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Towards automated Driving on Automobile Terminals

Automatisiertes Fahren auf Automobilterminals

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This paper presents a comprehensive analysis and conceptual development for integrating automated driving technologies within automotive terminals. The research addresses inefficiencies in current terminal operations by employing a two-phase approach: detailed process analysis and the design of a technological concept for automated vehicle integration. The proposed technological concept includes an intelligent infrastructure with advanced sensor systems, robust communication networks utilizing 5G, and Level 4 automated driving capabilities enhanced by Automated Valet Parking (AVP) systems. Additional emphasis is placed on ensuring safe human-technology interaction. The expected outcomes include improved operational efficiency, optimized space utilization, and enhanced safety, with future work focusing on prototype implementation and performance evaluation by simulations.

[Keywords: Automated driving, automated valet parking, automobile terminals, human machine interaction, process optimization]

In diesem Beitrag wird eine umfassende Analyse und konzeptionelle Entwicklung für die Integration von Technologien für automatisiertes Fahren in Automobilterminals vorgestellt. Die Forschung adressiert kritische Ineffizienzen im aktuellen Terminalbetrieb durch einen zweistufigen Ansatz: eine detaillierte Prozessanalyse und die Entwicklung eines technologischen Konzepts für die Integration automatisierter Fahrzeuge. Das vorgeschlagene technologische Konzept umfasst eine intelligente Infrastruktur mit fortschrittlichen Sensorsystemen, robusten Kommunikationsnetzen unter Verwendung von 5G und automatisierten Fahrfunktionen der Stufe 4, die durch automatisierte Valet-Parking-Systeme (AVP) ergänzt werden. Ein weiterer Schwerpunkt ist die Gewährleistung einer sicheren Interaktion zwischen Mensch und Technik. Zu den erwarteten Ergebnissen gehören eine verbesserte Betriebseffizienz, eine optimierte Raumnutzung und eine erhöhte Sicherheit, wobei sich die zukünftige Arbeit auf die Implementierung von Prototypen und die Leistungsbewertung durch Simulationen konzentriert.

[Schlüsselwörter: Automatisiertes Fahren, Automated Valet Parking, Automobilterminals, Mensch-Technik-Interaktion, Prozessoptimierung]

1 INTRODUCTION

The logistical services provided by seaports and inland ports are essential for the import and export activities of many countries and play a critical role in global distribution chains, particularly in the automotive industry. These ports serve as central nodes in the logistics of finished vehicles, facilitating both the export of domestically manufactured vehicles and the import of foreign vehicles on a significant scale [1]. Operators of automotive terminals face several challenges, including increasing throughput volumes, limited terminal space, and a shortage of personnel. Current processes at automotive terminals heavily rely on manual vehicle movements, and recruiting new driving personnel is becoming increasingly difficult [2].

Technological advancements in digitalization and automation offer new opportunities to optimize terminal operations and address these challenges. Through the implementation of smarter job scheduling and optimized task assignments, efficiency has already seen improvements [3]. For example, real-time analytics and data integration can significantly enhance job scheduling and resource allocation, improving operational efficiency [4].

Recent developments in self-driving vehicle technology present a promising solution for improving efficiency in automobile terminals. Automated driving can be implemented through an intelligent infrastructure comprising Lidar, Radar, or camera systems. This infrastructure can detect all objects within the terminal and integrate them into a control system, allowing vehicles to be managed via Automated Valet Parking (AVP) systems. These systems can help reduce manual labor and improve the precision of vehicle movements within the terminal [5].

By leveraging these advancements, terminal operations can become more efficient and streamlined, paving the way for further exploration into the feasibility and potential benefits of implementing automated driving systems in automotive terminals. The aim of this project is to explore the feasibility and potential benefits of implementing automated driving systems in automotive terminals. Specifically, this study investigates the necessary process and infrastructure requirements, the design of technical infrastructure and sensor systems for robust and secure vehicle control, the development of intuitive and safe human-technology interactions, and the optimization potentials for adjacent storage and logistics processes via simulations.

