Automating Loading and Unloading for Autonomous Transport: Identifying Challenges and Requirements with a Systems Approach

Tarun Kumar Agrawal[1], Robin Hanson[1](✉), Farook Abdullah Sultan[1], Mats I. Johansson[1], Dan Andersson[1], Gunnar Stefansson[1], Konstantina Katsela[2], and Michael Browne[2]

[1] Chalmers University of Technology, 41296 Gothenburg, Sweden
robin.hanson@chalmers.se
[2] University of Gothenburg, 40530 Gothenburg, Sweden

Abstract. The logistics industry has undergone significant changes due to high demand, competition, cost pressures, interruptions, and labor market limitations affecting supply chains. As a result, there has been a significant adoption of automation in internal logistics such as warehousing, stock control, and material handling, leading to increased organizational competitiveness by reducing manual labor costs and time spent on these operations. The use of autonomous road transport holds potential to improve transport performance within areas of safety, sustainability, and efficiency. However, for autonomous transport to be fully realized, loading and unloading processes at shipping and receiving facilities must also be automated. This paper takes a systems approach to identify the challenges and requirements for automated loading and unloading in a setting of autonomous truck transport potentially within a production setting. By addressing these challenges and meeting the necessary requirements, it may be possible to fully realize the benefits of autonomous transport and improve overall transport performance.

Keywords: Material handling · Warehouse · Automation · Loading · Unloading

1 Introduction

The logistics industry has undergone significant changes due to factors such as high demand, competition, cost pressures, interruptions, and labor market limitations affecting supply chains. These factors, along with the expectation for shorter lead times and increased product availability, have resulted in the adoption of automation to overhaul conventional logistics practices. One area of logistics that has seen significant automation is internal logistics, which includes warehousing, stock control, and material handling. Automating these processes has led to increased organizational competitiveness by reducing manual labor costs and time spent on these operations. At the same time,

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there is an ongoing development towards autonomous road transport, which holds a potential to improve transport performance within areas of safety, sustainability, and efficiency, and there is an increasing interest in the area [1]. However, with autonomous truck transport, the loading and unloading of the trucks can become an issue, because, in traditional setups, the truck driver is often responsible for these tasks. Without a driver, an alternative solution must be found.

One potential solution is for personnel at the facilities to handle the loading and unloading. However, with the increasing use of automation in production and warehousing [2, 3], it may not be possible to rely on personnel at these locations either. In addition, many facilities are only manned during daytime hours, which could limit the availability of personnel for loading and unloading tasks. If these processes were automated, it could enable round-the-clock deliveries and reduce operational costs.

To achieve automated loading and unloading, several challenges and requirements must be addressed. These processes occur at the interface between shipping and receiving facilities and external transport systems. There are also upstream and downstream processes that are linked to loading and unloading, which may need to be managed to ensure the smooth flow of materials. Moreover, relevant information must be captured and utilized to enable successful management of the material flows.

This paper takes a systems approach and aims to identify the challenges and requirements for automated loading and unloading in a setting of autonomous truck transport, potentially within a production setting. Additionally, the study utilizes requirement engineering to identify the necessary specifications for automating the loading and unloading processes in the context of autonomous transport. By addressing the challenges and meeting the necessary requirements, it may be possible to fully realize the benefits of autonomous transport and improve overall transport performance.

Next, in Sect. 2, the paper's frame of reference is presented. Thereafter, Sect. 3 presents the methodology of the paper, which is mainly based on an in-depth case study. In Sect. 4, the case is presented and analyzed. Thereafter, in Sect. 5, a discussion of the results is outlined. Finally, Sect. 6 presents the conclusions of the paper.

2 Frame of Reference

This section describes a brief review of literature, including the research gap in the State of the art sub-section. This is followed by a short overview of the theoretical lens followed in this study i.e. the systems approach and requirements analysis.

