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Review

Prospects of automated driving in different road freight vocations: Why non-driving matters more than driving

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Cite this article: https://doi.org/10.26599/JICV.2026.9210094

ABSTRACT: Most truck modeling studies make generalized assumptions regarding driving times, distances, and non-driving tasks, except for loading and unloading, and therefore fail to capture the diversity of freight transport vocations, especially in the context of automated trucking analyses. To fill this gap, this study followed a three-stage process that involved reviewing existing literature, a typological analysis of driving and non-driving tasks in trucking vocations, and a quantitative assessment of the vocation specific benefits and challenges of automation. The last, however, was rather illustrative because of restricted available task-share data. The analysis grouped the tasks by their location: at the terminal/depot, on route, and at the customer site. From an operational perspective, tasks at the customer site are a key limiting factor for the use of automated vehicles. Non-driving tasks further determine the operational usefulness and benefits of automated vehicles. From a technical perspective, the traffic environment significantly influences the ease of implementing automated driving. For example, controlled traffic environments, such as yard transportation, are easiest to automate, while complex environments, such as urban areas, are the hardest. Overall, task shares significantly influence the utility of automated driving for individual freight vocations, with non-driving task shares ranging from 22 to 80%. Moreover, vocations that offer the greatest benefits may be more conducive to the development of automated driving technologies than those with the fewest technical and operational barriers to entry.

KEYWORDS: road freight transport; automated driving; non-driving tasks; operational challenges; task shares

1 Introduction

Automated driving is expected to benefit road freight transport in multiple ways. First, automation can improve driver conditions (ITF, 2017; Müller and Voigtländer, 2019; Van Meldert and De Boeck, 2016). Second, it can reduce overall operational costs, thereby providing a competitive advantage (Engholm et al., 2021; Müller and Voigtländer, 2019; Van Meldert and De Boeck, 2016). Third, it can enhance the safety, efficiency, and reliability of logistics processes, enabling better scheduling of production processes (Engholm et al., 2021; Müller and Voigtländer, 2019).

Road freight transport encompasses a wide range of vocations, and the benefits of automation vary significantly among those. Two important characteristics of truck vocations that can affect the efficiency and feasibility of automation are the driving environment and driver tasks beyond driving. The first one is a technical constraint and depends on the development of automated vehicles. Automation will likely be restricted to specific operational areas initially, expanding as the technology matures (Schuster et al., 2023; Van Meldert and De Boeck, 2016). The second one is an operational constraint. Automating the driving part may not be beneficial if tasks other than driving occupy a significant portion of the overall tasks and cannot be automated or done by non-drivers (Gittleman and Monaco, 2020).

Truck automation studies, to date, fail to represent freight transport in two key aspects accurately. First, modeling studies have mostly neglected non-driving tasks. The only non-driving tasks that have received attention are loading and unloading (Engholm et al., 2020; Ghandriz et al., 2020). Second, studies often make generalized assumptions regarding driving times, distances, and non-driving tasks, and do not capture the huge diversity of different freight transport vocations (Bray and Cebon, 2022; Engholm et al., 2024; Hao et al., 2023; Huang et al., 2024; ITF, 2017; Lee et al., 2023; Marzano et al., 2022).

This study helps to fill this gap by comprehensively analyzing road freight transport vocations and the associated driving and non-driving tasks. The study focuses on tasks performed at various locations, categorized as terminal or vehicle depot, on route, or at the customer site. Moreover, the study discusses the feasibility of vehicle automation under operational constraints.

The document is structured as follows. First, it describes the study methodology, which follows a three-stage process. It then analyzes existing studies on truck automation (Stage 1), focusing on assumptions regarding non-driving tasks and task shares. Afterwards, through a targeted second literature analysis (Stage 2), the study identifies task shares for individual vocations. Then, it discusses the findings from the literature analysis (Stage 3), presenting a typology of driving

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Received: April 21, 2026; Revised: August 4, 2026; Accepted: August 10, 2026

and non-driving tasks in truck transport, followed by a qualitative discussion of the benefits and challenges of automation across different road freight transport vocations. The study finally quantitatively discusses a set of selected vocations and their potential for automation.

2 Methodology

This study followed a three-stage process that involved reviewing existing literature on road freight transport and truck automation, a typological analysis of driving and non-driving tasks in trucking vocations, and an assessment of the benefits and challenges of automation.

In Stage 1, the study conducted a scoping literature review to identify the operational characteristics of truck transport considered in truck automation modeling studies. The study relied on the Web of Science, using the following query, and included references up to January 3rd, 2025:

```
TS = (
("Driv* Demand*" OR "Driv* Task*" OR "Driv*
Schedul*" OR "Driv* Job*" OR "Driv* Hour*" OR
"Oper* Hour*" OR "Driv* Cost*" OR "Oper* Cost*")
AND
("Truck*" OR "Freight*")
AND
("Autonom*" OR "Automa*" OR "Driverless*")
)
```

The search resulted in 118 references. A review of titles and abstracts identified 13 studies as potentially relevant for the analysis. Most studies were excluded because they either focused on specific optimization problems or addressed technical rather than operational aspects of automated vehicles. Ultimately, an in-depth review of the 13 studies highlighted two as not relevant and led to the discovery of four additional studies, resulting in a final sample of 15 relevant studies. **Fig. 1** a) shows the review workflow.

