on maintaining platooning status and can be categorized into centralized and decentralized approaches. In the centralized approach, researchers have proposed local controllers that adjust vehicle speed based on position, speed, and destination data to form platoons. They evaluated these algorithms through simulations on the German autobahn road network. Meanwhile, studies on automated highway systems (AHS) have concentrated on constructing vehicle platoons at highway entrances to optimize platoon distance. On the decentralized front, algorithms have been developed to enable convoys to follow a leader's path safely without collisions or deviation. Other studies have explored strategies for truck platooning, analyzing behavior patterns under different strategies and proposing hybrid approaches. Generally, these benefits stem from reduced aerodynamic drag resulting from platooning. Several studies have quantified these environmental advantages. For instance, one study focused on the operation of heavy-duty vehicles (HDVs) and developed a two-layer control architecture, optimizing fuel-efficient speed profiles through dynamic programming. Simulations demonstrated potential fuel savings of up to 12% across various scenarios. Another investigation assessed both environmental and safety benefits, revealing a 15% reduction in fuel consumption when smaller vehicles trailed heavy ones. Fuel savings have been a key metric in evaluating platooning scenarios, with studies exploring configurations to enhance fuel efficiency, such as adjusting vehicle paths, departure times, and speed profiles. Adjusting speeds for catch-up was a particular focus, showing potential fuel savings, especially when optimizing platoon composition. Additionally, there have been studies proposing algorithms for platoon formation and dissolution to maximize fuel efficiency, validated through examples. While previous research has touched upon environmental benefits, few have scrutinized smart vehicle platooning at a micro-level, considering factors like power consumption, and offering valuable insights.

a. Platoons of Automated Ground Vehicles (AGVs)

Figure 3, illustrates that Automated Ground Vehicles (AGVs) represent cutting-edge autonomous transportation systems, equipped with advanced sensing, computing, and communication capabilities. These vehicles are designed to operate without direct human intervention, navigating through environments such as warehouses, factories, and outdoor spaces autonomously. In the context of platooning, AGVs are coordinated to travel closely together in a convoy, leveraging sophisticated technology to maintain precise spacing and alignment. Platooning technology in AGVs relies on a combination of vehicle-to-vehicle (V2V) communication, onboard sensors, and control algorithms to enable smooth and efficient convoy operations. V2V communication allows AGVs within the platoon to exchange data in real-time, including speed, position, and braking information [15]. This communication enables AGVs to synchronize their movements, adjust speeds simultaneously, and react to changes in the environment collectively. Advanced control algorithms ensure that AGVs maintain safe following distances while optimizing fuel efficiency and minimizing traffic disruptions.

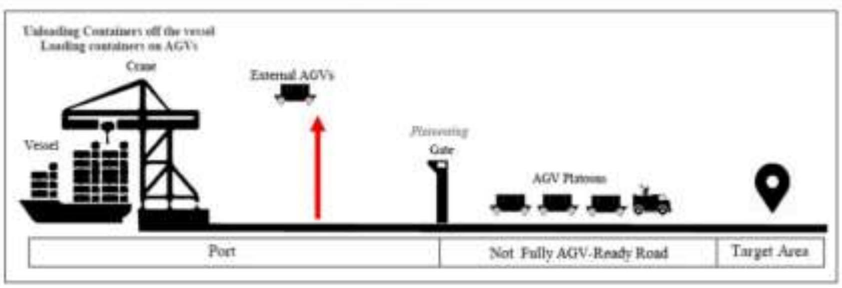

Figure 3: The container drayage process with conventional trucks and AGV platoons in port hinterland corridors.

The integration of platooning technology in AGVs offers several benefits, including improved fuel economy, reduced emissions, and increased road safety. By traveling closely together, AGVs can reduce aerodynamic drag, leading to fuel savings for the entire convoy. Moreover, platooning enhances traffic flow and reduces congestion by maintaining consistent speeds and minimizing sudden braking maneuvers [16]. However, challenges such as infrastructure requirements, regulatory frameworks, and public acceptance need to be addressed for the widespread adoption of AGV platooning technology.