2.1 State of the Art

The logistics automation market is predicted to grow significantly in the coming years, with automation being implemented in warehouses, material handling systems, transportation, order fulfilment, and inventory management. Despite these advancements, relatively little attention has so far been paid to the potential automation of the processes of loading and unloading, which comprise a crucial aspect of logistics involving material handling and act as interfaces between warehouses and transportation. Some research has been directed towards the area, often proposing solutions for managing certain aspects of the loading and unloading. Shen et al. [4] propose a framework for automated loading and unloading, utilizing parallel execution of a physical and an artificial system. Zhu et al. [5] apply digital twin technology in design and develop of an intelligent control system for automatic loading and unloading. Cao and Dou [6] propose a method for implementation of automating loading and unloading of containers by use of an automated forklift. Wilhelm et al. [7] evaluate a proposed solution for semi-autonomous container unloading. Stoyanov et al. [8] also address the area of unloading of containers, outlining challenges associated with robotic unloading. The study deals largely with the robotic handling of goods, including aspects of perception, motion planning, and grasping. With their focus on container unloading, the studies of Wilhelm et al. [7] and Stoyanov et al. [8] do not address aspects such as automatically opening the gate of the truck or securing the cargo, which are included in the current paper, applying a broader scope that includes both loading and unloading and addressing a setting of autonomous truck transport. Altogether, widespread implementation of solutions for automated loading and unloading is still lacking and there is a lack of clarity regarding which technology type to choose, not least in the context of autonomous truck transport. Further knowledge is needed given the wide variations and constraints in handling different sorts of unit loads and challenges in selecting appropriate equipment based on facility constraints and operation uncertainty involved.

2.2 Systems Approach

The application of a systems approach is rooted in the understanding that processes and activities are interconnected, forming a complex whole. In a system, elements are interdependent and interact with one another to produce a unified outcome. To illustrate, a supply chain comprises partner firms, each of which can be seen as a system with various subsystems, including production, inbound and outbound. According to Checkland [9], a system is characterized by several key features. First, a system has emergent properties, meaning that it has characteristics that make it possible to view it as a single entity, separable from its environment. Secondly, it displays a layered structure, so that it may comprise smaller subsystems or constitute a part of a larger system. Thirdly, to successfully interact with its environment, a system has processes of communication and control.

By adopting a systems approach, the study attempts to identify and manage the interdependent relationships between different components of the loading and unloading system. This approach can improve the processes, support decision-making, and enhance overall efficiency.

2.3 Requirements Analysis

Requirements engineering is the process of gathering stakeholder needs and desires and translating them into specific requirements to define the features and functions of a product or system. It aims to express the encountered problem in a clear and comprehensive manner and ensure that the solution is accurate, reasonable, and efficient. The primary goal of a program is to deliver a system that satisfies a given set of requirements that are generated internally or externally [10]. These requirements can be categorized into three sets: The business requirements refer to the overall objectives, goals, and needs of the system or service that needs to be provided. The user or stakeholder requirements are focused on the needs of those who will be using or affected by the system or service, including the stakeholders and operators [10]. The system requirements consist of the functional and non-functional requirements that are necessary to fulfill the customer's needs. Requirement analysis would enable in defining the scope of the loading and unloading system, identifying risks and constraints, and confirming that the end system would meets the desired needs. It also facilitates cost reduction by identifying possible issues early in the process.

3 Methodology

3.1 Case Description

The paper is based on a single case study at a production site where autonomous truck transport is being piloted. Focusing on this single case study, provided the opportunity to closely examine and explore the loading and unloading phenomenon in detail and offer flexibility in terms of research design and methodology. The autonomous truck is used to transport goods from a production plant to a nearby warehouse, with the aim of eventually implementing automated loading and unloading. The study is a collaboration between researchers from two universities and representatives from several companies involved in the project, including the manufacturing company, the autonomous truck provider, a company providing equipment for automated materials handling, and a company specializing in load securing solutions. Although, the study focuses on single case, the involvement of these different companies helped researcher to gain detailed insights into loading and unloading phenomenon but from different perspective i.e. not only the manufacturing company, also the automated material handling equipment provider, the autonomous truck, manufacturer and load securing solutions. Data was collected first with observations of the site with the whole project team and mapping the material flow. This helped to understand and examine not just the current manual loading and unloading process, but the interconnected processes included within the system boundaries. These processes would directly or indirectly impact the automation of the loading and unloading process. This was followed by in-depth interviews with the project team and the actors involved in the current LUL operation. At last, a focus group discussion between the researchers and representatives from the companies involved in the project was conducted to make an exhaustive list of challenges and requirements and make unsupervised clusters.

