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Autonomous Transportation Systems in Manufacturing Enterprises: A Comprehensive Analysis of the State of the Art in Driverless Transport Systems

Franz Ferdinand Anders, Alexander Mewes, Serkan Özmen, Julia Teppan, and Manuel Woschank
Research Group SAFdL
Chair of Industrial Logistics
Montanuniversität Leoben
Leoben, Austria
manuel.woschank@unileoben.ac.at

Abstract

This paper explores the evolving landscape of autonomous transportation systems in manufacturing, focusing on reducing manual labor and enhancing operational efficiency. Automated guided vehicles (AGVs) are widely adopted, integrating Artificial Intelligence and Big Data Applications. The imperative for companies to embrace these technologies and navigate innovation challenges is highlighted. Recent AGV developments are systematically reviewed using the PRISMA method, categorizing findings and assessing their implications. The historical evolution of autonomous vehicles, including milestones like DARPA's Grand Challenge, is traced. The methodology involves a structured literature search ensuring relevance and reliability. Results indicate increased AGV prevalence in manufacturing, offering advantages like 24-hour operation and optimized warehouse operations. The conclusion emphasizes safety, efficiency, and adaptability benefits, with future perspectives anticipating advancements driven by Artificial Intelligence. Market growth is projected to enhance accessibility, with collaborative efforts shaping regulatory frameworks. Convergence with Industry 4.0 technologies unlocks new possibilities, fostering data-driven decision-making. This paper underscores the critical role of comprehensive analyses for optimal integration into the evolving landscape of Industry 4.0.

Keywords
Autonomous Transport Systems, Driverless Transport Systems, Autonomization, Smart Logistics, Logistics 4.0

1. Introduction
The main goals of automatization are the reduction of manual labor, reducing the risk of injury, human failure, and the wastage of resources like time or space. To realize these goals and to further improve the efficiency of such factories Automated Guided Vehicles have become a widespread choice (Joppen et al. 2023).

As Industry 4.0 becomes a global industry standard, it also increases the possible usage of driverless transport systems among manufacturers. Examples of these new opportunities can be seen in the usage of Artificial Intelligence, Big Data Applications as well as the further expansion of smart devices, especially smart transporting machinery, which can combine in-house logistics with other departments along the production chain (Tsolakis et al. 2022). Another driver contributing to the latest innovations in this field is the widespread implementation of research, adaptation of development measures and the start of production of self-driving cars and motor vehicles. These research findings can be applied to and tested in the more secure environment of a closed factory with limited outside influences, as well as gaining useful development techniques and knowledge to further improve the self-guided vehicles already in use. It

has also led to an increase in attention for that matter in terms of awareness of the existence of these technologies as well as the possible forms of usage, leading to a further increase in resources, especially concerning funding and new enterprise sections and opportunities, directed to driverless transportation systems (Becker et al. 2020; Bissell et al. 2020). But one of the biggest changes made in recent times is referring to the overhead term of the driverless transportation technology itself, which is the autonomy of the vehicles. While older mechanized driverless systems still needed special environmental guidance such as cables or induction lines, newer models can operate by themselves using machine learning by AI, operating via ANNs and are therefore even more autonomous. This also improves their abilities, as it improves their functioning radius and fields of usage (Nishida and Nishi 2023).

These innovation boosts have led to a series of innovations concerning autonomous transportation systems and therefore to a lot of changes by the implementation of new technologies. Because of that, there is a common need to focus on the introduction of state-of-the-art technologies among manufacturing companies, as well as the growing importance of the goal of keeping up with the latest innovations. This task is also getting harder because of the growing speed of such innovations, being fueled by the increase of attention, resources, accessible technologies which can be integrated and the introduction of artificial intelligence as a form of improvement and as an integrated feature. As the choice of possible options grows, an analysis of the modern-day best practices is also becoming more useful to determine the best-suited product and application for individual usage of driverless transportation technologies. But with every solution, there are also certain parameters, such as resources needed for implementation and sustaining a certain technology, as well as financial costs of certain solutions and their ability to adapt to future innovations. Also, safety regulations as well as legal boundaries of certain places of production must be applied by the companies introducing new solutions. These parameters should always be considered and are a part of the comprehensive analysis. This paper aims to give an overview of some of the most important recent developments in the field of Automated guided vehicles, with a special emphasis on the importance of these developments in manufacturing enterprises and production. We are therefore systematically analyzing published results of certain techniques using the PRISMA method and evaluating their impact on further possibilities in this field.