2 State of the Art

This section provides an overview of the current technologies and practices in automotive terminal operations, automated driving, and Automated Valet Parking (AVP) systems, based on recent research findings.

2.1 Automobile Terminal Operation

Automobile terminals play a crucial role in the global distribution of vehicles, handling significant volumes for both import and export. These operations involve complex logistics, requiring efficient coordination of multiple transport modes, including ships, trains, and trucks. According to industry reports, the trend toward automation in port operations is becoming more prevalent, with many new projects incorporating semi- or fully automated systems to enhance efficiency and reliability [6].

In current automotive terminal operations, vehicle handling processes are typically planned before each shift, including assigning driving personnel to fixed teams, determining the sequence of vehicle pool handling, and arranging shuttles for transport [3, 7]. The primary goal is to fulfill driving orders swiftly while prioritizing loading and unloading transport carriers, particularly ships, and avoiding traffic congestion [8, 9]. However, shift planning is complex due to the need for real-time adjustments based on unforeseen changes or incomplete pre-planning of certain steps. For instance, ship loading involves real-time instructions from stowage personnel to optimize space utilization, requiring driving personnel to adapt spontaneously. Other unplanned events include deviations in vehicle volumes or delayed transport carriers, and must be managed dynamically within the shift [3]. Informal methods currently address unexpected events, such as shuttling personnel for defective vehicles or breaks. Changes in driving orders during a shift often necessitate manual interventions and updates communicated to shuttle teams by the control center. A critical inefficiency is that alternating trips between vehicles and shuttles result in unproductive shuttle trips, limiting the productive working time of driving personnel to about half of the shift. This issue is exacerbated by idle times due to fewer remaining assignments or waiting for shuttles, and incidents involving individuals can delay the entire team [10].

Several successful automation projects in automotive terminals demonstrate the potential benefits of these technologies. Projects focusing on the automation of car handling and parking have reduced manual labor and increased operational reliability in simulation case studies [11]. Additionally, automation initiatives have highlighted the strategic benefits of integrating advanced technologies in terminal logistics, improving both efficiency and scalability [12].

2.2 Automated Driving

Automated driving technologies have demonstrated notable potential in the logistics sector by enhancing operational efficiency and reducing labor costs. For example, the use of automated guided vehicles (AGVs) in container terminals has improved the speed and accuracy of container handling [13]. Also the use of automated straddle carriers was conducted [14, 15]. In the case of automobile terminals the recent advancements in automated driving technology holds a great potential for further enhancing operational efficiency and productivity. These technologies use sensors such as Lidar, Radar and cameras to navigate complex environments without human intervention. The implementation of automated driving can greatly improve efficiency by allowing continuous operation, optimizing space usage through precise navigation, and reducing the dependency on human drivers. The industry has adopted a 5-level model to evaluate the degree of automated driving, ranging from no automation (Level 0) to full automation (Level 5) (see figure 1). For automotive terminals, Level 4 automation (high automation) is targeted, where vehicles operate without human intervention in most situations. Level 5 is not targeted as it is more complex and won't be available in a large scale of automobiles in the next years. In contrast to automated container terminals where the AGVs or automated straddle carriers could be specially developed or adopted for the required needs, in automobile terminals no changes to the vehicles can be considered. Additional, automated container terminals are restricted areas without people. This leads to different not solved automation challenges for automobile terminals.