3.2 Data Collection

Observations and Materials Flow Mapping. The use of observations constitutes a valuable data collection method that involves closely examining behaviors, events, or physical characteristics in their natural setting. This technique can yield rich and nuanced insights into a wide range of phenomena, making it a popular choice in research fields.

The study followed direct observation through multiple site visits to understand in real-time the current process flow as interactions take place, which allowed us to capture the details of the material flows and of the activities associated with it.

To create a detailed understanding of the material flows and of the associated activities, a careful mapping was performed, based on information from the observations complemented with interviews. The materials flow mapping methodology was applied, based on the outlining of Finnsgård et al. [11], who proposed the materials flow mapping methodology as a development of value stream mapping [12].

The material flow mapping applied in the paper is slightly modified compared to the one used by Finnsgård et al. [11] and highlights the following entities occurring in the studied material flow: activities of *handling* and *transport*, as well as points in the flow where the materials are kept waiting, illustrated as *inventory* in the flow map. A *transport* activity has the purpose of transporting goods between two points. A *handling* activity instead involves a shorter movement of the goods, for example in the shift between two different modes of transport or in a sorting activity. In addition to describing the movement of the materials, the mapping also considers supplementary activities, which support and enable the movement and control of the material flow. Specifically, *administration*, *decisions*, and *enabling activities* are highlighted, where the latter two categories are not included in the material flow mapping methodology developed and applied by Finnsgård et al. [11]. *Administration* refers to activities of information handling, for example labelling or scanning barcodes. *Decisions* refer to issues like selecting which pallet to pick first or which lane to place pallets in. Issues like these may hardly be acknowledged in a manually operated flow but may be critical in a context of automation. *Enabling activities* are physical activities which are required for the material flow, but which do not focus on the goods themselves. An example of an enabling activity is the opening of a gate to enable the flow to pass through.

Interviews and Focus Group Discussions. Interviews are a popular method of research data collection that involve assessing the interviewee's perspectives on the topic at hand. Interviews are one of the most widely used and effective methods of research data collection. Interview technique was incorporated to engage with stakeholders that were directly or indirectly interacting with the loading and unloading system, and we asked them questions regarding the requirements and challenges in automating the system, in order to gain a deeper understanding of their perspectives on the topic.

Following the interviews, a focus groups discussion was performed with the different stakeholders involved in the project. It included researchers from two universities and representatives from the manufacturing company, the autonomous truck provider, a provider of equipment for automated materials handling, and a company specializing in load securing solutions. Everyone from the focus group visited the site at the case company to understand in real-time the current process and later discussed and provided list of requirement and challenges associated with automating the system. Before the focus group discussion, the participants were also shown an initial version of the mapping of the material flow at the case site, as input to the discussion.

4 Case Analysis and Results

This section presents the findings from the observations, interviews, and focus group study. It first presents the broader systemic description of the case company and focal system which is in this the outbound logistics system, to set the system boundaries.

4.1 Systemic Description of Case Company

As described in the methodology section, the case study focuses on the outbound material flow from a production process, with associated activities like information flows, administration, inventory, and transportation of finished goods from a manufacturing plant to a nearby warehouse. This would also be our system's boundaries i.e. starting from outbound material flow from production and ending at inbound of the nearby warehouse. This can be further visualized through Figs. 1 and 2. The plant produces industrial components in a B2B setting for customers all over the world. The products are made of steel and are therefore heavy. They vary in size, but in the studied flow, all products are handled on pallets with a size of 800 mm x 600 mm. The warehouse is operated by the manufacturing company itself, whereas the transports between the plant to the warehouse are operated by an external party. Currently, regular trucks are used for the transports, but a pilot is ongoing in parallel, where autonomous trucks, operated by a different external party, are used. The case study utilizes data largely from the regular flows and the activities included there, but as described in the methodology section, it uses insights from the pilot as well.