In Stage 2, the study conducted another scoping literature review, focusing on tasks performed across various freight transport vocations and seeking quantitative data on task shares. It used Web of Science with the following query and included references up to February 11th, 2025:

```
TS = (
("Task*" OR "Work* Hour*" OR "Driv* Hour*" OR
"Oper* Hour*")
AND
("Truck*" OR "Freight*")
AND
("Collect*" OR "Survey*" OR "Record*")
)
```

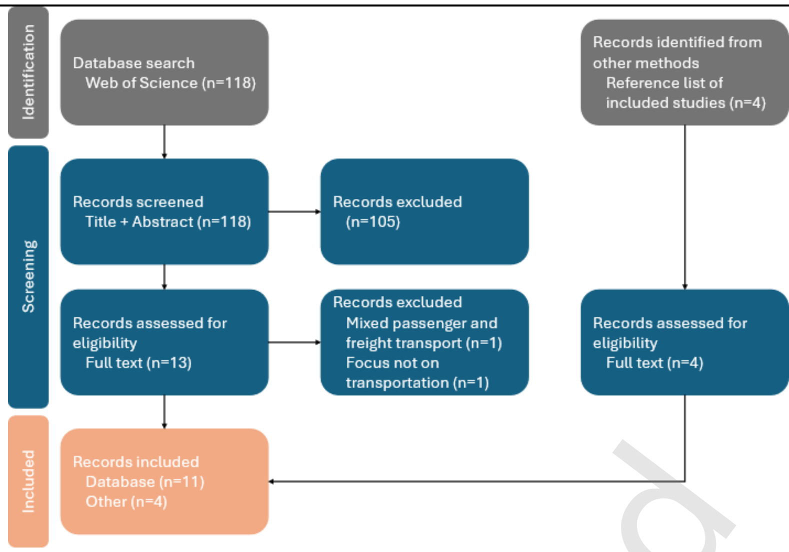
The search provided 426 results. After scanning the titles and abstracts, 20 studies were identified as potentially relevant for the analysis. Most studies were excluded because they did not quantify non-driving tasks. After reading the full texts of these studies, 10 were deemed relevant to the objective of the study, as well as two more studies from the studies' reference lists. Furthermore, the study by Sanchez-Diaz et al. (2020), which served as the basis for the typological assessment of truck driver tasks in this study, was included. The review workflow is shown in Fig. 1 b).

In Stage 3, the study analyzed the reviewed information and available quantitative data to: (1) Perform a typological assessment of truck transport activities and tasks (driving and non-driving), adapting the approach followed by Sanchez-Diaz et al. (2020), including various vocations in freight transportation. (2) Discuss vocation-specific benefits and challenges of automation, combining data from the National Renewable Energy Laboratory's Fleet DNA project (NLR, 2025) and yearly statistics "German truck traffic" (Kraftfahrt-Bundesamt, 2022), to derive an extensive list of commercial vehicle vocations. Vocations are grouped into five classes, based on operational area and task focus (see Table 1). (3) Quantitatively assess select vocations for which task share data is available. The selected vocations are snack delivery (local business delivery), parcel delivery (local private delivery), dedicated lane (hub-to-hub), and over-the-road (long distance).

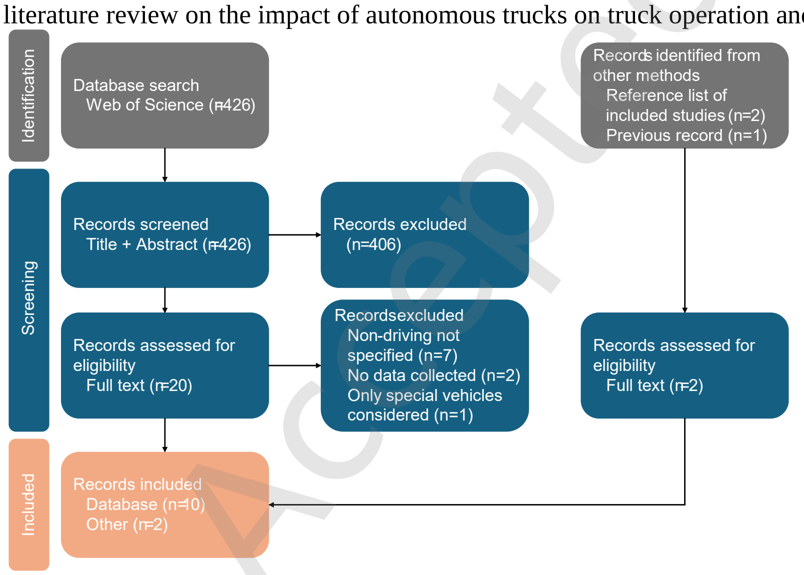
The study concludes with a comprehensive discussion of the findings and their implications.

Table 1. Commercial vehicle vocational classes and vocations used in the analysis, derived from Fleet DNA data (NLR, 2025) and German road freight statistics (Kraftfahrt-Bundesamt, 2022)

Vocation class	Vocation
Yard transportation	Container terminals, Manufacturing facilities, Distribution centers
Local deliveries (Business customers)	Beverage, Linen, Parcel, Tanker, Cement mixer, Dump truck
Local deliveries (Private customers)	Grocery, Food, Parcel, Tanker (heating oil)
Hub-to-Hub	Dedicated lane/customer transport, For-hire
Long distance	Long-haul, Over-the-road



a) First stage literature review on the impact of autonomous trucks on truck operation and driver demand.



b) Second stage literature review on task shares of freight vocations.

