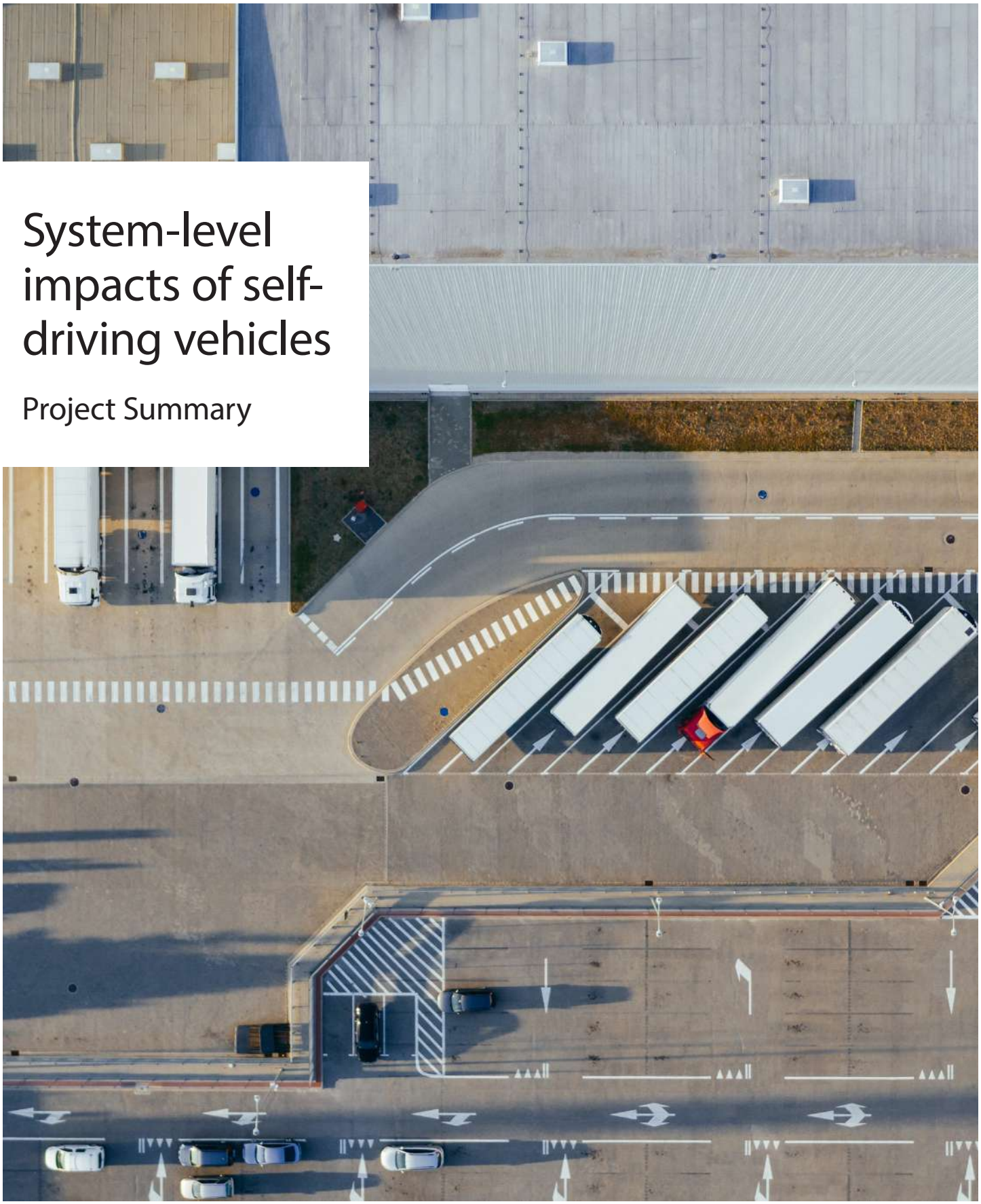
ITRL — INTEGRATED TRANSPORT RESEARCH LAB
KTH ROYAL INSTITUTE OF TECHNOLOGY

System-level impacts of self-driving vehicles

Project Summary



This research project was funded by Trafikverket under Grant TRV 2017/22806.

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Contents

1. Introduction

KTH ITRL and VTI have completed the research project System-level impacts of self-driving vehicles (Systemeffekter av Självkörande fordon) in collaboration with Trafikverket, who also commissioned the project. The purpose of the project was to increase Trafikverket's understanding of what role self-driving vehicles may have in a sustainable transport system and how it affects Trafikverket's planning and forecasts.

The research project was conducted in the form of a PhD (licentiate) project by Albin Engholm (KTH ITRL) together with Anna Pernestål (KTH ITRL) and Ida Kristoffersson (VTI) who also act as PhD supervisors. Peter Smeds was Trafikverket's project leader. Throughout the project, several people at Trafikverket have provided input to the project.

An overview of the project timeline and work packages is given in Figure 1. In addition to the core project work packages (blue in Figure 1), the project has hosted and supervised a number of master thesis and bachelor thesis projects (yellow in Figure 1). Also, during the project, Trafikverket commissioned two additional separate research tasks (pink in Figure 1) to the project. These were reported and delivered separately and included work by other researchers in addition to the System-level impacts of self-driving vehicles researchers. However, the output from one of these, denoted "SDV policy" in Figure 1[1] is covered in this summary as it is research closely related to WP3 and WP5 while the other one, denoted "AED prestudy"[2] is not included.

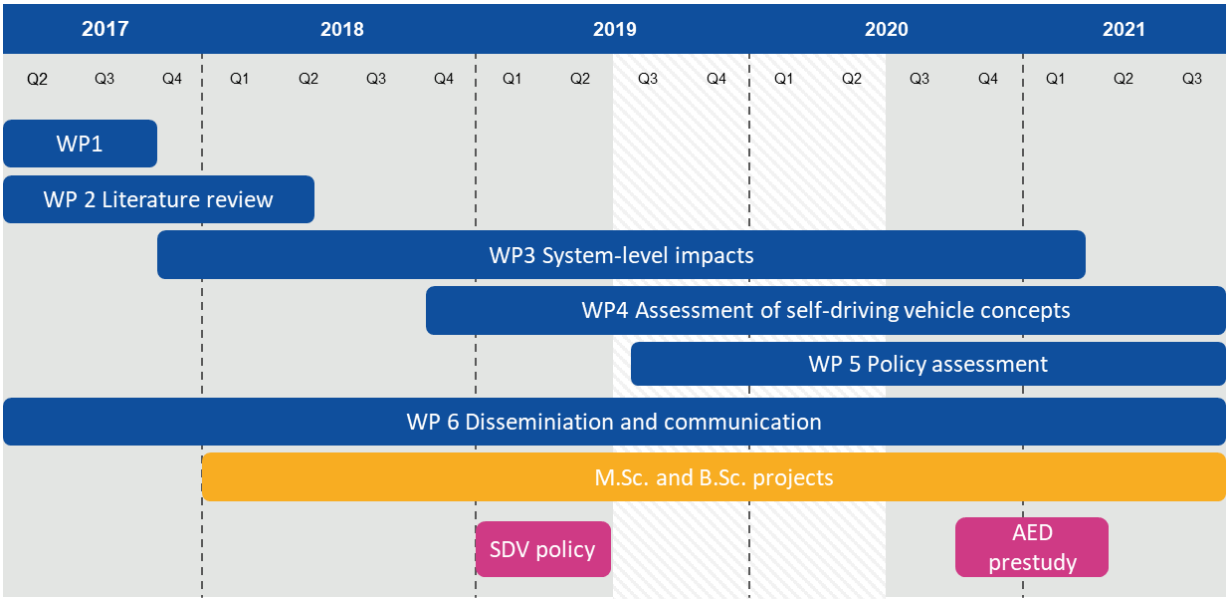

Figure 1 Overview of the project timeline and work packages.