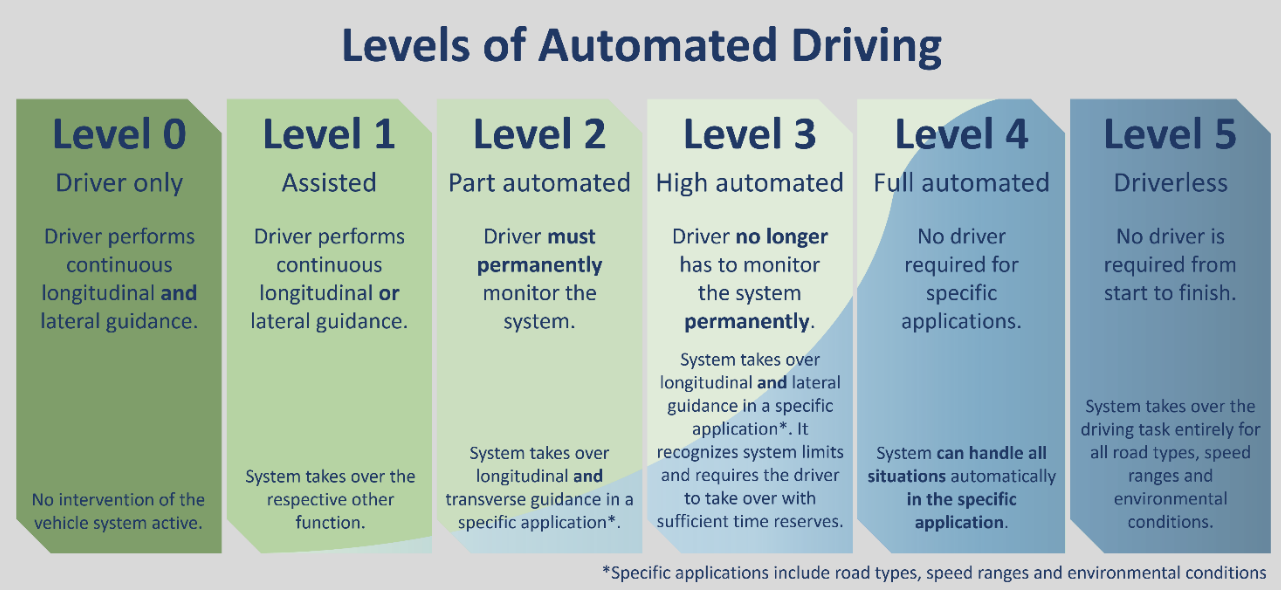

Figure 1. Levels of automated driving (according [16])

2.3 Automated Valet Parking (AVP)

Automated Valet Parking (AVP) systems, an application of automated driving technology designed for parking environments, automatically park and retrieve vehicles using advanced sensor technology and control algorithms. In automotive terminals, AVP systems streamline the parking process, reducing the time and labor needed, and allowing for denser parking, which maximizes space utilization. Additionally, reducing human intervention minimizes the risk of accidents and vehicle damage during parking [17].

There are three main approaches to implement automated driving and AVP systems: using vehicle sensors, intelligent infrastructure, or a combination of both. Automated driving is significantly hampered by the varying levels of automation capabilities among individual vehicles. This heterogeneity creates a complex landscape where vehicles with different autonomous functionalities must coexist, leading to challenges in coordination and communication. Infrastructure-based automated driving mitigates these limitations by embedding the intelligence within the terminal itself, rather than relying solely on the individual vehicle's capabilities. The project focuses on the intelligent infrastructure approach, utilizing Lidar sensors and software to continuously monitor and control vehicle movements. ISO 23374 defines various AVP functions and interfaces, ensuring that the vehicles equipped for AVP have necessary features like electronic parking brakes, automatic transmission, ESP, and remote engine start/stop. These capabilities are often present in modern battery electric vehicles, facilitating their integration into automated systems [18].

One of the critical challenges in implementing automated driving is achieving low latency communication, which is essential for real-time decision-making and vehicle control. Current 5G technologies have the potential to address this issue effectively by providing the high-speed, low-latency connectivity required for automated operations. While many existing use cases implement private 5G networks to ensure reliability and security, This project proposes leveraging public 5G networks to ensure fast and reliable communication. Utilizing public 5G can significantly reduce network architecture costs and enhance scalability. Advances such as network slicing, which allows for the creation of dedicated virtual networks within the public 5G infrastructure, make it feasible to meet the stringent requirements of automated driving applications [19]. The 5G standard, standardized by the 3rd Generation Partnership Project [20], provides the necessary data speed, network capacity, latency, and security. Technologies like Multi-Access Edge Computing (MEC) and Network APIs enable the configuration of network resources to meet the specific requirements of different applications, ensuring efficient and reliable operation.