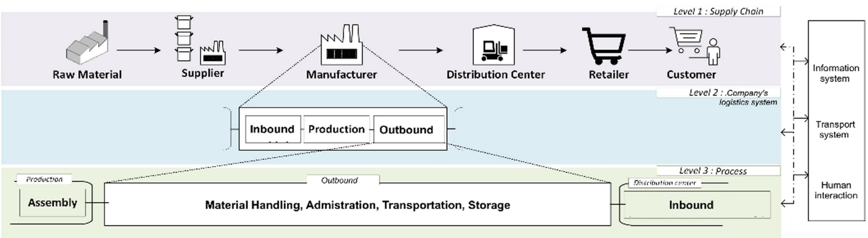

Fig. 1. Systemic visualization of the case company and focal system

4.2 Flow Mapping

The finished goods are first moved from the production shop floor to an in-house dispatching area, located one floor below the shopfloor, from which they are loaded onto the trucks. The case study follows the flow from the point where they leave the production shop floor up to the point when they have been unloaded and organized at the warehouse. The material flow, along with associated activities and information flows, is represented in the material flow map presented in Fig. 2 and 3 and is described in below.

In the first step included in the material flow map, the goods are waiting on a roller conveyor, located in the dispatching area of the manufacturing plant. Preceding this, and thus not included in the material flow map, the goods have been transported down from the shop floor, onto the roller conveyor, by use of an automatic lift, which is in turn fed with goods by forklifts (both automated and manually operated) on the shop floor. As can be seen in Figs. 2 and 3, the goods are subject to several activities on their way from the roller conveyor to the warehouse, including several process steps of Transport and Handling, and the goods are also kept waiting in many places, thus qualifying as Inventory according to the material flow mapping methodology. Also indicated in the material flow map presented in Figs. 2 and 3, there are activities of administration taking place, and there are decisions being made and enabling activities taking place to support the flow.

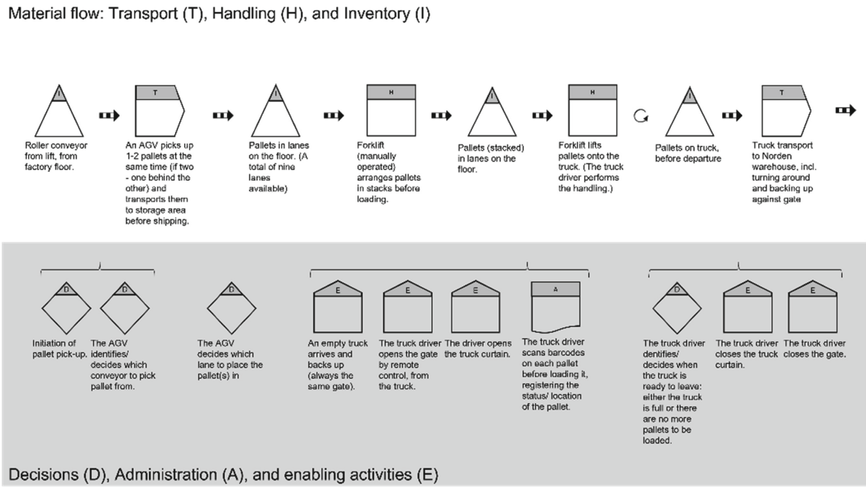

Fig. 2. The first part of the material flow map, illustrating the material flow and associated activities within the manufacturing plant as well as the transport to the warehouse. The flow map includes entities symbolizing handling (H), transport (T), inventory (I), Decisions (D), Administration (A), and Enabling activities (E).

4.3 Requirement Analysis

Several requirement and associated challenges were identified through focus group discussions and interview in automating the loading and unloading system. These were further clustered in themes presented in following section. Tables in each section describes the different requirements, associated observations that were made in the case company and challenges in fulfilling the requirements.