This document provides an introduction and overview of the research output from the System-level impacts of self-driving vehicles project. It includes short summaries of all reports and research publications produced during the project, see Table 1 for an overivew. It also gives a short introduction to other, unpublished work that was performed in the project.

Note that this is not a conventional research project final report and the reader is referred to the individual references or direct contact with the researchers for details.

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1. Swedish name of task: Digitaliseringens roll för tillgänglighet i ett hållbart samhälle och relationen till ekonomiska styrmedel

2. Swedish name of task: Kunskapsunderlag till Åtgärdsplaneringen 2021: Systemeffekter av digitaliseringen och den tekniska utvecklingen (automatisering och elektrifiering) på person- och godstransporter. Read more about the task here.

Table 1 Overview of publications from the project with hyperlinks to published versions. Please see the reference list for full details.
* Not summarized in Chapter 2 since key findings are included in (Pernestål et al. 2020)
^ Not publically available, but delivered to Trafikverket as a project deliverable

Title	*Authors and date*	*Purpose*	*Type*	*Main method*	*WP*
Effects of driverless vehicles – Comparing simulations to get a broader picture	Anna Pernestål and Ida Kristoffersson (2019)	Review simulation literature of system impacts of driverless vehicles – passenger transport.	Journal article	Literature study	2
Is the driverless future sustainable? - Strategic uncertainties and system impacts	Albin Engholm, Ida Kristoffersson and Anna Pernestål (2019)	Review literature on explorative societal scenarios to identify main uncertainties and impacts .	Conference article	Literature study	2
System-level impacts of self- driving vehicles: terminology, impact frameworks and existing literature syntheses	Albin Engholm, Anna Pernestål and Ida Kristoffersson (2018)	Analyze frameworks for system-level impacts Summarize existing literature on system-level impacts from SDVs and gaps in the literature.	Report	Literature study	2
Cost Analysis of Driverless Truck Operations	Albin Engholm, Anna Pernestål and Ida Kristoffersson (2020)	Analyze how automated driving may affect ownership and operational cost for road freight transport.	Journal article	Total cost of ownership analysis	3,4
Impacts of large scale adoption of driverless trucks on the freight transport system	Albin Engholm, Anna Pernestål and Ida Kristoffersson (2021)	Analyze system impacts of a large-scale adoption of driverless trucks in Sweden.	Journal article	Scenario analysis with large-scale transport model (Samgods v.1.2)	3,4
The Emerging Technological Innovation System of Driverless Trucks	Albin Engholm, Anna Björkman, Yuri Joelsson, Ida Kristoffersson, Anna Pernestål (2020)	Understand the innovation system of driverless trucks in Sweden and its sustainability challenges.	Conference article	Interview study, TIS	4
Driverless trucks in the Swedish freight transport system: An analysis of future impacts on the transport system and the emerging innovation system	Albin Engholm (2021)	Synthesis of research on driverless trucks.	Licentiate thesis	Thesis, synthesis.	2, 3, 4, 5
The impacts of automated vehicles on the transport system and how to govern towards a sustainable direction	Anna Pernestål, Albin Engholm, Ida Kristoffersson, Johanna Jussila Hammes (2020)	Analyze policy needs and discuss governance strategies for a sustainable introduction of driverless vehicles for passenger and freight transport.	Book chapter	Literature review, System dynamics	5,7
Digitaliseringens effekter på transportsystemet – en förstudie*^	Anna Pernestål, Albin Engholm, Ida Kristoffersson, Johanna Jussila Hammes (2019)	Summarize literature on digitalization and automation impacts on the transport system, discuss potential policies and their effects, and discuss methods for knowledge creation on the impacts of digitalizaiton and the effects of policies	Report	Literature review, System dynamics	7
Styrmedel för självkörande fordon*	Johanna Jussila Hammes (2019)	Review the literature on the effects of, and policy needs for driverless-vehicles	Report	Literature review	7
Future impacts of self-driving vehicles - A case study on the supply chain of e-commerce to investigate the effects on the transport adminstrators of Sweden	Kajsa Björsell and Josephine Hedman (2018)	How SDV will impact the supply chain of e-commerce and how the transportation can change in this particular area.	Master thesis (Luleå U.)	Scenario development, expert workshops	3,4
Mobility services outside the cities - Development of mobility services in rural areas with self-driving technology	Thomas Lindén and Toussaint Ishimwe (2018)	Identifying potential value generating SDV services in rural areas	Master thesis (U.U)	Service design approach based on an interview study	3,4

Assessing the potential for improving public transport in rural areas by using driverless vehicles	Joel Norman (2019)	How can new mobility concepts with driverless vehicles be used in rural areas to improve the public transport?	Master thesis (U.U.)	Case studies and operations analysis simulations	3,4
The Technical Innovation System of Self-Driving Vehicles in Road Freight Transport - Towards an understanding of Actor Dynamics, Sustainability Outcomes and New Competencies	Anna Björkman and Yuri Joelsson (2019)	Understand the innovation system of driverless trucks in Sweden and its sustainability challenges	Master thesis (KTH)	Interview study, Technological Innovation Systems framework	3,4
Traffic Flow Implications of Driverless Trucks - Microscopic Traffic Simulations using SUMO	William Erlandson (2020)	Explore traffic impacts of driverless trucks in highway driving for various driving styles and traffic conditions.	Master thesis (Lund)	Microscopic traffic simulation	3,4
Möjligheter för automatiserade godstransporter I Västerbotten: Vilken påverkan har väginfrastruktur för potentialen till automatiserade transportsystem i region Västerbotten?	Axel Törnell (2021)	A GIS-based analysis of how large share of industries in the Swedish region of Västerbotten that could access driverless trucks depending on various operating design domain	Bachelor thesis	GIS-analysis	3,4
Innovation Diffusion Dynamics and Behavior of Actors in Road Freight Transportation: A study of the market uptake dynamics and adoption of driverless trucks	Robel Menghes and Diar Balata (2021)	Understand the dynamics of a potential adoption rates of driverless trucks by Swedish road carriers. Investigate potential shifts in business models.	Master thesis (KTH)	Bass-model simulation based on interview + survey data	3,4

2. Research publications and reports

Effects of driverless vehicles: Comparing simulations to get a broader picture

Anna Pernestål and Ida Kristoffersson

Peer reviewed journal article.