Several case studies have demonstrated the successful implementation of AVP systems. For example, the AVP system implemented by Continental in Germany has shown significant improvements in parking efficiency [21]. Another study shows the benefits of AVP systems in reducing labor costs [22].

3 Method

This chapter outlines the method used to develop a comprehensive technological concept for integrating automated driving within automotive terminals. The research project consists of analyzing existing processes, designing a technical infrastructure, and planning for future implementation and testing.

3.1 Process Analysis

The initial phase involved a thorough analysis of the current terminal processes to identify inefficiencies and areas for potential improvement. Detailed maps of the terminal's physical layout were created to understand the spatial arrangement and flow of vehicle movements. Comprehensive documentation of vehicle movement processes was conducted to capture the current state of operations, including vehicle paths, task durations, and congestion points. Key operational metrics, such as vehicle throughput, dwell times, space utilization rates, and labor deployment statistics, were collected from terminal management systems, direct observations, and interviews with terminal staff. The collected data were analyzed to pinpoint bottlenecks that limited throughput, inefficiencies in space utilization, and areas heavily reliant on manual labor. Furthermore, new interactions between the manual and newly implemented automated processes were identified and analyzed for necessary information requirements. This aims to facilitate the transition to automated processes for terminal personnel through targeted human-technology interaction.

3.2 Design of the Technological Concept

The core of this research is the development of a technological concept for integrating automated driving technologies within automotive terminals. Based on the process analysis, specific requirements for the automated driving system were defined, including functional requirements such as vehicle navigation, parking automation, and safety protocols. A detailed design for the technical infrastructure was developed, incorporating Lidar and camera systems to detect and monitor vehicle movements. Control systems were designed to process sensor data and issue driving commands, involving software for real-time data processing and decision-making algorithms. One of the significant challenges addressed in the design phase was ensuring effective human-technology interaction, particularly in environments where driverless and driver-operated vehicles coexist.

The following procedure was employed: initially, the first set of human-technology interaction requirements was derived from test cases for the technical implementation of automated driving movements. These scenarios were then extended to further development stages of the system and supplemented with additional requirements. The specific information needs for each scenario were identified in an abstract manner. Furthermore, various technical methods for providing information were identified and categorized into types such as individual, wearable, general, and stationary. Subsequently, an assessment was conducted to determine which technical solutions could meet the identified information needs.

3.3 Planning for Future Implementation

While the simulation of the proposed improvements is ongoing, this paper focuses on the technological concept. Ongoing simulation models are being developed to test the feasibility and impact of automation concepts in a virtual environment. These models help predict performance improvements and identify potential issues. A detailed plan for developing a prototype was created, outlining the steps required to deploy automated vehicles and AVP systems in a controlled section of the terminal. Additionally, a framework for evaluating the performance of the prototype was established. This includes key metrics such as throughput, space utilization, and labor efficiency, which will guide the evaluation once the prototype is implemented

4 Results

This chapter presents the initial results of the analysis and conceptual development of integrating automated driving technologies within automotive terminals. The findings are categorized into two main sections: the outcomes of the process analysis and the proposed technological concept for automated driving integration.

4.1 Process Analysis Results

The process analysis provided valuable insights into the current operational inefficiencies and potential areas for improvement within the terminal.

Identification of Bottlenecks: The analysis identified several critical bottlenecks in vehicle movement processes, particularly in high-traffic zones and loading/unloading areas. These bottlenecks significantly limit throughput and increase dwell times. Congestion was frequently observed at intersections and narrow pathways, causing delays and reducing overall efficiency. The loading and unloading of ships is a top priority, as extended dock times incur significant costs. However, in certain cases, the personnel responsible for moving vehicles within the terminal are not permitted to load vehicles onto the ships; specialized personnel are required for this task. Vehicles are temporarily stored in buffer zones directly at the quay for transfer. This results in a high volume of one-way traffic on the access roads.

Space Utilization: The current layout and vehicle movement patterns result in suboptimal space utilization. Large areas of the terminal are underutilized, while certain zones experience high congestion and inefficient use of available space. The analysis highlighted the need for a more dynamic and flexible space allocation strategy to improve utilization rates. The vehicles are pre-sorted in a parking row for a truck or train trailer. This results in partially filled parking rows, leading to suboptimal utilization of the available space.