Physical Characteristics of the Load

Physical characteristics of load determine important aspects and place essential requirements for the automation of loading and unloading in autonomous truck transport. These are discussed in the Table1:

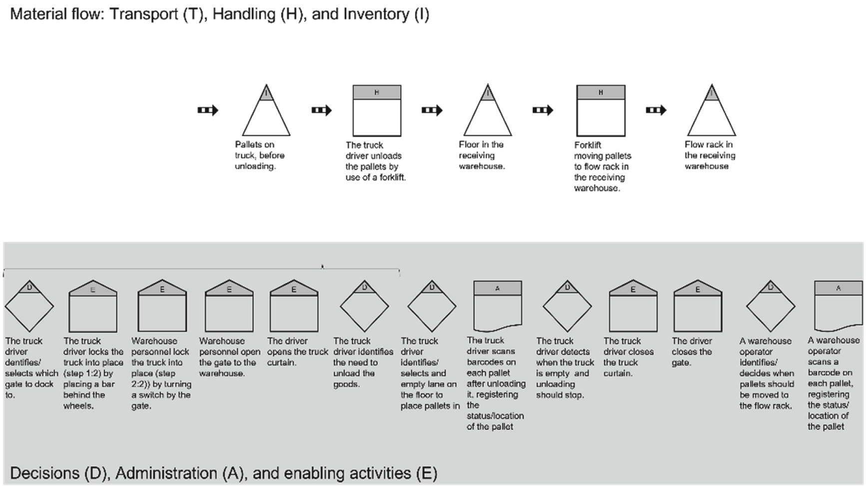

Fig. 3. The second part of the material flow map, illustrating the material flow and associated activities from the point when the goods arrive at the warehouse. The flow map includes entities symbolizing handling (H), transport (T), inventory (I), Decisions (D), Administration (A), and Enabling activities (E).

Table 1. Requirements and challenges associated with physical characteristics of load.

Requirements	**Observations**	**Challenges**
Ensuring the safety and preventing damage of the goods during storage and stacking	The goods are not always uniform in terms of dimensions, weight, packaging and have different stacking capabilities	Non-uniformity of goods
Weight distribution needs to be planned for safe and legal operations	The number, weights and sizes of pallets can vary for each shipment that have effect on weight distribution on the autonomies truck as well as max. Payload requirement	Non-uniformity of goods Arrangement of goods to ensure uniform distribution of weight on the truck
Automatic detection and recognition of size, weight, and type of good, to ensure correct loading	Pallet dimensions are not always the same and we need to know the size to be able to do loading correctly. Moreover, in an autonomous loading operation, identifying the type of goods is a challenge	Non-uniformity of goods

Planning and Interaction with Information System

The process of planning and interaction with information systems is crucial for the successful automation of loading and unloading in autonomous truck transport. The following Table 2 summarizes the key points:

Table 2. Requirements and challenges associated with planning and interaction with information system

Requirements	Observations	Challenges
Automated registering of goods	Pallets are currently manually scanned by a driver (or staff) before loading and after unloading	Selection of optimum location and type of identifier tag (technology) to ensure automatic detection through long- or short-range reader
Efficient communication among different systems	Transportation of goods requires multiple systems, including those for autonomous driving and loading/unloading. Communication between these systems needs to be linked	Interoperability of different information system, as there can be different make and supplier of these systems
Clear division of responsibilities	Clear boundaries need to be established for who initiates and ends loading/unloading, and how to communicate between involved parties	Parties might have conflicting interests and objectives
Planning an optimum loading sequence	A fixed time schedule is required that can ensure optimum number of pallets for loading/unloading and the sequence	A specific sequence should be considered and investigated for its effects on the sending/receiving sides, which is currently missing

Transportation onto and off the Trailer

See Table 3

Table 3. Requirements and challenges associated with transportation onto and off the trailer

Requirements	Observations	Challenges
Ensuring safe transportation of the goods from production line to loading area while avoiding potential harm or accidents involving human and machine	In a loading/unloading area, there are few fixed objects, and a lot of things and people are usually moving around	Dynamic environment
Ensuring safe loading and unloading of the goods while avoiding potential harm or accidents involving human and machine	There can be situations where manual and autonomous loading/unloading are done in the same area, maybe side by side. This situation can have effects on both operations in different ways	Dynamic environment. Autonomous & manual operations mix
Ensuring automatic coupling of the loading bay and cargo hold of the autonomous truck with a dock lip	Loading bay and cargo hold of the autonomous truck requires a loading bay interface also known as dock lip, to be manually placed (before loading/unloading) and removed (after loading/unloading) on the cargo hold to enable smooth loading/unloading activities	The height difference between the loading bay and cargo hold
Replacing manual decision making currently done by the truck driver while loading and unloading goods to automated one. AGV capabilities need to be built in a way to handle different situations	When loading/unloading, there are a lot of decisions/steps that are today handled by a physical driver	To explore, understand and implement extra features must be added to the autonomous truck, AGV engaged in transporting goods from production line onto and off the truck and loading bay