Published in The European Journal of Transport and Infrastructure Research (EJTIR) 2019

Link to article

Why

Driverless passenger vehicles have the potential to significantly affect the transport system, society, and environment. However, there are still many unanswered questions regarding what the development will look like, and there are several contradictory forces. This paper addresses the effects of driverless vehicles by combining the results from 26 simulation studies. Each simulation study focuses on a particular case, e.g., a certain mobility concept or geographical region.

How

By combining and analysing the results from the 26 simulation studies, an overall picture of the effects of driverless vehicles is presented. In the paper, the following perspectives are considered: What types of application of driverless vehicles have been studied in the literature? Which effects have these simulation studies predicted? Which research gaps still exist related to the effects of driverless vehicles in passenger transport?

Findings and takeaways

In the paper we show that it is primarily driverless taxi applications in urban areas that have been studied, whereas rural areas and private driverless car applications are rarely considered. Some parameters, such as trip cost, fleet size and waiting time, show small variations between the simulation studies, whereas other parameters, such as vehicle kilometres travelled (VKT), show large variations and depend heavily on the assumptions concerning value of time and level of sharing. Furthermore, the simulations indicate that driverless vehicles lead to decreased accessibility to city centres due to increased congestion and parking demand for drop-off and pick-up spaces, whereas accessibility in suburbs and outside cities have the potential to increase. Regarding ride sharing, the simulations show that ride sharing have potential to decrease VKT if level of sharing is sufficiently high, but the lower trip cost due to sharing does not seem to be enough to attract travellers to driverless ride sharing applications. In the paper we highlight the need for future simulations of more complex applications and aspects such as land use, congestion and energy consumption, to increase the understanding of system level effects of driverless vehicles.

Cost Analysis of Driverless Truck Operations

Albin Engholm, Anna Pernestål and Ida Kristoffersson

Peer reviewed journal article.

Published in Transportation Research Record 2020

Link to article

Why

In the literature, almost no attention has been given to how the diffusion of driverless trucks might occur and how it might affect the transport system. To make predictions on the market uptake and to model impacts of driverless truck deployment, valid cost estimates of driverless truck operations are crucial. In particular, such cost estimates are crucial inputs for freight transport models which can be used for system-level analysis of driverless truck impacts.

How

An analysis of costs and cost structures for driverless truck operations, including indicative numerical cost estimates, is presented. The total cost of ownership for driverless trucks compared with that for manually driven trucks has been analyzed for four different truck types (16-, 24-, 40-, and 64-ton trucks), for three scenarios reflecting pessimistic, intermediate, and optimistic assumptions on economic impacts of driving automation based on a review of current literature.

Findings and takeaways

Driverless trucks may enable substantial cost savings compared to the manually driven truck baseline. In the base (intermediate) scenario, costs per 1,000 ton-kilometer (TKM) decrease by 45%, 37%, 33%, and 29% for 16-, 24-, 40-, and 60-ton trucks, respectively. There is a clear relationship between truck size and relative cost savings with smaller truck types having larger relative cost savings while the relative cost savings are smaller for larger truck types. This suggests that driverless trucks may slightly counteract the economy of scale benefit that larger trucks have in terms of cost per TKM even though there is a significant economy of scale effect also for driverless trucks. The obtained cost reductions are primarily a result of reduced labor costs. Driver cost is a time-related cost and is practically independent of the truck size which explains why smaller truck types foresee larger relative cost reductions than larger trucks. The cost for remote operations required for driverless truck operations is an important cost component. The findings confirm the established view in the literature that freight transport is a highly attractive area for driverless vehicles because of the potential economic benefits.

Impacts of Large-Scale Driverless Truck Adoption on the Freight Transport System

Albin Engholm, Anna Pernestål and Ida Kristoffersson

Peer reviewed journal article.

Published in Transportation Research part A: Policy and practice 2021

Link to article

Why

Quantitative estimates of potential system-level impacts of driverless trucks could be important to inform transport policy and long-term infrastructure planning. However, research on transport system-level effects of driverless truck adoption is scarce which is in stark contrast to research on driverless vehicle impacts on passenger transport systems, for which there is an established and continuously growing body of simulation-based case studies which have provided valuable insights. In this paper, an analysis of the system impacts of large-scale adoption of driverless trucks on transport patterns and system costs for a national freight transport system with Sweden as a case study is performed with the use of a large-scale freight transport model.

How

The research approach in this study is to formulate and analyze a set of scenarios intended to depict various plausible alternatives for a large-scale driverless truck adoption. The analysis is performed by using the Swedish national freight transport model Samgods, which is for the first time applied to the study of driverless trucks. Two types of driverless truck scenarios are analyzed and compared against a baseline scenario without driverless trucks and against each other. The first scenario represents a full adoption of driverless trucks that can operate the complete road network and thereby substitute manually driven trucks. In the second scenario, the current fleet of manually driven trucks is complemented by driverless trucks that can operate on major roads between logistics hubs, but not in complex traffic environments like urban areas due to a limited operational design domain. This may be an initial use-case for driverless trucks operating on public roads. Also a sensitivity analysis is performed in which scenarios with varying driverless truck operating costs and, for the second scenario type, what parts of the road network the driverless trucks can operate is performed.

Findings and takeaways

In the first scenario, road transport tonne-kilometers on Swedish territory increase by 22%, vehicle kilometers traveled by trucks increase by 35% and annual total system costs decrease by 1.7 B€ compared to a baseline scenario without driverless trucks. In the second scenario, road tonne-kilometers increase by 11%, truck vehicle kilometers increase by 15%, and annual total system costs decrease by 1.2 B€ compared to the baseline. For both scenarios, the impacts of driverless trucks vary significantly between commodity types and transport distances which suggests heterogeneity of benefits of automated driving between different types of freight flows. The sensitivity analysis indicates that the magnitude of impacts is

highly dependent on the cost level of driverless trucks and that the ability for DL-trucks to perform international, cross-border transport is crucial for achieving reductions in system costs. An overarching conclusion of the study is that driverless trucks may lead to a significant increase in road transport demand due to modal shifts from rail and sea as a result of the improved cost performance of road transport. This would further strengthen the need to decarbonize road transport to meet nonnegotiable climate targets.