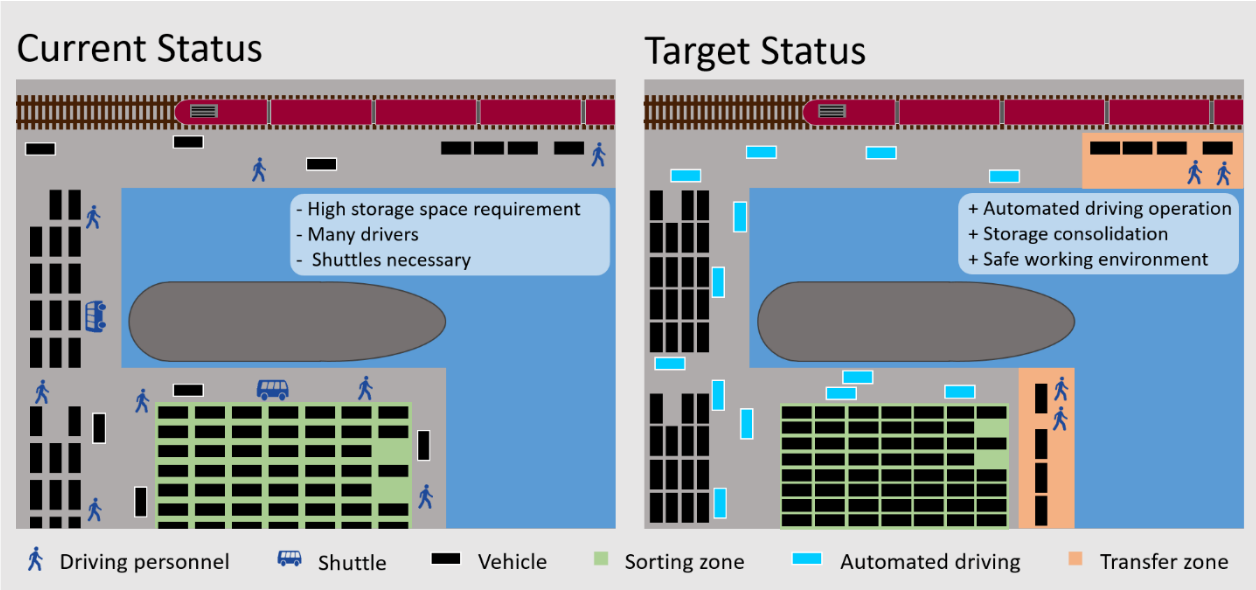

Figure 2. Current and target status on the automobile terminal

Labor Dependency: A significant reliance on manual labor for vehicle movements was identified, leading to increased operational costs. The shortage of skilled personnel further exacerbates these challenges. High labor dependency also introduces variability in process efficiency, with manual interventions often leading to inconsistencies in vehicle handling and parking. To prepare for the loading of ships, buffer zones are pre-filled, typically scheduled for the night preceding the loading operation. However, nocturnal labor incurs significantly higher costs compared to daytime work, thereby disproportionately escalating the overall loading expenses.

4.2 Technological Concept for Automated Driving Integration

The conceptual design was visualized to illustrate the flow of information and commands between the control systems and automated vehicles. Figure 3 provides a detailed overview of the concept, highlighting the key components and their interactions. The following elements should be considered:

Intelligent Infrastructure: The automation strategy is built around an intelligent infrastructure comprising a central monitoring system with Lidar and camera systems. This infrastructure detects and monitors all objects within the terminal, integrating this data into a centralized control system. This setup is crucial for ensuring that the vehicles can navigate the terminal environment safely and efficiently.

Automated Driving and AVP: The vehicles within the terminal are equipped with Level 4 automated driving capabilities, allowing them to operate without human intervention. Additionally, Automated Valet Parking (AVP) systems are implemented to enable the automated parking and retrieval of vehicles. The AVP system follows the ISO 23374 standard, ensuring compatibility with modern electric vehicles. This standardization is essential for integrating new and existing technologies seamlessly and for manufacturer-independent connection to vehicles.