3. Driver Engagement in Semi-Autonomous Platooning

Driver engagement plays a crucial role in semi-autonomous truck platooning operations, where drivers oversee the performance of automated systems while retaining responsibility for overall vehicle control and safety. In platooning scenarios, where trucks travel closely together, maintaining driver engagement is essential for ensuring timely intervention, monitoring system performance, and adapting to changing road conditions. Effective driver engagement enhances the safety, efficiency, and overall effectiveness of platooning operations [17]. Drivers in semi-autonomous platooning systems must remain actively engaged despite the reduced demand for manual driving tasks. While automation handles tasks like speed control and following distance maintenance, drivers are required to monitor the system, anticipate potential hazards, and intervene when necessary. Maintaining engagement can be challenging, particularly during long stretches of monotonous highway driving, where the temptation to become distracted or complacent may arise. Therefore, strategies to enhance driver engagement are essential for optimizing the performance of platooning systems.

Table 1, Provides a comparative analysis of the container drayage process using conventional trucks and Automated Ground Vehicle (AGV) platoons within port hinterland corridors. It highlights key aspects such as operational efficiency, fuel consumption, emissions, safety, traffic flow, and operational costs. The comparison underscores the basic problems associated with conventional trucks, including high fuel consumption, emissions, and driver fatigue, contrasted with the benefits of AGV platoons, such as improved efficiency, reduced emissions, and lower operational costs. The table also addresses infrastructure requirements and regulatory challenges, illustrating the potential advantages of transitioning to AGV platooning systems .

Table 1: Container Drayage Conventional Trucks vs. AGV Platoons

Aspect	***Conventional Trucks***	***AGV Platoons***
Operational Efficiency	Often inefficient due to traffic congestion, variable driving behavior	High efficiency with synchronized movement and optimized routing
Fuel Consumption	High fuel consumption	Reduced fuel

	due to stop-and-go traffic and idling	consumption through coordinated driving and reduced aerodynamic drag
Driver Fatigue and Safety	High risk of driver fatigue and human error leading to accidents	Reduced risk of fatigue and human error with automated systems
Traffic Flow	Disrupted traffic flow with frequent starts and stops	Smoother traffic flow with synchronized platooning
Operational Costs	High operational costs due to fuel, maintenance, and labor	Lower operational costs with fuel savings and reduced labor needs

In semi-autonomous systems, the role of the driver undergoes a significant transformation, requiring a balance between active supervision and automation reliance. While automation handles certain driving tasks, the driver remains responsible for overall vehicle operation and safety. The driver's primary role shifts from direct control of the vehicle to supervisory control, where they monitor system performance, maintain situational awareness and intervene when necessary. This shift necessitates a new set of skills and competencies, focusing on understanding automation capabilities, interpreting sensor data, and making informed decisions in dynamic driving environments[18]. Drivers in semi-autonomous systems serve as critical decision-makers, responsible for assessing environmental conditions, anticipating potential hazards, and ensuring safe operation. While automation can handle routine tasks like maintaining speed and lane-keeping, drivers must remain vigilant and ready to take over control when faced with complex or unexpected situations. Their ability to effectively supervise the system's performance and intervene when needed is paramount for ensuring safety and efficiency on the road.

- Driver engagement is crucial for overseeing the performance of automated systems in semi-autonomous truck platooning.
- Factors affecting driver engagement include trust in automation, workload, and system reliability.
- Trust in the automation system is essential for effective supervision and intervention when needed.

- High workload levels and monotonous driving conditions can reduce driver attention and vigilance.
- Reliable and transparent systems contribute to maintaining driver engagement by ensuring system dependability and understanding.
- Feedback mechanisms, such as visual, auditory, and haptic cues, help drivers stay alert to changes in system status and road conditions.

Comprehensive training programs are essential for improving drivers' understanding of semi-autonomous systems and enhancing their supervisory skills. Continuous training and refresher courses ensure drivers remain proficient and adaptable to evolving technologies in semi-autonomous truck platooning.