Is the Driverless Future Sustainable? Strategic Uncertainties and System Impacts

Albin Engholm, Ida Kristoffersson and Anna Pernestål

Peer reviewed conference article from the 15th World Conference on Transport Research WCTR 2019 Mumbai, India

Link to article

Why

Future sustainability impacts of driverless vehicles are subject to significant uncertainty which arise from complex systemic interactions within the transportation system and parallel social trends influencing transportation. One approach that has been used for making holistic assessments of impacts of driverless vehicles is to develop explorative societal scenarios. Explorative scenarios allows for and can be used to describe and problematize the complex interactions. However, they are speculative in their nature and sensitive to the pre-conceptions and knowledge of the experts developing the scenarios. In this paper, multiple scenarios developed in several different studies are analyzed and compared to create a deeper and broader understanding of system impacts of driverless vehicles and the future society with driverless vehicles than what is achieved through individual scenario studies.

How

16 scenarios from four previous studies are analyzed by creating a novel joint analysis framework that all scenarios are evaluated against. First, the main uncertainties (so-called scenario axes) that are used for constructing the scenarios in the respective studies are derived and grouped. Thereafter, all scenarios are mapped against the main uncertainties and then related to the reported impacts for each scenario related to transport volumes, vehicle fleet size, market share of driverless vehicles, public transport service level and social equity.

Findings and takeaways

The findings show that there are four strategic uncertainties shaping the development: the role of the public and private sector, policy making for driverless vehicles, the impact of the sharing economy and the pace of driverless technology development. Most of the studied scenarios report higher traffic volumes than today. Impacts on social equity and the role of public transport vary significantly between the scenarios. Furthermore, the scenario studies expect the sharing economy to be an enabler to curb growth in travel volumes which is important if climate goals for transportation should be possible to meet. Further research efforts should address impacts of driverless vehicles in more systematic forms than societal scenarios but with wider system delimitations than in existing simulation studies.

The Emerging Technological Innovation System of Driverless Trucks

Albin Engholm, Anna Björkman, Yuri Joelsson, Ida Kristoffersson & Anna Pernestål

Conference article from the 47th European Transport Conference, ETC 2019, Dublin, Ireland

Published in Transport Research Procedia Facing the complexity of transport models and innovative developments in sustainable mobility - Selected Proceedings of the 47th European Transport Conference, ETC 2019

Link to article

Why

Driving automation technology is attractive for the road freight transport sector since driverless trucks may drastically reduce driver costs, increase truck utilization and improve road safety. Although driverless trucks may result in significant impacts on the transport system, research on what factors are shaping the development of driverless trucks, and the involved actors is scarce. In this paper, an analysis of the innovation system for driverless trucks in Sweden is analyzed which allows for critical uncertainties and challenges for the development to be identified and forces influencing the direction of development of can be better understood. These are important factors for better understanding how the long-term diffusion and impacts of driverless trucks may materialize.

How

In this paper the sociotechnical innovation system developing, diffusing and utilizing driverless trucks in Sweden is analyzed based on the technological innovation systems (TIS) framework. The analysis is based on an interview study performed in 2018 comprising 20 expert interviews with a total of 23 representatives from 16 actors in the driverless truck TIS in Sweden.

Findings and takeaways

The TIS analysis shows that there are significant uncertainties in the timeline, operational capabilities, infrastructure requirements and regulative landscape for a widespread driverless truck deployment. There is a general view among the interviewees that driverless trucks is an important opportunity for Swedish industry and the economy. From a transport system perspective, driverless trucks are expected to bring sustainability benefits but it remains uncertain whether these benefits will be realized and what the negative side effects might be. The development of driverless truck is heavily influenced by incumbent firms in the truck manufacturing industry but new actors from the telecom sector, energy sector and emerging truck technology companies are entering the area and shaping the development. The current relatively rigid institutions for truck manufacturing and road freight transport will require significant alignment to adapt to driverless truck operations in areas such as laws and regulations, business models and operational practices. The value chain of road freight transport may be disrupted as some of the current key actors, for instance traditional road carriers, could become less relevant in future driverless truck value chains. A critical uncertainty is how and by which actors the setting of requirements, deployment and financing of digital infrastructure for driverless trucks will be done.

System-level impacts of self-driving vehicles: Terminology, impact frameworks and existing literature syntheses

Albin Engholm, Anna Pernestål & Ida Kristoffersson

Report, 2018

Link to report

Why

The intention with this report is to contribute toward the development of systemic and holistic studies of impacts of self-driving vehicles (SDVs). The report is adressing impacts of self-driving vehicles on the transportation system but also wider societal impacts on factors such as: land-use, public health, energy and emissions, etc. The first aim of the report is to summarize knowledge to enable future design of a high-level conceptual framework for impacts from self-driving vehicles from a systems perspective. The second aim is to summarize knowledge on impacts from self-driving vehicles in a selection of the available literature. The main contributions of the report are the following:

- A terminology for different types of automated vehicles, connected vehicles and mobility concepts for automated vehicles is presented
- Frameworks for classifying system-level impacts from SDVs in the existing literature are summarized and analyzed
- Existing literature studies on system-level impacts from SDVs are synthesized and common themes and gaps in current research are analyzed

How

A review and synthesis of a selection of the existing literature on system-level impacts of self-driving vehicles was performed. Relevant literature was identified through a combination of key-word based literature searches using the databases TRID and SCOPUS and snowballing.

Findings and takeaways

The terminology proposed in this report distinguishes between different types of automated and connected vehicles and is primarily intended as a tool to enable stringent analysis in this report when analyzing literature that apply different terminologies. Two frameworks for classifying system-level impacts are identified and compared. The analysis of the frameworks covers their scope, specification of mechanisms generating system impacts and briefly reviews their applicability as a starting point for developing a systems model of impacts from self-driving vehicles. The review of existing literature syntheses shows that there is a large variation in availability on literature for different system impacts. Impacts on road safety, road capacity and vehicle ownership forms are well studied. Examples of less studied impacts are costs of ownership, public health, infrastructure, air pollution and accessibility. The review identifies several contractionary mechanisms and effects that can affect various system-level impacts. The results of the review highlight the need to approach impact assessments of self-driving vehicles from a systemic and holistic point of view.

The Impacts of Automated Vehicles on the Transport System and How to Create Policies that Target Sustainable Development Goals

Anna Pernestål, Albin Engholm, Ida Kristoffersson & Johanna Jussila Hammes

Book chapter in Shaping Smart Mobility Futures: Governance and Policy Instruments in times of Sustainability Transitions, 2020

Link to publication

Why

Automated vehicles are likely to have significant impacts on the transport system such as increased road capacity, more productive and enjoyable time spent travelling in a car, and increased vehicle kilometres travelled. However, there is a risk that automated driving may negatively impact the environment if adequate policies are not put in place. This chapter examines the effects of driverless vehicles and the types of policies required to attain sustainable implementation of the technology.

How

First, a literature review on the impacts of automated vehicles is performed. To understand the effects on a systemic level, and to understand the needs and impacts of policies, the dynamics must be understood. Therefore, a causal loop diagram (CLD) based on learnings from the literature review and input from an expert workshop is developed and analysed.

