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SCALE - Supply Chain Automation of Loading/unloading for increased Efficiency	
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Nyckelord: 5-7 st	
Automatisk lastning och lossning, automatisk lastsäkring, autonoma transporter, elektrifierade transporter, energieffektivitet	

Preface

The project parties gratefully acknowledge the financial support provided by the Swedish Energy Agency. Moreover, the project parties are grateful for the input provided by the project's reference group, which consisted of representatives from Transportföretagen, Sveriges Åkeriföretag, Transportstyrelsen, Inter IKEA Group, and Translink.

Table of contents

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Sammanfattning

Två megatrender nämns ofta när framtidens transportsystem beskrivs: automatisering och digitalisering. Automatisering är dessutom starkt kopplat till användningen av eldrivna fordon. Genom att elektrifiera och automatisera godsfordon kan vägtransporternas miljöpåverkan minska och de lokala utsläppen elimineras. Men för att implementera de nya lösningarna måste gränssnitten mellan vägtransporter och intern materialhantering utformas så att de olika systemen kan integreras. För att fullt ut förverkliga potentialen hos autonoma transportsystem bör gränssnitten, inklusive lastning och lossning, automatiseras. Detta adresserades i projektet SCALE.

Inom projektet, som startade i januari 2022, deltog följande parter: Einride AB, Einride Autonomous Technologies AB, MariTerm AB, SKF Sverige AB och Toyota Material Handling Europe AB. Projektet omfattade fem arbetspaket: 1) Projektledning, 2) Nulägesanalys och systembeskrivning, 3) Teknikanpassning och utveckling, 4) Design och implementering av demonstration, samt 5) Demonstration och resultatspridning. Ett huvudresultat av projektet var utvecklingen och valideringen av en lösning för automatiserad lastning och lossning, vilket var i linje med projektets övergripande syfte. Kopplat till lösningen för att överföra godset till och från den autonoma lastbilen har projektet även utvecklat och validerat lösningar för att automatiskt säkra lasten efter lastningen, eftersom lastsäkringen är en väsentlig del av lastningsprocessen och har juridiska implikationer samt konsekvenser för säkerheten. Förutom att utveckla och validera praktiska lösningar för automatiserad lastning och lossning och för lastsäkring, har projektet genererat värdefulla insikter om utmaningar, krav, drivkrafter och implikationer som är förknippade med en övergång till automatiserad lastning och lossning, där implikationer har identifierats både på operativ nivå och med hänsyn till förändrade roller och affärsrelationer mellan aktörerna. Dessa resultat har presenterats vid konferenser och i forskningsartiklar.

Summary

Two megatrends are often mentioned when the future of transport systems is described: automation and digitisation. Automation is also strongly linked to the use of electric vehicles. By electrifying and automating freight vehicles, the environmental impact of road transport can be reduced, and the local emissions are eliminated. But to implement the new solutions, the interfaces between road transport and internal material handling must be designed so that the various systems can be integrated. To fully realise the potential of autonomous transport systems, the interfaces, including loading and unloading, should be automated. This was addressed in the project SCALE.

Within the project, which started in January 2022, the following parties participated: Einride AB, Einride Autonomous Technologies AB, Toyota Material Handling, MariTerm, SKF, University of Gothenburg, and Chalmers University of Technology. The project comprised five work packages: 1) Project management, 2) Current state analysis and system description, 3) Technology adaptation and development, 4) Design and implementation of demonstration, and 5) Demonstration and results dissemination. A main result of the project was the development and validation of a solution for automated loading and unloading, which was in line with the overall purpose of the project. Linked to the solution for transferring the goods onto and off the truck, the project has also developed and validated solutions for automatically securing the cargo after the loading, as the cargo securing is an essential part of the loading process and has legal implications as well as implications with regard to safety. In addition to developing and validating practical solutions for automated loading and unloading and for cargo securing, the project has generated valuable insights into challenges, requirements, driving forces, and implications that are associated with a transition to automated loading and unloading, where implications have been identified both on an operational level and with regard to changing roles and business relationships between the actors in the supply chain. These insights have been presented at multiple conferences and in research articles.