Arranging and Securing (and "Unsecuring") the Load on the Trailer

See Table 4

Table 4. Requirements and challenges associated with arranging and securing (and "unsecuring") the load on the trailer

Requirements	**Observations**	**Challenges**
Ensure optimum fill rate Ensure goods safety and security while transportation in the autonomous truck. Ensuring that the goods do not topple off the truck and onto the road	Due to dimension restriction of the autonomous truck storage area, there are small margins when loading multiple pallets side by side	Difficult/not possible with current AGV capabilities to load more than two pallets due to dimensions restrictions
Correct alignment of goods to prevent toppling	Small margins get even smaller when the double stacked pallets are not aligned. These situations currently require human interaction	Pallets are of different dimensions and type that requires automated and precise stacking
Ensure optimum fill rate Ensure goods safety and security while transportation in the autonomous truck Ensuring that the goods do not topple off the truck and onto the road	Different transport demands may cause a gap in the front of the cargo hold and different gap variations in the back and uneven stacking	Uniform load distribution with non-uniform goods (pallets) while ensuring no toppling due to potential empty space
Securely locking the goods to prevent toppling or any accident	Currently the goods are secured with strips and latches that require manual work and needs to be automated in order to reduce human interaction One of the biggest challenges for load securing is to find a generic and/or customizable solution that would apply to different types of cargo in different sizes and weights	Automating the load securing process with non-uniform goods (pallets) while ensuring no toppling Eliminating lashing as it is not feasible process Generic and customizable load securing mechanisms
Securely unlocking the goods to prevent toppling or any accident	This can be as problematic as load securing. Currently the goods are unlocked manually which needs to be automated	Automating un-securing process with non-uniform goods (pallets) while ensuring no toppling

Legal Aspects
See Table 5

Table 5. Requirements and challenges associated with legal aspects

Requirements	Observations	Challenges
Ensure accountability through traceable information related to state of the good at different stages in the system	In case of claims, there is need for information about if the goods were already damaged before loading or under transportation and when the damage occurred	Systems/solutions are needed to detect damages to facilitate traceability and manage claims The system needs to confirm that the load is secured in line with the requirements and regulations
Ensure safety of personal around the loading and unloading area	We need to make sure the solution is safe or ensure no one is around the area where autonomous loading/unloading activities are taking place	Dynamic environment. Autonomous & manual operations mix
Managing the claims and figuring out the liability	It is unclear who is responsible if something happens during load securing etc. Important to figure out for liability/insurance purposes, for instance in case of an accident	As multiple actors are involved along with automated machines which makes difficult to confirm accountability
Ensuring security of cargo and preventing theft	In case of an inspection request by the authorities, difficulties could arise to know when the authorities want the truck to stop and how the communication works afterwards	Risk for not being able to identify "fake" police or other authorities that have wrong intentions for the cargo

5 Discussion

Previous research on automated loading and unloading is scarce and the publications that exist are mostly focused on proposing solutions for certain aspects or steps of the loading and unloading processes [e.g., 5–8]. The current paper makes a contribution to existing theory by providing a broad perspective, taking a systems approach in providing insight regarding both the loading and the unloading operations and considering interfaces and links upstream and downstream. The paper is also rare in that it specifically addresses a setting of autonomous truck transport. This setting is especially challenging in that all process steps associated with loading and unloading, including cargo securing, need to be automated. Moreover, the paper makes a practical contribution by highlighting requirements and challenges that need to be addressed for a successful automation of loading and unloading processes. This knowledge can support an introduction of automated loading and unloading solutions, helping to clarify which requirements need to be fulfilled and which challenges need to be overcome to do so.