Findings and takeaways

One important insight is that the effects of driverless vehicles are mainly on the vehicular level (e.g., the reduced number of accidents per vehicle). These effects can be cancelled out on a systemic level (e.g., due to increased vehicle-kilometre travelled (VKT) that increases total number of accidents). The marginal costs of road transport are central to both freight and passenger transport. Automation will reduce marginal costs and shift the equilibrium in the transport system towards a state with higher VKT. This will lead to greater energy consumption and higher emissions. To attain sustainability goals, there might be a need to balance this reduction of marginal costs by using policy instruments. In the work, CLDs is experienced to be a useful tool to support the collaboration between experts from different fields in the dialogue about policies.

Driverless trucks in the Swedish freight transport system: An analysis of future impacts on the transport system and the emerging innovation system

Albin Engholm

Licentiate thesis, KTH Royal Institute of Technology, 2021

Link to thesis

Why

A large-scale introduction of driverless trucks could start taking place during the next decade. While this could bring several economic benefits for freight transport actors and society, it may also change the freight transport system and exacerbate the negative effects of road transport. This thesis aims to increase the understanding of how an introduction of driverless trucks could materialize and impact the freight transport system in Sweden. Two overarching issues are addressed. The first is how freight transport patterns will change due to the impacts of driverless trucks on road transport supply. This is addressed in Paper 1 (*Cost analysis of driverless truck operations*) and Paper 2 (*Impacts of large-scale driverless truck adoption on the freight transport system*). The second issue, which is studied in Paper 3 (*The emerging technological innovation system of driverless trucks)*, is what factors are shaping the ongoing development towards an introduction of driverless trucks in Sweden.

How

The thesis is a synthesis of the three papers; Cost Analysis of Driverless Truck Operations (Paper 1), Impacts of Large-Scale Driverless Truck Adoption on the Freight Transport System (Paper 2) and, The Emerging Technological Innovation System of Driverless Trucks (Paper 3), as well as a literature review and discussion on how the research relates to the literature.

Findings and takeaways

Paper 1 shows that driverless trucks could enable cost reductions of around 30%-40% per ton-kilometer. A key determinant of the cost reduction is to what extent reduced driver costs will be offset by other forms of human labor that may be required for driverless truck operations. Other factors, including changes to the truck acquisition cost, have marginal importance. The cost-saving potential provides a strong motivation for freight transport actors to develop and adopt driverless trucks. In Paper 2, the impacts of driverless trucks on road transport demand, utilization of different truck types, modal split, and total logistics costs are studied by using the Swedish national freight transport model Samgods. Two scenario types are studied, one in which driverless trucks substitute manually driven trucks and one where driverless trucks capable of operating between logistics hubs are introduced as a complement to manually driven trucks. The analysis shows that in both scenarios, driverless trucks could reduce total costs for Swedish freight transport in the range of billions of SEK per year. Road transport demand and truck traffic volumes may increase significantly through modal shifts from rail and sea. This could lead to increased societal costs through, for instance, increased CO2 emissions and congestion which are not quantified in the study. The findings from Paper 3 suggest that there are several favorable factors for a successful introduction of driverless trucks, but also that the innovation system is characterized by a

high degree of uncertainty related to what infrastructure will be required and available, what business models will be emerging, and which actors will be able to capitalize on the development and which actors that become marginalized in a future with driverless trucks.

3. Master- and bachelor theses

Mobility services outside the cities: Development of mobility services in rural areas with self-driving technology

Toussaint Ishimwe, Thomas Lindén

Master thesis, Uppsala University, 2018

Link to thesis

Why

This thesis aims to create a first draft of a value-driven business model describing a mobility service for areas outside cities, which uses self-driving vehicles.

How

User studies are conducted using qualitative interviews to explore the mobility needs and behaviour in rural areas. This is then combined with a morphological analysis, which is used as a structuring method for creating new business model concepts for the mobility service. Finally, stakeholder interviews are conducted in order to revise the developed business model and to find out their opinions about the proposed mobility service.

Findings and takeaways

The resulting mobility service is a feeder-service that includes self-driving vehicles, operated by the public transport authority. The study shows that a concept with self-driving vehicles like this would meet the users' mobility needs. Regarding the implementation of the service, stakeholders involved have driving factors that could facilitate the implementation, such as cost savings, increased accessibility, rural development, and environmental aspects. However, some barriers are identified as well, that mainly concerns the sparse structure and long distances in rural areas, the dimension of the vehicle fleet, laws and regulations, but also the psychological barriers such as acceptance of the users to go from using their own car to utilize self-driving vehicles in a mobility service.

Future impacts of self-driving vehicles: A case study on the supply chain of e-commerce to identify important factors for the transport administrators of Sweden

Kajsa Björsell, Josephine Hedman

Master thesis, Luleå University of Technology, 2018

Link to thesis

Why

The rapid pace of the development of the transport and vehicle industry in combination with megatrends such as digitalization, automation, and electrification can have huge effects on how transport planning and the society evolves. In order to meet goals such as increased traffic safety, improved environment, and reduced congestions a lot needs to be done. Two tools expected to be of significance when creating a more transport efficient society are automation and digitalization, whereby self-driving vehicles (SDVs) is an important area. The race towards fully autonomous vehicles is ongoing and scholars argue that the implementation of SDVs can be faster within freight transportation than passenger transportation. Higher cost savings, as well as decreasing availability on the labor market, are two arguments for why freight transportation can be autonomous faster. Depending on how ambitious or slow the policy and planning are as well as the development of shared solutions, different future scenarios, as well as penetration rates of SDVs, can come through. One certain trend argued to continue to grow as well as having an impact on the development of SDVs is the rapid growth of e-commerce

How

This study addresses the uncertainty concerning SDVs from a transport administrator's perspective by identifying important factors for Trafikverket regarding the implementation of SDVs within freight transportation. Four already developed future plausible scenarios for the year 2030 lay the ground for this study and a case study concerning the supply chain of e-commerce in Sweden is used to delimitate the study. Interviews with distributors were held to conduct the case and two workshops with experts within the transport sector, academia, and authorities, as well as a meeting with a reference group with representatives from Trafikverket were held to collect data. In the workshops, the experts identified trends and system impacts within the four future scenarios.

Findings and takeaways

A key insight gained in this study is that SDVs is an area with a lot of insecurity and thus, it needs to be investigated further. One solution to study the subject further is to implement restricted lanes for SDVs to test the technique properly. The results of this study clearly show that even though SDVs is a topical issue, it should not be studied as a solitary subject but rather in a larger context together with other significant factors. Nighttime transports and deliveries, platooning, and electric roads and electric vehicles are three factors that are likely to be implemented very soon and should, therefore, be studied together with SDVs. Moreover, the result from the workshops implies that there will be an increased number of vehicles as well as vehicle kilometers within the distribution of e-commerce packages in the

future. In addition, the experts expect SDVs to be present in the year 2030, but the number of SDVs depend on multiple factors.