4. Case Studies and Future Directions

Several successful implementations of optimized driver-truck synergy in semi-autonomous truck platooning operations have demonstrated significant improvements in efficiency, safety, and operational costs. For example, Peloton Technology has successfully deployed truck platooning systems that leverage vehicle-to-vehicle (V2V) communication to maintain optimal distances between trucks. These implementations have resulted in substantial fuel savings, reduced emissions, and improved road safety. Similarly, Volvo’s Vera project showcases the integration of fully autonomous trucks in logistics, optimizing load handling and reducing operational downtime. These implementations highlight the potential for semi-autonomous systems to enhance driver-truck interactions and overall operational efficiency.

Case studies from these implementations provide valuable insights into the challenges and best practices associated with optimizing driver-truck synergy. One key lesson is the importance of driver training and engagement. Ensuring that drivers are well-versed in the capabilities and limitations of semi-autonomous systems is crucial for maintaining safety and efficiency. Another lesson is the need for robust communication systems; reliable V2V and vehicle-to-infrastructure (V2I) communication is essential for seamless platooning operations. Additionally, case studies have highlighted the necessity of iterative testing and refinement, emphasizing the role of continuous feedback from drivers to improve system performance and user experience. The future of driver-truck synergy in semi-autonomous truck platooning operations is poised to leverage advanced technologies and innovative practices to enhance efficiency, safety, and sustainability. One critical area of development will be the integration of artificial intelligence (AI) and machine learning, which can significantly improve the decision-making capabilities of platooning systems. These technologies will enable better prediction and response to various road conditions, optimizing the synchronization and coordination of platooned vehicles. AI-driven predictive maintenance will also become more prevalent, reducing downtime and improving the reliability of the trucks. Additionally, advancements in human-machine interfaces (HMIs) will play a pivotal role in maintaining driver engagement. Future HMIs are expected to provide more intuitive and real-time feedback, helping drivers maintain situational awareness and effectively collaborate with the automated systems. Innovations such as augmented reality displays and advanced haptic feedback mechanisms will enhance the overall user experience and safety. These technologies will support faster and more reliable data exchange, enabling more responsive and adaptive platooning operations. Furthermore, regulatory and infrastructure advancements will be essential for the widespread adoption of semi-autonomous truck platooning. Governments and industry stakeholders will need to work together to create standardized regulations and invest in smart infrastructure, such as connected roadways and intelligent traffic management systems. Sustainable practices will also be prioritized, with a focus on integrating electric and hybrid-electric trucks into platooning operations to reduce emissions and promote environmental goals. Continuous driver training and adaptive programs will ensure that drivers are well-equipped to work with these advanced systems, fostering a synergistic relationship between human operators and automated technologies. By addressing these areas, the transportation industry can achieve a more efficient, safe, and sustainable future for semi-autonomous truck platooning.

5. Conclusion

In conclusion, this paper represents a transformative advancement in the logistics and transportation sector. By enhancing the collaboration between human drivers and automated systems, significant improvements in fuel efficiency, safety, and operational efficiency can be achieved. This paper has highlighted the critical role of driver engagement, the importance of robust communication systems, and the necessity for comprehensive training programs. As the industry moves forward, embracing AI, advanced human-machine interfaces, and sustainable practices will be key to overcoming existing challenges and fully harnessing the benefits of platooning technology. Through continuous innovation and cross-industry collaboration, the future of semi-autonomous truck platooning promises a more efficient, safe, and sustainable freight transportation landscape.

Reference

[1] Y. Hao, Z. Chen, J. Jin, and X. Sun, "Joint operation planning of drivers and trucks for semi-autonomous truck platooning," *Transportmetrica A: Transport Science,* pp. 1-37, 2023.

[2] W. Dai, "Safety evaluation of traffic system with historical data based on Markov process and deep-reinforcement learning," *Journal of Computational Methods in Engineering Applications,* pp. 1-14, 2021.