Fig. 1 Workflow of the first and second stage scoping literature reviews based on PRISMA guidelines (Page et al., 2021).

3 Technical and operations factors considered in truck automation studies

Table 2 summarizes the scope and modeling considerations of the studies identified in the Stage 1 review. The studies primarily include computational experiments and analytical estimations. Key characteristics considered are costs, loading and unloading activities, and the potential for remote operations.

Sindi and Woodman (2021) studied the expected benefits and barriers to adopting automated trucks through semi-structured interviews with 76 professionals from the UK transport industry. In the long run, participants expected automated trucks to reduce the demand for drivers and the overall number of people employed in the transport industry. Most participants further agreed that operational costs will be the key to the adoption of automated trucks.

Many studies on the operational costs of automated trucks, however, consider only driving time, without accounting for other tasks such as loading and unloading, e.g., Engholm et al. (2024) compared the operational costs in full truckload drop-and-hook shuttle operations in Sweden; Huang et al. (2024) modeled the impacts of automated trucks on US freight flows; Lee et al. (2023) investigated total operational costs for middle-mile transport between a port and a large distribution center in South Korea; Hao et al. (2023) analyzed semi-autonomous truck platoon operation in the US; Marzano et al. (2022) evaluated various platooning strategies for motorway driving in Italy; Mohan and Vaishnav (2022) analyzed what share of operating hours might be affected by automated trucking for long-distance transport (> 150 miles) in the US; Bray and Cebon (2022) investigated how vehicle sizes and delivery routes for customer deliveries in the UK may be affected by the use of automated trucks; and the International Transport Forum (2017) estimated the impact of automated trucks on driver demand in the US and Europe, stating that, under automation, most driving and non-driving tasks will likely still require a human driver, however, assuming in their analysis that automated trucks do not require human drivers at all.

Non-driving tasks, however, play a crucial role in the operation of a truck. Gittleman and Monaco (2020) estimated the number of truck driver jobs in the US that might be affected by automated trucks, focusing on long-haul driving, emphasizing the importance of non-driving tasks for drivers, without further specifying these. Schuster et al. (2023) interviewed professionals (drivers, managers, and supervisors) from the US trucking industry and identified fixing equipment during minor breakdowns as a non-driving task that would still require a human driver on the vehicle, even in automated trucks.

Loading and unloading are the non-driving tasks that have received the most attention in studies so far. Three studies explicitly modeled loading and unloading times in their analysis: Huang and Kockelman (2020) investigated the impact of automated trucks on US freight flows; Engholm et al. (2020) performed a cost analysis of driverless trucks, including operational costs for loading, driving, and unloading; Ghandriz et al. (2020) compared the operational costs of internal combustion engine trucks, battery-electric trucks, and automated battery-electric trucks. Furthermore, Wadud (2017) assumed a clear split between driving and loading and unloading, regardless of truck size or operational strategy, in a total cost of ownership analysis of different commercial vehicles in the UK.

Lastly, Bray and Cebon (2022) argued that loading and unloading costs need not be considered if personnel at the loading/unloading site perform loading and unloading, rather than the driver. This consideration, however, is reasonable only when focusing on driver costs and omitting total logistics costs. Although shifting loading and unloading tasks from drivers to warehouse personnel does not necessarily reduce logistics costs or the overall workforce, it can shift the demand from drivers to warehouse personnel who require lower qualifications.

Overall, the literature indicates that non-driving tasks are integral to logistics processes. Therefore, when investigating the impact of automated driving, it is insufficient to consider only the driving task; non-driving tasks must also be considered. However, current literature fails to do so because the scope of the studies is sometimes too narrow. For example, some studies focus on optimizing driver costs rather than total logistics costs, while others focus on specific operational modes. Additionally, automating or shifting non-driving tasks to other personnel may create new organizational or technical challenges beyond simply removing a driver task (Thylén et al., 2025).

Table 2 Scope and aspects considered by studies included in the literature review.

Study	Scope	Methodology	Aspects considered					
			Total cost	Driver cost	Remote operation	Load / unload	Other non-driving	Driver demand
Modeling studies using generalized assumptions for operational costs								
Engholm et al. (2024)	Modeling truck operational costs for different drivetrains in a truckload shuttle operation in Sweden	Computational experiments	X	X	X			
Huang et al. (2024)	Modeling impacts of automated trucks on US freight movements	Computational experiments	X					
Lee et al. (2023)	Modeling the total cost of operation for autonomous trucks in middle-mile transport in South Korea	Computational experiments	X	X	X			
Hao et al. (2023)	Modeling driver and truck schedules for semi-autonomous truck platooning	Computational experiments	X	X				
Marzano et al. (2022)	Modeling operational costs for truck platooning in multimodal transport in Italy	Computational experiments	X	X				
Bray and Cebon (2022)	Modeling operational costs for different vehicle sizes and delivery routes for autonomous vehicles in the UK	Computational experiments	X	X	X			
International Transport Forum (2017)	Modeling driver demand for automated trucks in the US and Europe	Computational experiments	X	X				X
Modeling studies considering loading and unloading as non-driving tasks								
Wadud (2017)	Modeling operational costs of automated vehicles in the UK	Computational experiments	X	X	X			
Engholm et al. (2020)	Modeling operational costs of automated trucks in Sweden	Computational experiments	X	X	X	X		
Huang and Kockelman (2020)	Modeling impacts of automated trucks on US freight movements	Computational experiments	X			X		
Ghandriz et al. (2020)	Modeling truck operational costs for different drivetrains in an artificial road network	Computational experiments	X	X	X	X		
Studies estimating drivers affected by automation								
Gittleman and Monaco (2020)	Calculating the number of drivers in different US trucking segments	Analytical calculation/ estimation						X
Mohan and Vaishnav (2022)	Calculating long-haul trucking operator-hours in the United States	Analytical calculation/ estimation						X
Studies on industry expectations regarding automated trucks								
Sindi and Woodman (2021)	Survey on expected benefits and barriers for adopting automated trucks among professionals from the UK transport industry	Semi-structured interviews	X	X			X	X
Schuster et al. (2023)	Survey on the expected impact of automated trucks on the workforce and driver shortage among professionals from the US trucking industry	Focus group interviews					X	X