The Technical Innovation System of Self-Driving Vehicles in Road Freight Transport - Towards an understanding of Actor Dynamics, Sustainability Outcomes and New Competencies

Anna Björkman, Yuri Joelsson

Master thesis, KTH Royal Institute of Technology, 2019

Link to thesis

Why

This thesis provides a synthesized view of opportunities and barriers that actors are facing in relation to a large scale introduction of self-driving vehicles (SDVs) in road freight transport in Sweden. This understanding makes it possible for stakeholders to identify expectations, needs, policies and strategies to govern a sustainable transitions of the transport system. In addition, the paper provides an investigation of requirements for new knowledge and competencies along with development.

How

By using technical innovation systems (TIS) as a theoretical approach for the study, different components and aspects of the Swedish freight transport system are described and analysed in relation to SDV development and innovations. The TIS framework consists of a set of system components involved in the generation, diffusion and utilisation of a technology, and the relationships between the components. TIS components include actors, institutions, and networks, where networks describe the relationships between actors and institutions. In the paper Sweden is used as case study. The results are based on 19 qualitative interviews with representatives from a broad spectrum of actors all being part of, or expected to be part of, a road freight transport system where SDVs is a central component were held to collect data. In the workshops, the experts identified trends and system impacts within the four future scenarios.

Findings and takeaways

The public sector together with truck manufacturers are key actors in governing and enabling a commercialization of SDVs in road freight transport. Truck manufacturers have a great power in shaping the system by driving the technical development of SDVs, while government agencies are responsible for regulations and guidelines influencing the direction of development. The introduction of SDVs in road freight transport would imply changing dynamics between the actors and other components of the TIS. One example is the role of road carriers and freight forwarders who are currently two of the most central actors in the freight transport system. In a transport system with SDVs, those actors may become less influential. Likewise, actors that are currently not having a central role in the freight transport system may become more influential. For instance, SDVs can catalyse a

development towards electrification. This is a way of expanding the system boundaries and implies that new actors, such as energy companies and fuel retailing companies, begin to investigate how they could develop their business models to become a part of an evolving market. Another finding is that there is a consensus among interviewed actors that SDVs must be adapted to the existing road infrastructure system rather than the other way around. At the same time, a completely new digital infrastructure system is being created around SDVs, which is necessary to handle the large amounts of data required for SDVs to operate. Furthermore, the connection between electrification and automation is somewhat ambiguous, some claim that there is clear symbiosis between the two technologies while others argue that they just happen coincided in time. Finally, the results indicate a lack of holistic and systematic perspectives among the actors on how the development and deployment of SDVs could contribute to sustainability in the freight transport system. It is critical to at this early state of implementation govern and shape technological development and business models in a direction that ensures a sustainable path for a future transport system with SDVs.

Assessing the potential for improving public transport in rural areas by using driverless vehicles

Joel Norman

Master thesis, Uppsala University, 2019

Link to thesis

Why

Driverless vehicles might fundamentally change the transport system in multiple ways. Reducing driver costs in mobility services could create opportunities for new mobility concepts. Research on driverless vehicles have previously concentrated on urban areas, though driverless vehicles in rural areas could have greater positive effects. Hence, the aim of the study is to see how driverless vehicles can be used in rural areas to contribute to a more sustainable transport system.

How

Three rural mobility concepts for driverless vehicles are developed and by applying these to different case locations, the feasibility of the concepts is discussed. Interviews with local actors in Sweden were conducted to learn about general and local challenges with specific case locations. A modelling approach of a first and last mile feeder service is used to evaluate the feasibility of this mobility concept further.

Findings and takeaways

What rural mobility concept for driverless vehicles to use depends on access to public transport, distance to main roads and spatial density of travel demand. Model results show that driverless shuttles can feed travel demands of 100-150 passengers daily and still perform alternative tasks. Even though rural areas have general challenges, local issues also need consideration to optimize the benefits of the services. Public transport authorities are experts on local challenges and could take more responsibility in questions regarding driverless vehicles. For instance, flexibility, accessibility and equality could be improved by merging routes and shorten travel times for entire bus routes. Furthermore, other societal functions can be developed by reinvesting capital in other areas.

Traffic Flow Implications of Driverless Trucks: Microscopic Traffic Simulations using SUMO

William Erlandson

Master thesis, Lund University, 2020

Link to thesis

Why

Driving automation technology is attractive for the road freight transport sector since driverless trucks (DL-trucks) may drastically reduce driver costs, increase truck utilization and improve road safety. Although DL-trucks may bring significant impacts to the transport system, research on the future diffusion and impacts of DL-trucks is scarce compared to passenger transport

How

In this thesis, the microscopic traffic simulation software SUMO is used to investigate how DL-trucks with a conservative driving style, and DL-trucks with enhanced driving capabilities, affect travel times, maximum road capacity and emissions of CO_2.

Findings and takeaways

When simulating DL-trucks in a heterogeneous traffic flow, the conservative driving style turned out to have a negative effect on both maximum road capacity and average travel times. Congestion around an on-ramp that worked as a bottleneck, significantly increased when conservative DL-trucks were introduced. Total emissions of CO_2 however, decreased. The DL-trucks with enhanced driving capabilities, showed a much better performance, with insignificant effects on travel times, increases in road capacity and decreases in emissions of CO_2. It is therefore likely that, in early stages of DL-truck deployment, the overall effect on traffic could be negative. Once the share of DL-trucks with enhanced driving capabilities increase, the effect is instead assumed to be positive. The introduction of DL-trucks advocates an increased share of trucks at night, when there is free capacity available. In order to save energy, these DL-trucks would drive at much lower speeds than the surrounding traffic. Simulations show that nighttime DL-truck traffic has limited effects on travel times but results in large increases in total emissions of CO_2. The simulations showed that a very low traffic flow is crucial in order to ensure low emission levels. Introduction of nighttime DL-truck traffic should therefore come with sufficient time- and route restrictions, in order to ensure ecological sustainability.

Innovation Diffusion Dynamics and Behavior of Actors in Road Freight Transportation - A study of the market uptake dynamics and adoption of driverless trucks

Diar Balata, Robel Menghes

Master thesis, KTH Royal Institute of Technology, 2021

Link to thesis

Why

Technological innovations have long been a driving force of change in different industries. However, not all innovations gain widespread diffusion and adoption, regardless of it being an incremental or a radical innovation. Driverless trucks are expected to have a substantial disrupting effect on the road freight transportation sector. Technological innovations have long been a driving force of change in different industries. However, not all innovations gain widespread diffusion and adoption, regardless of it being an incremental or a radical innovation. The commercial timeline is characterized by great uncertainty and signs are pointing towards many trucks becoming completely driverless in the coming years. As such, it is of interest to study how the market dynamics will be affected by the introduction of driverless trucks and the potential adoption rate among companies within this industry.