Introduction

The road transport industry today faces several challenges, the most difficult of which are its dependence on fossil fuel, capacity constraints and system-level inefficiencies. Today, heavy vehicles account for around six percent of European CO2 emissions and is the largest source of NOX emissions in cities. To reach the Swedish the goal of a 70% reduction in greenhouse gas emissions from domestic transport by 2030, this must dependence on fossil fuels is changing. Secondly, there are difficulties in meeting demand, which is mainly related to a lack of trained drivers, while the market is growing by 3-4% per year. A study conducted by the International Road Transport Union in Europe (IRU) 2018 revealed a major shortage of drivers and a rapidly aging labour force. Furthermore, there is an extreme imbalance between women and men, women accounting for only 2% of the European driver population. There are several reasons for this, but the IRU's survey shows that difficult working conditions are the main reason for the lack of female drivers. Finally, the cost of road freight transport is increasing by 2-3% per year and capacity utilisation remains low. Studies have shown that trucks all over the world have long waiting times and low utilisation rates. At the same time, there is a rapid development towards increasing automation in warehouses and today loading and unloading is a bottleneck where great development potential exists.

Two megatrends are often mentioned when the future of transport systems is described: automation and digitisation. Automation is also strongly linked to the use of electric vehicles. By electrifying and automating freight vehicles, the environmental impact of road transport can be reduced, and the local emissions are eliminated. But to implement the new solutions, the interfaces between road transport and internal material handling must be designed so that the various systems can be integrated. To fully realise the potential of autonomous transport systems, the interfaces, including loading and unloading, should be automated. This will be even more noticeable when considering the ongoing trend of increasing automation within both warehouses and production. When the transports, as well as the shipping and receiving units in the form of warehouses and factories, are eventually automated, there is a clear need to automate also the interfaces of loading and unloading. Automatic loading and unloading can thus be seen as an enabler for autonomous transport and the potential benefits they bring. In addition, automation would increase the possibilities of loading and unloading during all hours of the day and create a smoother flow. More efficient load handling also increases the resource efficiency and utilisation rate of the vehicles, which in turn would accelerate a transition to electric trucks, as a higher vehicle utilisation is comparatively more important for an electric truck than a diesel one. The higher purchase cost of electric vehicles is today an obstacle to a rapid transition to electric freight transport, a higher utilisation rate of the vehicles would however make electric trucks even more competitive in terms of cost as they are cheaper to run than diesel trucks.

A transition to autonomous and remotely controlled vehicles would help to solve the shortage of drivers as one driver can control several vehicles. It would also help to create a more equal driver population as a recent survey shows that 45% of the

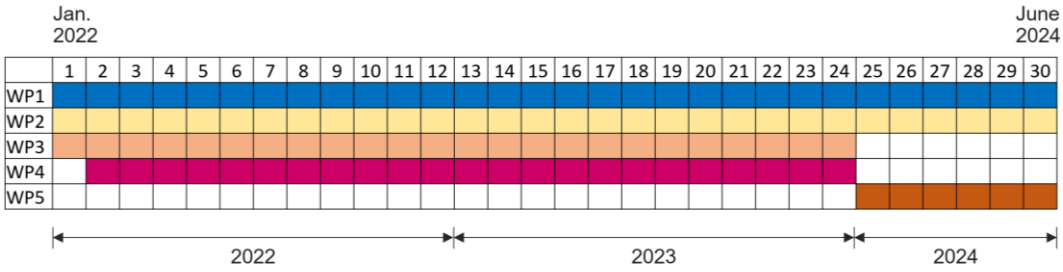
women surveyed would consider working as truck drivers thanks to improved working conditions such as autonomous and remotely controlled trucks implies.

The overall purpose of this project was to, with a system perspective in mind, develop and validate a solution that would streamline and automate loading and unloading, and at the same time make it safer and more robust.