4 Overview of truck tasks and activities

The Stage 2 review focused on quantifying non-driving tasks and activities. Task shares across the studies are summarized in Fig. 3. The review drew on other domain knowledge areas, such as occupational health and time-use studies. The scope of the included studies is briefly presented below.

Many studies collect task data to investigate the impact of working time on fatigue, traffic safety, and health outcomes. Hanowski et al. (2000) investigated fatigue levels among local and short-haul drivers in the US, Friswell and Williamson (2008) among short-haul drivers in eastern Australia, and Williamson and Friswell (2013) among long-haul drivers in eastern Australia. Soccolich et al. (2013) examined the relationship between work hours and traffic safety among long-haul and line-haul drivers in the US. Williamson et al. (2009) studied the relationships between job characteristics and operational safety, as well as health outcomes, among short-haul truck drivers in eastern Australia. The physical strain drivers experience during their working day was the focus of further studies by Sekkay et al., which examined the tasks of long- and short-distance truck drivers at a Canadian company delivering industrial gases using gas tankers and gas cylinders, respectively (Sekkay et al., 2021, 2020). Finally, Kubo et al. (2021) examined the relationship between sleep duration and mortality from overwork among Japanese truck drivers.

From an operational standpoint, time-use efficiency is a major focus. Belman et al. (2004) summarized data from the University of Michigan Trucking Industry Program (UMTIP) survey to provide insights into the work lives of over-the-road truck drivers in the US. Belzer and Sedo (2018) modeled the relationship between driver wages and working hours. Since they used a sample from the UMTIP survey, their dataset was excluded from our analysis. Kudo and Belzer (2019) investigated the relationship between compensation for non-driving work and working hours of long-haul truck drivers in the US, using data from a 2010 survey conducted by the National Institute for Occupational Safety and Health (NIOSH). Sanchez-Diaz et al. (2020) conducted a time-use study on truck drivers in pallet and parcel delivery in Gothenburg, Sweden. Finally, Friswell and Williamson (2019) identified long waiting times as an issue, surveying long-haul truck drivers in eastern Australia about their waiting times at customer depots.

Some of the cited task share studies are already 10-20 years old. In the meantime, digitalization and advancements in logistics technologies have altered the trucking industry with potential effects on task shares. We expect modern communication technology and route planning to reduce waiting times, digitalization to reduce paperwork during delivery tasks, and automated truck loading systems to reduce loading and unloading times at warehouses.

From the task-share literature analyzed in the Stage 2 literature review, the following conclusions can be made regarding the utilization of automated vehicles.

Automated trucks can **reduce time-use inefficiencies**. Waiting times are currently a large inefficiency, cutting into drivers' working hours and limiting truck utilization. Waiting times accounted for 6.4–7.5% of working time in deliveries (Hanowski et al., 2000; Sanchez-Diaz et al., 2020) and 18.4–26.7% in local and over-the-road transport (Belman et al., 2004). Considering the long distances traveled between stops, waiting times of more than 25% in over-the-road transport seem high. This number is based on data collected in 1997 and 1998, which might no longer be accurate. We expect waiting times to be much lower in 2025 due to modern communication technology and route planning. Waiting times also constitute unproductive times from the drivers' perspective. Only one in four long-haul drivers in eastern Australia receives compensation for waiting times (Williamson and Friswell, 2013), while less than 50% of long-distance truck drivers in the US were paid for non-driving work at all (Kudo and Belzer, 2019). Further gains for automated vehicles come from the breaks human drivers need. Break times were found to comprise 6–17% of overall working time in short-distance and 10–11.5% in long-distance (Sanchez-Diaz et al., 2020; Sekkay et al., 2021, 2020; Soccolich et al., 2013). Removing waiting and break times can improve vehicle utilization and delivery times for automated trucks compared to human-driven trucks.

Automated driving can **enhance the compensation human drivers receive**. Currently, drivers are paid less or not at all for performing non-driving tasks. Long-haul truck drivers in eastern Australia often perform loading and unloading and local delivery work (93.5% and 81.3%, respectively); however, less than half of these drivers (42.7% and 39.6%, respectively) were paid for these tasks (Williamson and Friswell, 2013). Automated driving, in contrast, requires non-driving tasks to be performed by other personnel because there is no driver to perform them. During the early stages of automated driving, not all driving environments can be automated, and human drivers will still be required. In this case, teleoperation can ensure that the driver's work is restricted to driving only, guaranteeing full pay for their actual working time.