[3] S. Lakshmanan *et al.*, "Semi-autonomous truck platooning with a lean sensor package," in *AI-enabled Technologies for Autonomous and Connected Vehicles*: Springer, 2022, pp. 19-59.

[4] S. Chen, H. Wang, and Q. Meng, "Cost allocation of cooperative autonomous truck platooning: Efficiency and stability analysis," *Transportation Research Part B: Methodological,* vol. 173, pp. 119-141, 2023.

[5] Z. Dai, X. C. Liu, H. Li, M. Wang, and X. Ma, "Semi-autonomous bus platooning service optimization with surrogate modeling," *Computers & Industrial Engineering,* vol. 175, p. 108838, 2023.

[6] G. Rödönyi, P. Gáspár, J. Bokor, and L. Palkovics, "Experimental verification of robustness in a semi-autonomous heavy vehicle platoon," *Control Engineering Practice,* vol. 28, pp. 13-25, 2014.

[7] Y. Liu, H. Yang, and C. Wu, "Unveiling patterns: A study on semi-supervised classification of strip surface defects," *IEEE Access,* vol. 11, pp. 119933-119946, 2023.

[8] Z. Xue, H. Lin, and J. You, "Local container drayage problem with truck platooning mode," *Transportation Research Part E: Logistics and Transportation Review,* vol. 147, p. 102211, 2021.

[9] H. Guan, H. Wang, Q. Meng, and C. L. Mak, "Markov chain-based traffic analysis on platooning effect among mixed semi-and fully-autonomous vehicles in a freeway lane," *Transportation Research Part B: Methodological,* vol. 173, pp. 176-202, 2023.

[10] X. Deng, S. Oda, and Y. Kawano, "Graphene-based midinfrared photodetector with bull's eye plasmonic antenna," *Optical Engineering,* vol. 62, no. 9, pp. 097102-097102, 2023.

[11] X. Deng and Y. Kawano, "Surface plasmon polariton graphene midinfrared photodetector with multifrequency resonance," *Journal of Nanophotonics,* vol. 12, no. 2, pp. 026017-026017, 2018.

[12] Y. Liu, L. Liu, L. Yang, L. Hao, and Y. Bao, "Measuring distance using ultra-wideband radio technology enhanced by extreme gradient boosting decision tree (XGBoost)," *Automation in Construction,* vol. 126, p. 103678, 2021.

[13] W. Zhang, E. Jenelius, and H. Badia, "Efficiency of connected semi-autonomous platooning bus services in high-demand transit corridors," *IEEE Open Journal of Intelligent Transportation Systems,* vol. 3, pp. 435-448, 2022.

[14] A. Kishore Bhoopalam, *Truck Platooning: Planning and Behaviour* (no. EPS-2021-540-LIS). 2021.

[15] A. Validi, N. Smirnov, and C. Olaverri-Monreal, "Semi-Autonomous Electric Vehicles in Platooning Mode and Their Effects on Travel Time: A Framework for Simulation Evaluation," in *2022 IEEE Intelligent Vehicles Symposium (IV)*, 2022: IEEE, pp. 45-50.

[16] A. Rahimi and Y. He, "A review of essential technologies for autonomous and semi-autonomous articulated heavy vehicles," in *Proceedings of the Canadian Society for Mechanical Engineering International Congress*, 2020, pp. 21-24.

[17] M. Repoux, N. Geroliminis, and M. Kaspi, "Operational analysis of an innovative semi-autonomous on-demand transportation system," *Transportation Research Part C: Emerging Technologies,* vol. 132, p. 103373, 2021.

[18] A. Colling, Y. van Delft, V. Peeten, T. Verbist, S. Wouters, and R. Hekkenberg, "Assessing Semi-Autonomous Waterborne Platooning Success Factors in Urban Areas," in *COMPIT'21: 20th International Conference on Computer and IT Applications in the Maritime Industries*, 2021: Technische Universität Hamburg-Harburg, pp. 43-57.