How

The study was carried out using a mixed-method approach consisting of the Bass model to estimate the future adoption rate of driverless trucks and semi-structured interviews with industry actors as well as a survey distributed to haulage organizations to contextualize the model and interview results.

Findings and takeaways

The findings suggest that 20 percent of the organizations within road freight transportation in Sweden will have adopted driverless trucks 15 years after market introduction. In addition, the model suggests that 100 percent adoption will be reached after 40 years. However, achieving a fully driverless fleet will be difficult due to complex traffic environments and non-driving related tasks. The interview respondents acknowledge the significant impact driverless trucks are expected to have on the industry that has been operating with the same practices for many years. Furthermore, the haulage companies expressed a reluctance towards driverless trucks and a low willingness to pay, albeit being open to innovations in general. This may be due to changes in the current way of operating, the emergence of new business models challenging the status quo, and the limited financial strength among these organizations that may have a harming effect on the opportunity to adopt the innovation.

Opportunities for automated freight transport in the Västerbotten region: What impact does the road infrastructure have for the potential for automated transport systems in the Västerbotten Region?

Axel Törnell

Bachelor thesis, Umeå University, 2021

Link to thesis

Why

The technology behind self-driving trucks in currently under development for deployment on public road. The objective of this study is to explore and understand the number of industries that could be reached by self-driving trucks with the limits of Västerbottens current road network. The effect from implementing self-driving trucks is an emerging research field. We do not understand to what extent the physical infrastructure affect which industries may be able to use self-driving trucks since there is a lack of exploration and research within the scientific literature

How

The thesis has been conducted by a literature study, interviews, and a spatial analysis. The spatial analysis examined the potential for self-driving trucks to access industries depending on what road infrastructure self-driving trucks are assumed to be able to operate. The number of industries that self-driving trucks can access was calculated for four different subsets of the road networks: The European highway network, National highway network, Functional priority road network and roads with driving lane with over 5m

Findings and takeaways

This resulted in the conclusion that the European highway network had the lowest number of industries within the search radiuses, a considerate amount of all industries (49%) was still within a 1 km radius. The road type “Driving lane with over 5m” having a clear majority of the industries with a total of 94% of the industries within a 1 km radius. The findings of this study suggest that self-driving trucks which are capable of operating only at a limited part of the road network still potentially could be used for a relatively large number of industrial freight transport flows in Västerbotten. This could indicate that self-driving trucks with a limited operating design domain could address a substantial share of the freight transport market.

4. Unpublished research and other work

System dynamics modeling of the introduction and climate impacts of automation and electrification of heavy trucks in Sweden

Albin Engholm, Claudia Andruetto, Anna Pernestål

Oral presentations given at and the Swedish National Transport Conference 2020 and the European Transport Conference, ETC, 2020.

For more information, contact Albin Engholm: aengholm@kth.se

Why

Recent evaluations of implemented and planned climate transport policies in Sweden show that GHG emission reductions of around 40% in 2030 compared to 2010 are likely to be achieved in Sweden. However, this falls short of the Swedish target of a 70% reduction by 2030 compared to 2010. The Swedish strategy to overcome the anticipated gap is based on three pillars: a more transport efficient society (i.e. reduce transport volumes and use energy-efficient modes), more energy-efficient vehicles, and renewable fuels. However, there is also a rapid technological development within automation and electrification which could have substantial impacts on both transport demand and emissions. This development has not been fully explored previously. This work intends to develop a tool for exploring the impacts of a gradual deployment of automaton and electrification in the Swedish heavy truck fleet to support policy analysis for reaching the climate targets for the transport sector.

How

A system dynamics model with a simplified representation of the Swedish road freight transport system and its development over time is developed in Vensim. The model consists of three sub modules:

- A freight demand sub-model that calculates the demand for road freight transport TKMs based on exogenous inputs of total freight demand and endogenously calculated road mode split and induced demand from changes in road freight transport costs due to the introduction of new technologies.

- A fleet sub-model that calculates the size and composition of the truck fleet over time based on the road freight TKM demand (from the demand sub-model) and exogenous S-curves of the diffusion of electric vehicles technology and driving automation technology. The fleet model simulates decommissioning and sales of new trucks so that the total truck fleet capacity (in terms of TKM) fulfils the TKM demand for road freight transport.

- An emission sub-model that, based on the numbers of trucks per type, calculates life cycle emissions separated into three stages: production, operations and decommissioning.

In the model it is possible to simulate the impacts of several types of policies and interventions aimed at reducing the CO_2 emissions of the transport system. The policies

considered in the model are based on a Swedish perspective and in particular policies discussed in the Swedish strategic plan for transformation to a fossil free transport sector. An initial calibration of the model for key variables related to demand for transport- and traffic activity (ton-kilometers and vehicle-kilometers), CO2 emissions and fleet size has been done.

The model is still in a preliminary version and substantial work to improve modeling of key causal mechanisms (e.g. impacts on road transport cost structures and changes in transport demand) as well as validation and testing is still required.

Findings and takeaways

An initial version of the model has been used for a scenario based pilot study on the impacts of automation and electrification of heavy trucks on transport demand and greenhouse gas emissions in Sweden, see Figure 2. The scenarios were separated by different hypothetical cases of the fill rate and electrification rates achieved, in combination with a gradual deployments of driverless trucks. Each scenario was run as a monte-carlo simulation to cover uncertainties in the pace of the market uptake of electrified and driverless trucks. The results from this case study are highly preliminary and should only be taken as an example for what type of analyses the model could support.