6 Conclusions

The manufacturing and logistics industry is facing various challenges like high demand, competition, cost pressures, interruptions, and labor market limitations, which are affecting supply chains. Adopting automation in internal logistics such as material handling, can lead to increased organizational competitiveness. Similarly, autonomous road transport has the potential to improve transport performance. Nevertheless, for full realization of the benefits of autonomous transport, loading and unloading processes at shipping and receiving facilities should also be automated. In this direction, this paper takes a systems approach to explore the challenges and requirements for automated loading and unloading in a setting of autonomous truck transport, within a manufacturing setting. The main requirements and associated challenges identified can be categorized into five clusters, (a) physical characteristics of the load; (b) planning and interaction with information system; (c) transportation onto and off the trailer; (d) arranging and securing (and "unsecuring") the load on the trailer and (e) legal aspects. By meeting the necessary requirements and addressing the associated challenges, it can be possible to fully realize the benefits of autonomous transport and improve overall transport performance.

The paper reports on an in-depth case study, where it was possible to carefully study the processes of loading and unloading, capturing the details of the material flow and of the activities supporting it. With this approach, it was possible to gain a comprehensive understanding of the requirements and challenges associated with the loading and unloading processes in the studied material flow. While the approach applied in the paper thus enabled a high level of detail, the study was limited to a single setting and to a single process design. Future research efforts could broaden the perspectives, studying further cases to be able to consider further settings and other process designs. By doing so, further requirements and challenges could potentially be identified, and further insight could be reached regarding potential links between requirements and challenges on the one hand and the process design and the environment on the other.

References

1. Sindi, S., Woodman, R.: Implementing commercial autonomous road haulage in freight operations: an industry perspective. Transp. Res. Part A: Policy Pract. **152**, 235–253 (2021)
2. Bortolini, M., Faccio, M., Galizia, F.G., Gamberini, M., Pilati, F.: Adaptive automation assembly systems in the industry 4.0 era: a reference framework and full–scale prototype. Appl. Sci. **11**, 1256 (2021)
3. Custodio, L., Machado, R.: Flexible automated warehouse: a literature review and an innovative framework. Int. J. Adv. Manufact. Technol. **106**, 533–558 (2020)

4. Shen, D., Hu, J., Zhai, T., Wang, T., Zhang, Z.: Parallel loading and unloading: smart technology towards intelligent logistics. In 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC), pp. 847–851. IEEE (2019)
5. Zhu, Z., Xu, X., Zhu, J.: Intelligent management and control of automatic loading and unloading system based on digital twin. In 3rd International Conference on Artificial Intelligence and Advanced Manufacture, pp. 328–332 (2021)
6. Cao, W., Dou, L.: Implementation method of automatic loading and unloading in container by unmanned forklift. In 2021 International Conference on Machine Learning and Intelligent Systems Engineering (MLISE), pp. 503–509. IEEE (2021)
7. Wilhelm, J., Hoppe, N.H., Petzoldt, C., Rolfs, L., Freitag, M.: Evaluation of performance and cargo-shock of an autonomous handling system for container unloading. Logist. Res. **15**(1), (2022)
8. Stoyanov, T., et al.: No more heavy lifting – Robotic solutions to the container-unloading problem. IEEE Robot. Autom. Mag. **23**(4), 94–106 (2016)
9. Checkland, P.: Systems thinking. In: Currie, W.; Galliers, B. (eds.) Rethinking management information systems, pp. 45–56. Oxford University Press (1999)
10. James A. Crowder, Curtis W. Hoff,: Categories of Requirements. In: James A. Crowder, Curtis W. Hoff, (ed.) Requirements Engineering: Laying a Firm Foundation, pp. 139–153. Springer International Publishing, Cham (2022). https://doi.org/10.1007/978-3-030-91077-8_11
11. Finnsgård, C., Medbo, L., Johansson, M.I.: Describing and assessing performance in materials flows in supply chains: a case study in the Swedish automotive industry. In: Proceedings of the 4th International Swedish Production Symposium, pp. 329–338 (2011)
12. Rother, M. and Shook, J.: Learning to see, Brookline: The lean enterprise institute (1999)