Communication Systems: The control of automated vehicles is facilitated through robust communication systems that utilize public 5G networks. This ensures fast and reliable data transmission, essential for real-time vehicle control and coordination. Multi-Access Edge Computing (MEC) is employed to reduce latency and enhance the responsiveness of the system. This infrastructure is critical for managing the large volumes of data generated by the sensors and ensuring timely decision-making.

Human-Technology Interaction: To ensure safe and efficient operations, the concept includes various interfaces for human-technology interaction. These interfaces provide real-time updates and allow for manual overrides if necessary. Safety measures are integrated to manage environments where automated and manual processes coexist. Effective human-technology interaction is crucial for handling unexpected situations and maintaining safety standards. Furthermore, to ensure that manual processes are not interfered too much by the new implemented automated processes and to increase the usability of the new system for workers.

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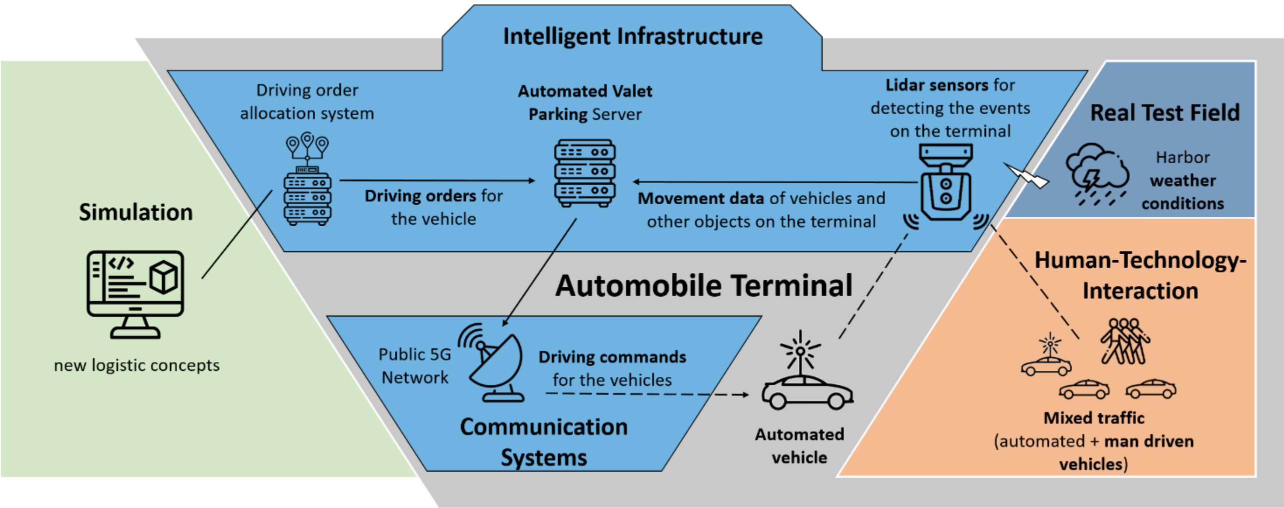

Figure 3. *Technical concept*

Environmental Adaptability: The system is designed to operate effectively under various environmental conditions typical of seaports and inland terminals. This includes poor visibility, extreme weather conditions, and physical obstacles. The intelligent infrastructure's sensor systems are capable of detecting and responding to such challenges, ensuring continuous and safe operations. This adaptability is vital for maintaining operational efficiency in diverse and potentially harsh environments. These issues are tested on a real test field to ensure the functionality.

5 DISCUSSION

This section discusses the implications of the proposed technological concept for integrating automated driving within automotive terminals, addressing potential challenges, anticipated benefits, and future research directions.