The project was conducted by the following parties: Einride AB, Einride Autonomous Technologies AB, Toyota Material Handling, MariTerm, SKF, University of Gothenburg, and Chalmers University of Technology. Originally, there was only one Einride company in the project, but following an organisational change, the contribution of Einride AB was, during the autumn of 2023, split between Einride AB and Einride Autonomous Technologies AB. Chalmers University of Technology managed the project. In total, the project had a budget of MSEK 11.886, of which the Swedish Energy Agency provided MSEK 7.068 and the participating companies (Einride AB, Einride Autonomous Technologies AB, Toyota Material Handling, MariTerm, SKF) the rest. The project started in January 2022 and was originally intended to last for two years, but due to some delays, it was extended to two and a half years.

Approach

The project was structured into five work packages, as outlined below and illustrated in the project timeline presented in Figure 1.



WP1: Project management (Chalmers)
WP2: Current state analysis and system description (Chalmers)
WP3: Technology adaptation and development (Einride)
WP4: Design and implementation of demonstration (Toyota)
WP5: Demonstration and results dissemination (Einride)

Figure 1: The project's five work packages and their respective duration.

Work package 1: Project management

Work package 1 comprised the project management. This concerned setting up the project agreement, convening the steering group and the reference group, coordinating the work packages, coordinating and ensuring quality in the reports to the Swedish Energy Agency, and making sure that the project delivered what was agreed upon.

Throughout the project, project meetings were held monthly, in which representatives from all project parties participated and where the progress of the work packages was presented and coordinated. Steering group meetings were held quarterly with the purpose of ensuring that the project goals were met and that potential risks could be identified and managed.

Reference group meetings were held twice a year, with a total of five meetings during the project. Based on the regular feedback from the reference group, the relevance of the project was ensured.

Work package 2: Current state analysis and system description

Work package 2 included a critical review of the current state-of-the-art and, linked to this, a gap analysis where the need for new knowledge was identified. The gaps identified in this state-of-the-art review formed a basis for the continued work in work packages 2, 3, 4 and 5. In addition to the current state analysis, work package 2 included a system description, which had the aim of creating an understanding of the logistics system in which automated loading and unloading was applied. As part of this, the work package identified challenges, requirements and potential implications associated with a transition to automated loading and unloading of autonomous electric vehicles. Moreover, within the work package, potential implications for the business models of the various actors of a logistics setup were explored.

Work package 2 was mainly run by the researchers from Chalmers and the University of Gothenburg, but close communication was maintained with the other project parties throughout the project. The research articles that resulted from the project (see List of publications) were generated within work package 2.

Work package 3: Technology adaptation and development

Work package 3 took its point of departure in existing requirements and technologies, and developed solutions both for automated loading and unloading and for automated cargo securing. The developed solution for loading and unloading utilised a Toyota AGV which was configured to automatically move pallets onto and off the autonomous vehicle. Several different technologies for cargo securing were tested during the project.

The work package was managed by Einride. The activities of work package 3 was closely tied to those of work package 4, and in practice, these two work packages were largely run jointly, with common meetings.

Work package 4: Design and implementation of demonstration

The specification for the demonstration, was developed within this work package in an iterative process that started early in the project. The demonstration will further develop the gap analysis and evaluation parameters as well as make visible complexity and potential deviations by being carried out under realistic conditions.

The work package was managed by Toyota Material Handling. In line with what was noted above, under work package 3, work packages 3 and 4 were largely run jointly, with common meetings.

Work package 5: Demonstration and results dissemination

The demonstration covered by work package 5 constituted the final technical validation of the developed solutions for automated loading and unloading as well as cargo securing. It was thus closely connected to work packages 3 and 4. The demonstration was also closely connected to work package 2 and the performance evaluation that was performed within this work package.

The demonstration was video recorded and a video with information about the project and the demonstration was disseminated on social media. In addition to this dissemination activity, numerous presentations of project results were made at conferences and trade shows, both national and international (see List of publications).

Results

The project generated multiple results. A main result was the development and validation of a solution for automated loading and unloading, which was in line with the overall purpose of the project. The solution was based on the use of a specifically configured Toyota AGV, picking up and moving pallets onto and of the autonomous truck automatically. That solution, along with a presentation of the project, can be viewed in a video that was made as part of the project – The SCALE project (youtube.com) – and that was published on YouTube and disseminated via social media, foremost LinkedIn.