2. Literature Review

Theories of autonomous vehicles have been coursing around since the 1950s but were limited due to the constraints of technological research and advancement of that time. It wasn't until the 1980s that the first significant strides in computational technologies were made, which allowed furthermore sophisticated experimentation and research in the field of automation (Halin et al., 2021). The advancements in Artificial Intelligence and Machine Learning during the 2000s marked a critical period in the advancement of autonomous systems. The first innovations in this field were enabled by the so-called DARPA's Grand Challenge, a robotics competition for driverless automobiles funded by the Defense Advanced Research Projects Agency's technology department of the U.S. Department of Defense. Integration in terms of advanced sensors such as (Global Positioning Systems) and LiDAR (Light Detection and Ranging) during the 2010s made the topic more accessible to the world increasing emphasis in the field of autonomous systems and driverless transport systems. The first well-known project that saw a driverless car gain the eyes and interest of future competitors was the Google Self-Driving Car Project in 2009 (Singh and Saini 2021) later named Waymo in 2016. Companies such as Tesla and Google were the first big names to bring innovation to the public and thus made driverless vehicles not only a matter for military defense purposes but for all people. Google's approach to the topic of autonomous driving sees a self-sustaining ideology in terms of innovation. The collection of data throughout years of research regarding information on maps and navigation was provided by themselves to further enhance the development of autonomous driving. (Sehajbir and Singh 2020). Nowadays the focus is set on refining technology and ensuring safety. The increasing emphasis on the potential of autonomous vehicles reason for the transformation of urban transport, labor, logistics and personal mobility. Here it is to be seen that driverless vehicles and intelligent transport systems are further on the evolution path (Kröger 2021). Both are still reliant on further innovation. Nevertheless, it seems like the theme is still on refining the state and development of AI and Machine Learning the ensure a high standard upon entrance into the public (Bissell et al. 2020).

3. Methods and Data Collection: Systematic Literature Review

To obtain a precise and up-to-date overview of the state of the art in the field of driverless transportation systems in industrial companies, a structured literature search was carried out using 'Scopus' and 'Scimago' as well as 'Google Scholar'. Various search strings were used for this purpose. Examples include the following links and terminologies:

- 'Driverless transportation systems' AND 'industries'

- 'Autonomous vehicles' AND 'warehouses'
- 'modern warehousing systems'
- 'Driverless transportation systems' AND 'state of the art'

Furthermore, the search results obtained were narrowed down to papers from Q1 and Q2 journals and selected for a maximum publication date of five years in the past to be able to answer the research question as up-to-date as possible. The selected approximately 150 articles were then analyzed using the PRISMA method to filter out the relevant content as effectively as possible (Kaiblinger and Woschank 2022; Miklautsch and Woschank 2022; Pacher et al. 2024; Page et al. 2021, Woschank et al. 2020). The procedure for this is shown in Figure 1 to give an overall impression of the method.