The integration of automated driving technologies in automotive terminals promises to revolutionize terminal operations by significantly enhancing efficiency, safety, and overall productivity. Advanced sensor technologies, such as Lidar and cameras, enable precise navigation and monitoring of vehicle movements, reducing the dependency on human intervention. This shift is expected to streamline vehicle handling processes, minimize errors, and optimize space utilization. Implementing Automated Valet Parking (AVP) systems in accordance with ISO 23374 standards ensures compatibility with modern electric vehicles and supports the broader adoption of automated technologies. Robust communication systems leveraging 5G networks and Multi-Access Edge Computing (MEC) are critical for real-time data transmission and effective vehicle coordination, addressing latency issues and enabling timely decision-making.

Despite the promising outlook, several challenges must be addressed to ensure the successful integration of automated driving technologies in automotive terminals. Managing the coexistence of automated and human-driven vehicles presents significant challenges. Clear communication protocols and safety measures are essential to prevent accidents and ensure smooth operations. Developing intuitive interfaces for human operators to interact with automated systems and providing manual override options in case of emergencies are crucial for maintaining safety standards. Additionally, automated systems must operate effectively under diverse environmental conditions typical of seaports and inland terminals, such as poor visibility, extreme weather, and physical obstacles. Ensuring the reliability and robustness of sensor systems in these conditions is crucial for continuous and safe operations.

The proposed concept for integrating automated driving technologies within automotive terminals is expected to yield several benefits. Automating vehicle movements can streamline processes, reduce bottlenecks, and increase throughput, leading to improved overall efficiency. Precise navigation and dynamic space allocation strategies can enhance space utilization rates within the terminal, reducing congestion and maximizing the use of available space. Robust safety protocols and predictive algorithms can minimize the risk of accidents, ensuring a safer working environment for human operators and reducing damage to vehicles. Decreasing dependency on manual labor can lead to cost savings and more consistent operational performance, addressing labor shortages and variability.

Future research will focus on the practical implementation of the proposed concept through a prototype project. This will involve deploying automated vehicles and AVP systems in a controlled section of the terminal, followed by a comprehensive evaluation of their performance. Key metrics such as throughput, space utilization, and labor efficiency will be measured to assess the impact of the integration. Ongoing simulation models will continue to be refined, providing further insights into potential improvements and adjustments. Particularly in storage and logistics concepts. By eliminating the dependency on driving personnel, these terminals can operate without the limitations of working hours and personnel availability, allowing for night-time pre-sorting of vehicles to streamline subsequent transport processes. Automated driving facilitates the implementation of chaotic storage strategies, which optimize space utilization more effectively than traditional clustering methods. It also enables more efficient loading and unloading procedures, including reverse driving for unparking, which enhances access to vehicles in densely packed areas. Additionally, the flexibility to create spontaneous aisles and utilize larger blocks within the terminal layout further maximizes yard space utilization. Optimizing the processing of driving orders to minimize traffic congestion and integrating vehicle platoons can further enhance operational efficiency. Automated vehicles can also dynamically close gaps in parking areas, ensuring a consistently high utilization rate of the terminal space. Overall, these advancements promise significant improvements in the efficiency and capacity of automotive terminal operations [23].

Furthermore, collaboration with industry partners, regulatory bodies, and stakeholders will be crucial to address challenges and ensure the successful adoption of automated driving technologies in automotive terminals.

6 Conclusion

In conclusion, this paper presents a comprehensive analysis and conceptual development for integrating automated driving technologies within automotive terminals. The process analysis identified critical bottlenecks, inefficiencies in space utilization, and high labor dependency. Addressing these issues, the proposed technological concept incorporates advanced sensor technologies, robust communication networks, and Automated Valet Parking (AVP) systems. This integration is expected to enhance operational efficiency, optimize space utilization, and improve safety within the terminal environment. Future research will focus on implementing a prototype and conducting detailed evaluations to validate the proposed concept. Parallel to the pilot implementation of the intelligent infrastructure and field testing at the automotive terminal, simulation studies are being conducted to assess the overall impact on the terminal and to test new storage and logistics methods enabled by automated vehicle movements. Additionally, interfaces for human-technology interaction are being developed and tested to ensure a smooth transition from manual to automated processes for the driving personnel. The insights gained from this study will inform broader applications of automated technologies, ultimately transforming automotive terminal operations.

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