To determine the operational benefits of automated trucks, **detailed task data needs to be collected on a case-by-case basis**. The tasks identified by current time-use studies are summarized in Fig. 2, excluding break and rest times to focus solely on working time. On average, non-driving tasks constitute a smaller share of working time in long-distance driving than in short-distance driving (30% vs 54%). However, task shares in short-distance transport vary widely across specific vocations and regions. While non-driving constitutes up to 80% of working time for snack deliveries in the US (Hanowski et al., 2000), it accounts for only 30% of working time for short-haul transport in eastern Australia (Williamson et al., 2009). The data collected from the cited time-use studies varies widely due to multiple factors. First, differences arise from regional variations.

Second, differences arise from the time period during which the data was collected. Third, differences arise from the specific task taxonomy of the respective studies. Therefore, task shares are not widely comparable between studies.This suggests that collecting recent data for specific use cases, entailing vocations and regions, is necessary to determine the respective prospects of automated trucks.

5 Driving and non-driving tasks in truck transportation

This section reviews tasks commonly found in truck transportation and assesses their potential for automation. The study builds upon the typological assessment of truck delivery activities conducted by Sanchez-Diaz et al. (2020), which focused on urban freight distribution. This study adopts their approach to investigate tasks in the context of truck automation, grouping activities into three locations: **Terminal/Depot**, **On-Route**, and **Customer Site**. Table 3 presents examples of various activities conducted at these locations.

The following subsections discuss the likelihood of individual tasks being automated or, where this is not possible, how human input would be provided. The study distinguishes four categories for automation/human input: **automated (AUT)**, **remote operating person (ROP)**, **person on site (POS)**, and **person on vehicle (POV)**. The category is not predetermined for each task but depends on individual circumstances, taking into account two key factors. First, the **repetitiveness/predictability of tasks** (Engholm et al., 2024; Ghandriz et al., 2020): for fixed daily/weekly schedules, sites can be selected to allow automation or to have tasks taken over by on-site personnel (e.g., dedicated lane/customer transportation). For irregular schedules, it cannot be guaranteed that all tasks can be automated or taken over by on-site personnel (e.g., for-hire transport). Second, **customer type** (Viscelli, 2018): for business customers, the customer's personnel can handle (un)loading and paperwork (e.g., hub-to-hub transport). For private customers, the driver must perform (un)loading and handle paperwork (e.g., parcel/postal delivery).

Examples of activities per location, along with an assessment of automaton potential, are discussed below.

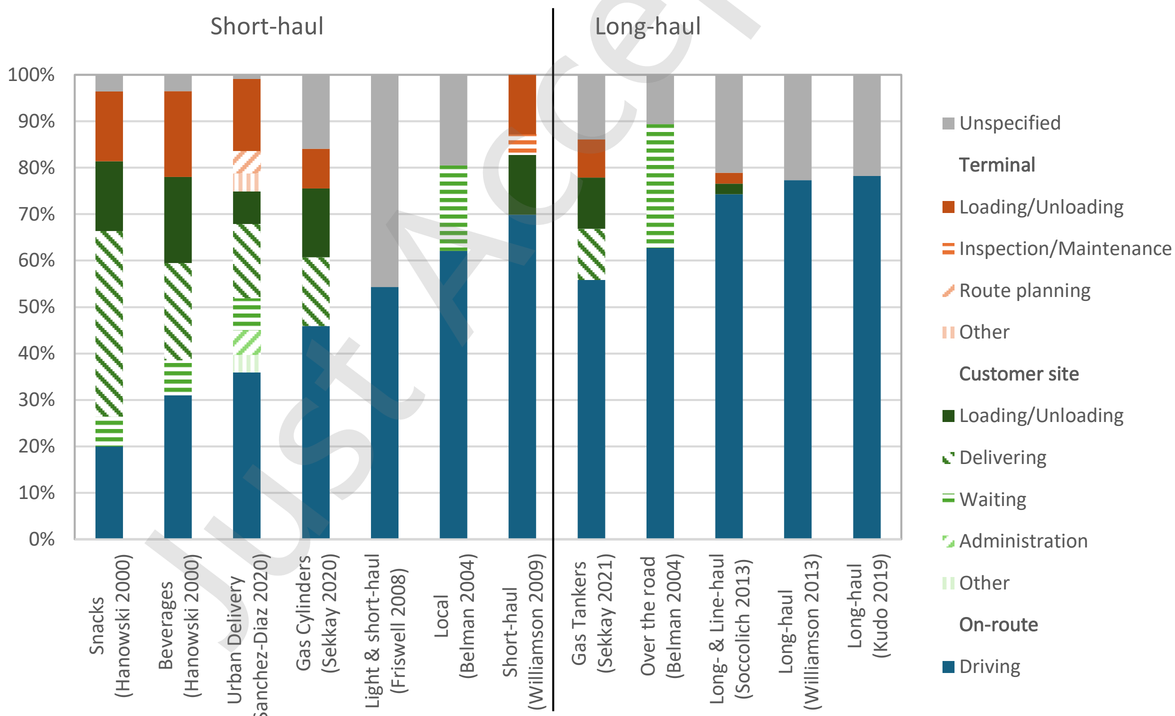


Fig. 2 Task *shares identified by time-use studies. Break and rest times were excluded to show the respective shares of pure working time; see: Belman 2004 (Belman et al., 2004), Friswell 2008 (Friswell and Williamson, 2008), Hanowski 2000 (Hanowski et al., 2000), Kudo 2019 (Kudo and Belzer, 2019), Sanchez-Diaz 2020 (Sanchez-Diaz et al., 2020), Sekkay 2020 (Sekkay et al., 2020), Sekkay 2021 (Sekkay et al., 2021), Soccolich 2013 (Soccolich et al., 2013), Williamson 2009 (Williamson et al., 2009), Williamson 2013 (Williamson and Friswell, 2013).*

Table 3 Considered driver tasks and task locations.