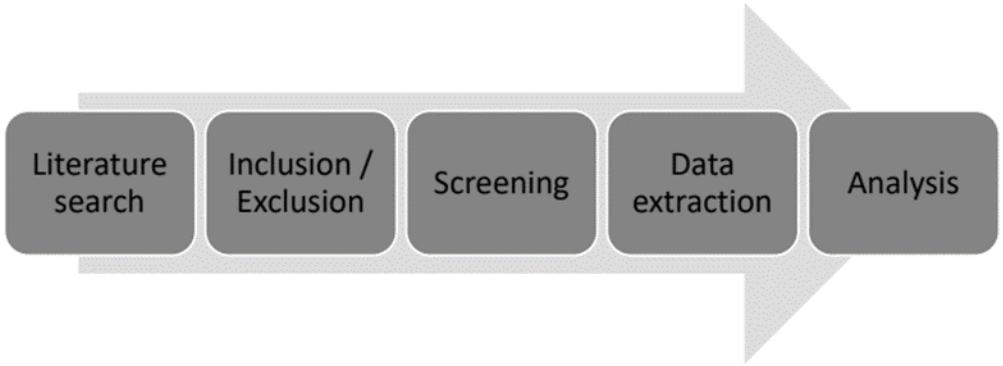

Figure 1: PRISMA Process (Page et al. 2021; Pacher et al. 2024)

4. Results and Discussion

As already briefly explained in the previous section, the search results obtained were selected according to the criteria of author, title, and year of publication. In the area of the research question we defined, there was a very low proportion of publications before 2019. After a renewed slump in the years of the COVID-19 pandemic, driverless transport systems in the industrial sector experienced an upswing again from 2021 and especially in the past year 2023. Research interest therefore appears to be very high, especially in the last two years. In addition to the industrial application of these vehicles, which do not require a human driver, there has also been a significant increase in the number of publications in the field of local public transport. However, we excluded these papers as they were not relevant to answering the research question.

After applying the selection criteria, we were left with around 20 papers that we examined more closely. As this is a manageable number, we read through each of them individually and highlighted and summarized important passages. These summaries were then used to write the following sections and find an answer to the research question posed. The main criteria here were 'relevance', 'topicality', 'comprehensibility' and 'practical relevance'. This revealed the following key aspects of the use of driverless transport systems in an industrial environment: The advantages of using this technology (e.g.: unlimited working hours of 24 hours, increased efficiency, and no human-related accidents during transportation processes) (Pakasoy 2021). The use of driverless transport systems in industry has increased massively in recent years. Among other things, these ensure smooth transportation within the warehouse, whereby they move independently to their destination on programmed routes. With newer systems, it is also possible to switch between manual control and autonomous driving, depending on the complexity of the task to be performed (Custodio and Machado 2020). Another important point to mention is that although autonomous transportation systems have been in use since the 1950s, the number of tasks that can be handled today is much higher. The latest sensors and navigation mechanisms are being used to further increase efficiency and safety in the warehouse of the future (dos Reis and Morandin 2021). This is an aspect of today's driverless transport system technology that should not be neglected, as occupational safety is often a point of discussion about the use of driverless systems. Therefore, it is also part of the current application philosophy of these systems to ensure the highest possible level of safety for "real" personnel. To this end, technologies are primarily used to detect obstacles or threats at an early stage to ensure that the vehicle reacts correctly using a wide range of mechanisms (Javed et al. 2021). During this research, the safety

aspect was defined as the main point of today's use of driverless transport systems, which is considered using the latest sensor technology, as already mentioned (dos Reis and Morandin 2021).

5. Conclusion

From the viewpoint of Industrial Engineering and Management respectively from the interdisciplinary perspective of modern Engineering Education, it can be stated that the rapid development of driverless transport vehicles and automated transport systems has significantly changed the cooperation between manufacturing enterprises, production and logistics processes and ultimately the holistic integration of human beings in production and logistics processes (Pacher et al. 2022; Pacher et al. 2023; Pacher et al. 2024; Zunk and Marchner 2009; Zunk 2018; Zunk et al. 2020). The overall objectives of reducing manual labor, minimizing the risk of human error and injury, and optimizing the use of resources were the driving forces behind the widespread adoption of these technologies. The advent of Industry 4.0 has further accelerated the integration of driverless transport vehicles, leveraging advances in artificial intelligence, big data applications, and smart devices.