While a specific solution was developed and tested in SCALE, the project has also considered other potential solutions for automated loading and unloading. A review of the state of the art was presented in the research paper “Automated Loading and Unloading Operations: A Systematic Review”, which was written as part of the project and which was presented at the international NOFOMA conference in Helsinki, June 2023 (see List of publications). In addition, the project has specifically considered that different levels of automation may be applied in the processes linked to loading and unloading, including the transport between loading and unloading locations. An overview of different levels of automation is presented in Appendix A.

Linked to the solution for transferring the goods onto and off the truck, the project has also developed and validated solutions for automatically securing the cargo after the loading, as the cargo securing is an essential part of the loading process and has legal implications as well as implications with regard to safety. The results relating to cargo securing are included in appendices B and C, presenting a summary of the of cargo securing methods that have been studied in the project and a summary of liability rules for cargo securing in different European countries, respectively.

In addition to developing and validating practical solutions for automated loading and unloading and for cargo securing, the project has generated valuable insights into challenges, requirements, driving forces, and implications that are associated with a transition to automated loading and unloading, where implications have been identified both on an operational level and with regard to changing roles and business relationships between the actors in the supply chain. For example, it is clear from the project that under the right circumstances, a successful application of automated loading and unloading can enable system-wide benefits in the form of resource efficiency and smooth material flows. However, it is also clear that there are several challenges that need to be overcome for automated loading and unloading to be possible, both operationally and organisationally, for example in terms of distributing and ensuring responsibilities and liabilities between parties in a setup of automated loading and unloading. Results from the project/ have been presented at multiple conferences and in research article (see List of publications).

Discussion

By developing and demonstrating solutions for automated loading/unloading and cargo securing, the project has helped to connect the electrified, autonomous transports to the overall logistics system, thereby contributing to their applicability. Moreover, the project has shown that by use of a solution like these, the resource utilisation of the vehicles can increase, which further supports a transition to electric vehicles, as the relatively high investment cost of electric vehicles in practice requires a high resource utilisation for the investment to be economically feasible. The demonstrated solutions are promising with respect to limiting risks of personal safety and damage to goods, which provides an additional contribution to sustainability.

While the project has achieved its targets and made important contributions, future efforts in research and development could further support a widespread utilisation of electrified, autonomous transports. One area that would benefit from further attention is the use of automated loading/unloading in settings that display higher levels of complexity than the transport chain that constituted the main focus of SCALE. For example, a higher level of heterogeneity among the handled goods could entail additional challenges, as could situations where the sender and receiver of the goods are less tightly integrated.

List of publications

Several publications have been generated as part of the project. Below is a list of these publications, including a brief summary of each publication.

“Automated Loading and Unloading Operations: A Systematic Review” (See Appendix D for the full article)
Authors: Farook Abdullah Sultan, Robin Hanson, Dan Andersson, Mats Johansson, Tarun Kumar Agrawal, Gunnar Stefansson, Konstantina Katsela, Michael Browne, Sai Rohan Gowtham Kodati

Published in: The proceedings of the NOFOMA conference, Helsinki, Finland, 2023.
Summary: Material handling has witnessed changes with automations occurring in the transport sector. The increasing implementation of autonomous trucks lays questions on the loading and unloading operations that the conventional truck driver used to perform. Loading and unloading operations interface warehouses and transportation. Conventionally characterised by the manual operating nature causing inefficiencies and discontinuities, automated loading and unloading (ALUL) benefit by enhancing workflows, improves performance, and reduces losses. Despite these benefits, research on ALUL is minimal. This article i) details focus of ALUL systems in research, ii) indicates adopted evaluation indicators and iii) highlights key enablers and impediments witnessed during implementation.

Developments are assessed by carrying out a systematic literature review including published literature, technical articles etc. Review is initiated by identifying appropriate keywords, coupled with Boolean operators, to retrieve literature from scientific databases.

Research on LUL reveals a classified research focus on perception systems, manipulators, and general solution type. Operating time was identified to be a commonly evaluated performance parameter despite research revealing diverse parameters. The review highlights i) variable loading and unloading methods with changing good types. ii) Complexities in identifying and manipulating goods. iii) Frequent human involvement, and iv) high implementation costs and associated infrastructural modifications to influence implementation despite many enablers supporting the implementation of this technology. Despite the above issues, commercial solutions with varied degrees of automation are available and are listed in this article.