Location	Tasks
Terminal / Depot	Route planning, (Un)Loading, Pre-driving inspection, Cleaning, Fueling, Break times

On-route	Driving, Pre-driving inspections, Break/Rest time (according to driving time restrictions), Fueling (if necessary)
Customer site	Park in (un)loading position, (Un)Loading, Confirm delivery/ pickup (Signatures, Check for potential damages), On-site work

Terminal/Depot

Pre-driving inspection: Vehicles need to be inspected before driving, including, amongst other things, functionality checks of lights, brakes, and tires, to increase traffic safety (FMCSA, 2025a). For automated trucks operating locally, starting at the vehicle depot/facility each day, depot/facility staff can perform pre-driving inspections. (POS)

Cleaning/fueling: Cleaning and fueling must be performed regularly, depending on the goods transported and the distance traveled. Both activities can be performed at the terminal/depot at the end of the working day. For automated trucks, personnel at the depot/facility can perform cleaning and fueling. (POS)

Route planning: The level of driver involvement in route planning varies by the type of operation (Viscelli, 2018). Fleet drivers typically have fixed routes or get their routes assigned by dispatchers. Owner-operators, on the other hand, organize their own routes, search for freight opportunities, and negotiate rates. For automated trucks, route planning can be performed by dispatchers or automated in the future. (ROP / AUT)

Loading and unloading: In some cases, these operations may occur directly at the terminal/depot (Sekkay et al., 2021, 2020). In that case, it can be performed by available personnel (POS). Technologies for automated loading and unloading have also been developed as solutions for warehouses and large freight centers (AUT).

Break: Drivers are required to take breaks from driving during their working day (FMCSA, 2025b). For local drivers, breaks might be taken at the terminal/depot between delivery tours (Sanchez-Diaz et al., 2020). For automated vehicles, break times can be eliminated to increase vehicle utilization. (AUT)

Most tasks performed at the terminal/depot require manual labor. For automated trucks, available personnel at the terminal/depot must perform these tasks. Only route planning can be performed remotely or automated, and break times can be eliminated.

The workforce impacts of automated trucks are case-specific. Personnel are required at the start of the day for pre-driving inspections and loading, and at the end of the day for unloading, cleaning, and fueling. This would require either employing personnel part-time or having personnel perform administrative tasks during the day. For local deliveries, personnel are also needed during the day if vehicles return to the terminal/depot to replenish delivery goods or drop off collected goods. For a terminal/depot operating multiple trucks, this can reduce the overall workforce, as one person at the facility can serve multiple trucks, rather than needing one driver per vehicle.

On-route

Driving: The complexity of the driving environment dictates the challenge for driving automation. Freeway driving is relatively simple, with no intersections and exclusively motorized vehicles as traffic participants. City driving, on the other hand, is complex, with vehicles meeting at intersections and vulnerable traffic participants, such as pedestrians and cyclists (Qian et al., 2022). (AUT)

Fueling/Charging: If a vehicle travels long distances without returning to its depot, en route refueling may be necessary. Available personnel at gas stations and charging facilities can fuel automated trucks. For electric vehicles, inductive charging or automated docking solutions could also be used. (POS / AUT)

Break/Rest times: Drivers are required to take breaks after certain periods of driving and are limited to a maximum number of driving hours per day (FMCSA, 2025b). Especially on long distance drives, breaks and rest stops are taken en route. For automated vehicles, break and rest times are no longer necessary, potentially reducing overall delivery times and the number of parking spaces needed along freight corridors. (AUT)

Pre-driving inspection: For trucks that do not start at the terminal/depot each day, pre-driving inspections must be performed en route. For automated trucks, checks could be performed at fueling/charging stations where personnel are available. (POS) Furthermore, the vehicle's state must be monitored while driving. For automated trucks, sensors continuously collect data on relevant vehicle systems and components (Gittleman and Monaco, 2020), allowing supervision of the vehicle's state, either automated by software or remotely. (ROP / AUT)

Most tasks performed on route can either be automated or performed remotely. Only pre-driving inspections and fueling require in-person performance at respective on-route facilities. Fueling is bound to fueling stations. Conducting pre-driving inspections during fueling can reduce overall workforce and infrastructure requirements. This would not strictly be "pre-driving," but it would still guarantee regular inspection intervals.