The paper stresses the importance of keeping up with the latest developments in driverless transport system technology, given the dynamic nature of innovations in this field. The growing speed of progress, fueled by increased attention, resources, and accessible technologies, presents a challenge for manufacturing companies to follow the latest best practices. A comprehensive analysis is therefore essential to select the most suitable products and applications for individual requirements. One of the primary lessons learned from the current state of autonomous transportation systems is the paramount importance of safety, efficiency, and adaptability. These three pillars have become the cornerstone of the successful implementation and integration of autonomous technologies in manufacturing environments. Looking ahead, we can anticipate a continued emphasis on refining and enhancing the safety features of autonomous transportation systems. As technology progresses, sensor capabilities will likely see improvements, enabling more precise obstacle detection, threat identification, and responsive mechanisms to ensure a heightened level of safety for both autonomous vehicles and human personnel. Efficiency, another key attribute of autonomous transportation systems, is anticipated to witness significant advancements. The ongoing research and development in the field of artificial intelligence, machine learning, and navigation algorithms will contribute to the optimization of routes, task management, and resource utilization. The integration of real-time data analytics and predictive modelling may further enhance the decision-making capabilities of autonomous transportation systems, allowing for adaptive and intelligent responses to dynamic manufacturing environments. Adaptability will be a critical factor influencing the evolution of autonomous transportation systems. The ability of these systems to seamlessly switch between manual control and autonomous driving will likely become more sophisticated. This adaptability is crucial for addressing the diverse and evolving needs of manufacturing processes. As industries continue to embrace smart manufacturing concepts and the Internet of Things, autonomous transportation systems will play a pivotal role in providing flexible and agile solutions. Looking at the broader industry trends, collaborative efforts among key stakeholders, including manufacturers, researchers, and policymakers, will shape the regulatory landscape for autonomous transportation systems. Clear and standardized regulations will be essential to facilitate widespread adoption, ensuring a harmonious integration into existing industrial frameworks. As industries increasingly recognize the benefits of autonomous transportation systems, we can expect continued collaboration between technology providers and manufacturing enterprises to drive innovation and address industry-specific challenges.

In the next five to ten years, the market for autonomous transportation systems is likely to experience significant growth. The affordability and accessibility of these technologies are expected to increase, enabling a broader spectrum of manufacturing companies to embrace automation. Small and medium-sized enterprises may find more tailored and cost-effective solutions, contributing to the democratization of autonomous transportation systems. Furthermore, the convergence of autonomous transportation systems with other Industry 4.0 technologies, such as the Industrial Internet of Things and cloud computing, will unlock new possibilities. The seamless integration of data from various sources will provide a holistic view of manufacturing processes, fostering data-driven decision-making and optimization.
In conclusion, the current state of autonomous transportation systems technology reflects a decisive focus on safety, efficiency, and adaptability in industrial applications. The continuous refinement of sensor technology and navigation mechanisms underlines the desire to ensure the highest level of safety for both autonomous vehicles and human personnel. As technology continues to evolve, it is critical for manufacturing companies to manage the complexities of implementation, considering factors such as resource requirements, financial costs, regulatory requirements, and the ever-increasing pace of technological progress. The results of the study underline the importance of a comprehensive analysis to guide the selection and integration of state-of-the-art AGV technologies to ensure optimal performance and adaptation to the changing landscape of Industry 4.0.

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Biographies

Franz Ferdinand Anders, Alexander Mewes, Serkan Özmen and Julia Teppan are students of the working group SAFdL in the study programme Industrial Logistics at Montanuniversität Leoben in Austria.

Manuel Woschank received a Ph.D. in Management Sciences with summa cum laude from the University of Latvia and the Habilitation in Industrial Engineering and Management from the Montanuniversitaet Leoben. He is currently Deputy Head of the Chair of Industrial Logistics at the Montanuniversitaet Leoben and an Adjunct Associate Professor at the Faculty of Business, Management, and Economics at the University of Latvia. He was a visiting scholar at the Technical University of Kosice and the Chiang Mai University. His research interests include the areas of logistics systems engineering, production planning and control, smart logistics/logistics 4.0 concepts and technologies, circular economy and the decarbonization of logistics systems, behavioral decision-making, and engineering education.

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