ALUL systems are described comprehensively providing a detailed representation of existing knowledge regarding ALUL, making selection easier for interested industries and guiding them through the transformation process.

Research aids in determining function-specific systems enabling a detailed understanding of ALUL systems.

“Automating Loading and Unloading for Autonomous Transport: Identifying Challenges and Requirements with a Systems Approach” (See Appendix E for the full article)
Authors: Tarun Kumar Agrawal, Robin Hanson, Farook Abdullah Sultan, Mats I. Johansson, Dan Andersson, Gunnar Stefansson, Konstantina Katsela, Michael Browne
Published in: The proceedings of the APMS (Advances in Production Management Systems) conference, Trondheim, Norway, 2023.
Summary: 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 organisational 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 realised, 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 realise the benefits of autonomous transport and improve overall transport performance.

"Drivkrafter och utmaningar vid automatisk lastning och lossning av autonoma lastbilar" (See Appendix F for the full article, in Swedish)
Authors: Robin Hanson, Tarun Agrawal, Konstantina Katsela, Pia Wijk, Måns Isacsson, Nils Andersson, Henrik Bäcklund
Published in: The proceedings of the Plan conference on research and application, Trollhättan, 2023.
Summary: As the degree of automation increases in the logistics chains, so that factories, warehouses and even transport are increasingly automated, it becomes increasingly important to also find solutions for automatic loading and unloading. When applying autonomous transport, the situation may arise where no human is present to manually carry out loading and unloading. This paper aims to identify both drivers and challenges associated with the application of automated loading and unloading of autonomous trucks. The article is mainly based on a qualitative case study, and data has been collected through observations, interviews and a focus group discussion. The case study identifies challenges in automated loading and unloading. In addition to this, the article also presents drivers for developing solutions for automated loading and unloading. This is done from the perspectives of several different parties: a manufacturing company, a supplier of autonomous transportation solutions, a supplier of material handling equipment, and a company that specialises in cargo securing. The article shows that there are strong driving forces to develop solutions for automated loading and unloading. There are potential benefits related to the environment, safety and efficiency, where automation can contribute to smooth and predictable flows. At the same time, the article also shows that the automation of loading and unloading is a complex task associated with many challenges. The challenges are grouped together in the article based on five themes: 1) challenges linked to the physical characteristics of the goods, 2) challenges linked to planning and interaction with information systems, 3) challenges linked to transport on and off the trailer, 4) challenges linked to placement on the truck and load securing, and 5) challenges linked to liability and legal issues.

"Conditions for achieving high levels of automation in loading and unloading of autonomous trucks" (See Appendix G for the full article)
Authors: Nils Thylén, Mats I. Johansson, Robin Hanson, Jonas Flodén
Published in: The proceedings of the Euroma conference, Leuven, Belgium, 2023.

Summary: Automation of loading and unloading (LU) is important for fully reaching the suggested benefits from autonomous trucks, but has thus far received limited attention. Current LU solutions automate the physical movement of goods, but many activities are still performed manually. Through a case study consisting of 2 cases, this paper explores automation in LU and has the purpose of identifying conditions for achieving high levels of automation. This paper identifies conditions relating to the interoperability between sender and receiver, and in the activities performed in the material flow, both physical activities and activities in the information flow.

"Assessing the performance in automated loading and unloading of autonomous trucks and the implications for the logistics system" (See Appendix H for the full article)

Authors: *Farook Abdullah Sultan, Robin Hanson, Dan Andersson, Mats I. Johansson, Gunnar Stefansson, Tarun Kumar Agrawal, Michael Browne, Konstantina Katsela*

Published in: The proceedings of the Euroma conference, Barcelona, Spain, 2024.