Customer site

Contact customer: Upon arrival at the customer site, the customer must be notified of the arrival to prepare to take the delivery. The process can be automated, keeping the customer informed about delivery progress, which is already commonplace in parcel deliveries (e.g., X stops away, geofencing). (AUT)

Getting into the loading/unloading position: Loading/unloading may occur at designated sites to enhance the efficiency of the process. For automated vehicles, (electronic) landmarks and communication technology can guide vehicles into the exact loading position, as already practiced in manufacturing facilities or warehouses (Van Meldert and De Boeck, 2016). For loading sites visited infrequently, vehicle guidance systems may be too expensive, and vehicles could be maneuvered remotely instead. (AUT, infrequent usage ROP)

Loading and Unloading: Loading and unloading of goods at the customer site involves the driver in certain cases (Sekkay et al., 2021, 2020). For automated trucks, the customer must perform loading and unloading. For certain types of goods, special equipment or training is required for handling, e.g., heavy or hazardous goods. Businesses are more likely to have personnel and equipment to handle deliveries than private customers. Different solutions are available for private customers, including curbside pickup at a store, parcel lockers (mobile or stationary), and delivery robots. Each option has its own limitations regarding technical feasibility and user acceptance. For smaller deliveries, such as groceries or parcels, the final leg to private customers can be handled by automated delivery robots (Alverhed et al., 2024). However, deliveries exceeding size and weight restrictions still require a person to perform the delivery. (business POS, private POV, private small size AUT)

Document delivery and pickup: The delivery/reception of goods needs to be documented, including any potential damage. For automated trucks, this process must be carried out by the customer, requiring trust. Business customers tend to be more reliant, particularly in ongoing or recurring relationships, whereas private customers often involve one-time transactions. For deliveries by automated delivery robots, delivery conditions can be documented by monitoring the robot's loading space. (POS, small size delivery robots AUT)

Tasks that need to be performed at the customer site are the limiting factor to profiting from vehicle automation. For goods transportation and delivery, loading and unloading at the customer site requires an on-site person, and depending on the type of goods, additional handling equipment and training. For automated vehicles, this can be a burden, especially for deliveries to private customers, and less so for business customers.

Table 4 summarizes the key operational challenges for the use of automated vehicles at the defined locations. Tasks performed at the customer site are identified as the limiting factor for the use of automated vehicles.

Table 4 Operational challenges for the use of automated vehicles for each of the three task locations.

Terminal / Depot	On-route	Customer site
No challenge for automation	Slight challenge for automation	Limiting factor to automation
Most tasks require manual labor	Most tasks can be performed automatically or remotely operated	Automation potential strongly depends on the vocation
Available personnel at the terminal/depot can perform tasks	The traffic environment determines the difficulty for automated driving	Loading and unloading require an on-site person and, eventually, additional handling equipment/training
	On-route facilities for manual labor, such as fueling and pre-driving inspections, are required	
		Qualified on-site personnel cannot be guaranteed at all sites

6 Truck vocations: Challenges for task automation

The challenges and benefits of automation for individual vocations vary with the distribution of tasks. This section ranks benefits and challenges for typical vocations specified in Table 1. Task shares will only be discussed qualitatively here; a quantitative discussion will follow in the next section. The benefits and challenges for all vocations are summarized in Table 5 and will be discussed in the following. Both benefits and challenges are rated on a three-point scale ranging from positive ⊕ (best) over neutral ◯ to negative ⊖ (worst).

Yard transportation

Yard transportation refers to transportation within company grounds or similar confined areas. Because of short transport distances, non-driving tasks constitute a large share of overall tasks. The driver's involvement in those tasks, therefore, dictates the potential benefits of automated driving. If the non-driving tasks do not require the driver's input and constitute waiting times for the driver, removing the driver from the vehicle can provide significant benefits. Yard transportation can serve as a testing ground for automated vehicle technology, as the implementation barriers are relatively low (Van Meldert and De Boeck, 2016). Yards are enclosed areas that provide a controlled traffic environment. Automated vehicles in yards do not need to navigate real-world traffic with various traffic participants. Furthermore, yards and facilities can be mapped precisely to provide automated vehicles with accurate data. Lastly, transport routes are well-known and predictable. Remote operation is already practiced in yard transportation as a step toward full automation, thereby improving driver efficiency (Van Meldert and De Boeck, 2016).

Local deliveries (Business customers)

Business deliveries provide essential materials, goods, and other supplies to businesses such as craft businesses, restaurants, and office buildings. Differences between goods exist in terms of dimensions, ease of handling, and the number of delivery sites visited during a workday. However, these differences do not significantly alter the prospects for

automation.
Automation can eliminate wage costs associated with driving time. Personnel at the vehicle facility and customer site must perform loading and unloading tasks, which is especially viable with a fixed set of customers and repetitive routes. Construction vehicles, such as cement mixers, are a special case for this, as the availability of workers to handle them at the construction site is ensured. In some cases, such as oversized goods, hazardous goods, or irregular deliveries, businesses may lack the trained personnel or equipment to perform loading and unloading themselves.

Local deliveries (Private customers)

Deliveries to private customers are, in many regards, similar to deliveries to business customers, with a major difference, however, in the activities at the customer's site. For deliveries to private customers, the driver has greater responsibility in performing and documenting deliveries.
The automation potential for deliveries to private customers is significantly lower than for deliveries to business customers, as additional equipment may be required. First, vehicles need to be equipped with surveillance systems or lockers to ensure that only the intended recipients can access their deliveries. Second, it may be necessary to use micro-vehicles, such as delivery robots or drones, to deliver parcels from the delivery vehicle to the door if customers are unwilling to leave their homes to collect them (Jaller et al., 2023). In both cases, wages can be saved during driving time; however, additional costs arise from the need for extra technology or micro-vehicles (Alverhed et al., 2024). Special goods deliveries, such as heating oil, cannot be automated at all because specialized training is required to handle them.

Given the different automation potential and the need for additional equipment for deliveries to private customers, it is recommended that companies separate their deliveries to private and business customers. Separating deliveries based on customer type might, however, not be feasible depending on the respective shares of deliveries to business and private customers in certain areas.