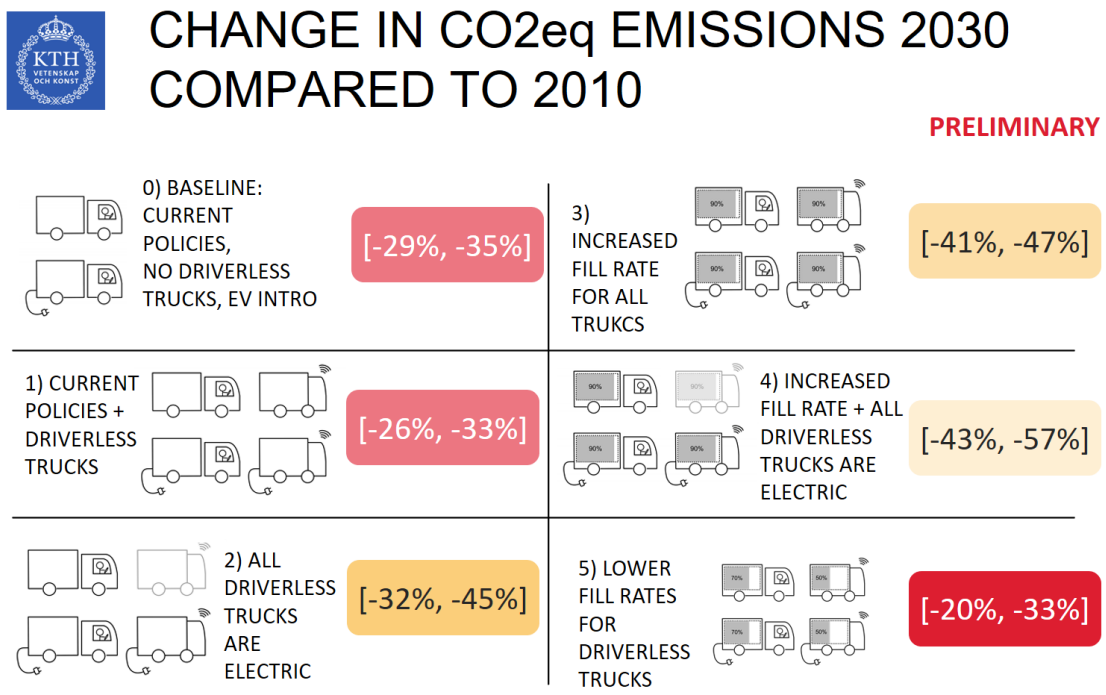

Figure 2 Preliminary results from a pilot study using an initial version of the system dynamics model

Other work

During the project, several tools have been developed to support the research in the project. Possibly, these tools may be of interest for other researchers working with similar topics. Use, or further development, of these tools may be possible for academic purposes but will have to be discussed and decided on a case- to case basis. Contact Albin Engholm, aengholm@kth.se for more details. Please note that none of these tools have been developed with external use in mind.

- A first version of a system dynamics (Vensim) model for demand and climate impacts of automation and electrification of heavy trucks (see the previous section).
- An Excel-based tool to calculate Total Cost of Ownership for heavy trucks.
- Various Excel tools and Matlab scripts for analysis and visualization of output data from the Samgods model (v.1.2).

5. References

Björkman, Anna, and Yuri Joelsson. 2019. 'The Technical Innovation System of Self-Driving Vehicles in Road Freight Transport'. Master Thesis, Stockholm, Sweden: KTH Royal Institute of Technology. http://www.diva-portal.org/smash/get/diva2:1316658/FULLTEXT01.pdf.

Björsell, Kajsa, and Josephine Hedman. 2018. 'Future Impacts of Self-Driving Vehicles: A Case Study on the Supply Chain of e-Commerce to Identify Important Factors for the Transport Administrators of Sweden'. Master Thesis, Luleå University of Technology. https://ltu.diva-portal.org/smash/get/diva2:1219540/FULLTEXT01.pdf.

Engholm, Albin. 2021. 'Driverless Trucks in the Swedish Freight Transport System: An Analysis of Future Impacts on the Transport System and the Emerging Innovation System'. KTH Royal Institute of Technology.

Engholm, Albin, Anna Björkman, Yuri Joelsson, Ida Kristoffersson, and Anna Pernestål. 2020. 'The Emerging Technological Innovation System of Driverless Trucks'. *Transportation Research Procedia* 49: 145–59. https://doi.org/10.1016/j.trpro.2020.09.013.

Engholm, Albin, Ida Kristoffersson, and Anna Pernestål. 2019. 'Is the Driverless Future Sustainable? Strategic Uncertainties and System Impacts'. In . Mumbai, India.

Engholm, Albin, Ida Kristoffersson, and Anna Pernestal. 2021. 'Impacts of Large-Scale Driverless Truck Adoption on the Freight Transport System'. *Transportation Research Part A: Policy and Practice* 154 (December): 227–54. https://doi.org/10.1016/j.tra.2021.10.014.

Engholm, Albin, Anna Pernestål, and Ida Kristoffersson. 2018. 'System-Level Impacts of Self-Driving Vehicles: Terminology, Impact Frameworks and Existing Literature Syntheses'. ITM-RP 2018:6. KTH Royal Institute of Technology. https://www.diva-portal.org/smash/get/diva2:1268871/FULLTEXT02.pdf.

———. 2020. 'Cost Analysis of Driverless Truck Operations'. *Transportation Research Record: Journal of the Transportation Research Board* 2674 (9): 511–24. https://doi.org/10.1177/0361198120930228.

Erlandson, William. 2020. 'Traffic Flow Implications of Driverless Trucks'. Master thesis, Lund Sweden: Lund University. http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=9014879&fileOId=9015709.

Jussila Hammes, Johanna. 2019. 'Styrmedel För Självkörande Fordon'. 2019:3. Working Papers, Swedish National Road & Transport Research Institute (VTI). Swedish National Road and Transport Research Institute (VTI). http://www.diva-portal.org/smash/get/diva2:1345231/FULLTEXT01.pdf.

Lindén, Thomas, and Toussaint Ishimwe. 2018. 'Mobility Services Outside the Cities: Development of Mobility Services in Rural Areas with Self-Driving Technology'. Master Thesis, Uppsala University. https://uu.diva-portal.org/smash/get/diva2:1239149/FULLTEXT01.pdf.

Menghes, Robel, and Diar Balata. 2021. 'Innovation Diffusion Dynamics and Behavior of Actors in Road Freight Transportation: A Study of the Market Uptake Dynamics and Adoption of Driverless Trucks'. Master Thesis, KTH Royal Institute of Technology. https://www.diva-portal.org/smash/get/diva2:1561439/FULLTEXT01.pdf.

Norman, Joel. 2019. 'Assessing the Potential for Improving Public Transport in Rural Areas by Using Driverless Vehicles'. Master Thesis, Uppsala University. https://www.utn.uu.se/sts/student/wp-content/uploads/2019/10/1910_Joel_Norman.pdf.

Pernestål, Anna, Albin Engholm, Ida Kristoffersson, and Johanna Jussila Hammes. 2020. 'The Impacts of Automated Vehicles on the Transport System and How to Create Policies That Target Sustainable Development Goals'. In *Shaping Smart Mobility Futures: Governance and Policy Instruments in Times of Sustainability Transitions*, edited by

Alexander Paulsson and Claus Hedegaard Sørensen, 37–53. Emerald Publishing Limited. https://doi.org/10.1108/978-1-83982-650-420201003.

Pernestål, Anna, and Ida Kristoffersson. 2019. 'Effects of Driverless Vehicles – Comparing Simulations to Get a Broader Picture'. *European Journal of Transport and Infrastructure Research* 19 (1): 23. https://doi.org/10.18757/ejtir.2019.19.1.4079.

Törnell, Axel. 2021. 'Möjligheter För Automatiserade Godstransporter I Västerbotten -Vilken Påverkan Har Väginfrastruktur För Potentialen till Automatiserade Transportsystem i Region Västerbotten?' Master Thesis, Umeå University. http://umu.diva-portal.org/smash/get/diva2:1567884/FULLTEXT01.pdf.