Summary: The logistics industry is changing due to the introduction of autonomous trucks (ATs). Although there are many promising benefits associated with ATs, there is a limited exploration into automating the loading and unloading (L/UL) process that was performed manually. However, for autonomous transport to be fully realized, the L/UL processes at shipping and receiving facilities must also be automated. Despite automation being a solution to address the challenges, the broader impacts of automating L/UL are not well explored. This study assesses the effects of automating L/UL with AT on a broader system level using context-intervention-mechanism-outcome logic (CIMO).

Automated Loading and Unloading for Trucks A Case Study Based on the Business Model Canvas (See Appendix I for the poster that was presented at the conference)

Authors: Michael Browne, Konstantina Katsela, Robin Hanson, Dan Andersson, Mats Johansson, Gunnar Stefansson, Tarun Kumar Agrawal, Abdullah Sultan

Published at the

Autonomous vehicles for freight transport have potential benefits but the transition to a future autonomous (and electric) freight system needs to take account of the interface between the vehicle and other parts of the logistics system. The purpose of the research is to assess the prerequisites for automated loading and unloading and to understand how this could impact the business relationships between partners in the supply chain.

The research is based on a pilot project at a manufacturing company where pallets are currently moved between a production location and a storage site using conventional trucks - loading and unloading is carried out by the truck driver using a conventional Forklift Truck. During the pilot project the conventional truck will be replaced by an autonomous electric vehicle and the loading and unloading will be carried out using an Automated Guided Vehicle. This paper is focused on

changes in the business relationships between the various actors involved in the current and future system. The Business Model Canvas framework has been used based on in-depth interviews and observations.

Findings include the greater complexity and the need to introduce new supply chain partners to achieve a fully automated process. Issues concerning regulations and responsibility have also emerged as factors that will affect the business case for such an innovation.

The research will lead to greater insights into the complexity of the interfaces in autonomous and automated transport and logistics systems and the empirical findings will enrich the discussion of this field.

Autonomous transport systems may bring many benefits. However, the scale of these benefits will be diminished if questions about the interface points in the logistics system are not addressed. Research outputs will provide insights for managers addressing the challenges.

In addition, several oral conference presentations have been made as part of the project, as listed in Table 1.

Table 1: List of conference presentations made during the project.

Date	**Conference**	**SCALE parties presenting**
October 2022	Swedish Transportation Research Conference	Chalmers and University of Gothenburg
November 2022	Logistik & Transport (https://logistik.to)	Einride
November 2022	Swedish Electromobility Center	Einride
November 2022	ITS Sweden	Einride
June 2023	NOFOMA, Helsinki, Finland	Chalmers and University of Gothenburg
July 2023	EurOMA, Leuven, Belgium	Chalmers
July 2023	WCTR, World Conference on Transport Research, Montreal, Canada	Einride, Chalmers and University of Gothenburg
August 2023	Swedish Electromobility Center	Einride
September 2023	APMS (Advances in Production Management Systems), Trondheim, Norway	Chalmers

September 2023	Helsingsborgsdeklarationen	Einride
October 2023	PLANs forsknings- och tillämpningskonferens, Trollhättan	MariTerm and Chalmers
October 2023	VREF Conference on Urban Freight, Gothenburg	University of Gothenburg
January 2024	Transportforum, Linköping	Einride, Chalmers and University of Gothenburg
July 2024	EurOMA, Barcelona, Spain	Chalmers

List of appendices

- Appendix A – Summary of Autonomous Transport Chain Levels
- Appendix B – Summary of Cargo Securing methods in the Scale project
- Appendix C – Summary of liability rules for cargo securing in different countries
- Appendix D – Automated Loading and Unloading Operations: A Systematic Review (research article)
- Appendix E – Automating Loading and Unloading for Autonomous Transport: Identifying Challenges and Requirements with a Systems Approach (research article)
- Appendix F – Drivkrafter och utmaningar vid automatisk lastning och lossning av autonoma lastbilar (research article)
- Appendix G – Conditions for achieving high levels of automation in loading and unloading of autonomous trucks (research article)
- Appendix H – Assessing the performance in automated loading and unloading of autonomous trucks and the implications for the logistics system (research article)
- Appendix I – Automated Loading and Unloading for Trucks: A Case Study Based on the Business Model Canvas (poster)
- Appendix J – Administrativ bilaga till slutrapport