Hub-to-Hub

Hub-to-hub transport refers to the movement of freight between large freight facilities or distribution centers. Automation is easy to achieve because loading and unloading can be performed by personnel at the hubs (Viscelli, 2018), in some cases supported by the driver (Engholm et al., 2020). Furthermore, hubs are typically located near freeways, reducing the complexity of the driving task.
Two operational modes need to be distinguished: dedicated lane/customer transport, e.g., transporting goods between warehouses of a grocery chain; and for-hire transport, e.g., freelancers seeking freight transport opportunities after completing a delivery. The potential benefits of automation in dedicated lane/customer transport are high, as routes are repetitive and can be planned. Besides eliminating wage costs associated with driving, the utilization of trucks can be increased, as driving times are no longer limited by the maximum driving hours of a human driver. The potential benefits of automation in for-hire operations, on the other hand, are limited, as delivery tours are planned opportunistically, searching for loads in or around the area of the last delivery. These opportunities might include deliveries to facilities other than large warehouses, where personnel to handle loading and unloading might not always be available. Therefore, a driver would still need to accompany the vehicle, limiting operational savings to taking rest times and searching for new freight opportunities while driving. Without a driver in the vehicle, however, for-hire operations would lose their biggest strength: flexibility.

Long distance

Long distance transport refers to transportation over distances that can take several days. Because of the long driving distances, non-driving tasks have a lower share than in other vocations, and driving mainly occurs on freeways.
The potential benefits of automating long distance transport are high. Eliminating wage costs for driving results in significant savings. Additionally, eliminating the need for driver rest breaks can potentially reduce delivery times.
Long periods on the road, however, pose operational challenges for automated vehicles in terms of monitoring the vehicle's state and safety. Current vehicles must be inspected before driving (FMCSA, 2025a). For automated trucks, pre-driving inspections must be carried out by available personnel en route. Another concern is safety regarding theft. Drivers serve as security guards for their trucks during stops at rest facilities and fueling (Gittleman and Monaco, 2020). For automated trucks, stops at rest facilities are no longer necessary; however, fueling still needs to take place.

The discussion in this section showed that each freight vocation has its own challenges regarding automation. The discussion centered around qualitative differences. Automated driving is easiest to achieve for yard transportation. However, short transport distances and high shares of non-driving tasks reduce the benefits of automated driving. Local deliveries, with comparably longer driving distances, may already benefit more from automated driving. The complex traffic environment, however, poses a technical challenge. Operational barriers for business deliveries are low; deliveries to private customers, on the other hand, face operational challenges in the actual delivery process. Hub-to-hub transportation is easier to automate technically, given long stretches of freeway driving. In dedicated lanes and customer operations, automated driving can reduce driver costs and increase vehicle utilization. In a for-hire operation, however, using automated vehicles reduces flexibility and utilization. Long distance transportation ultimately benefits most from automated driving, reducing driver costs and potentially delivery times.

In the next section, the study quantitatively assesses select vocations.

Table 5 Challenges and benefits of automated vehicles in individual vocations. Both benefits and challenges are rated on a three-point scale ranging from positive ⊕ (best) over neutral ○ to negative ⊖ (worst).

Vocation class	Vocation	Technical challenges (On-route)		Operational challenges (Customer site)		Benefits of automation
		Driving environment	Regularity	Non-driving tasks	Customer type/ facility	
Yard transportation	Container terminal, Manufacturing facility, Distribution center	Controlled environment ⊕	High ⊕	High share of non-driving ○	Regular ⊕	Save driver costs Increase labor efficiency ⊕
Local deliveries (Business)	Beverage, Linen, Parcel	Urban / rural ⊖	Medium ○	(Un)loading and paperwork ○	Regular ⊕	Save driver costs ⊕
	Tanker	Urban / rural ⊖	Medium ○	Special training for handling ⊖	Regular ⊕	Save driver costs ⊕
	Cement mixer, Dump truck	Urban / rural ⊖	Low ⊖	(Un)loading ⊕	Regular ⊕	Save driver costs ⊕
Local deliveries (Private)	Grocery, Food, Parcel	Urban / rural ⊖	Low ⊖	Delivery and paperwork ○	Varied ⊖	Save driver costs, Add cost for delivery solution ○
	Tanker (heating oil)	Urban / rural ⊖	Low ⊖	Special training for handling ⊖	Varied ⊖	Save driver costs ⊕
Hub-to-Hub	Dedicated lane / customer	Freeway ⊕	High ⊕	(Un)loading and paperwork ⊕	Regular ⊕	Save driver costs ⊕
	For-hire	Freeway / rural ○	Low ⊖	(Un)loading and paperwork ⊖	Varied ⊖	Freight search and rest times during driving ⊖
Long distance	Long-haul, Over-the-road	Freeway ⊕	Medium ○	(Un)loading and paperwork, Vehicle safety ○	Varied ⊖	Save driver costs, Reduce delivery times ⊕

7 Automation in selected vocations

This section assesses the prospects of automated trucks in four selected vocations for which task share data is available. Each vocation belongs to a different vocation class, as defined in Table 1. Furthermore, the vocations cover a wide range of driving distances and customer site modalities. The selected vocations are **snack delivery** (local business delivery), **parcel delivery** (local private delivery), **dedicated lane** (hub-to-hub), and **over-the-road** (long distance). Fig. 3 summarizes the benefits of automated trucks for all vocations.

Snack delivery

Snack delivery refers to the transportation of snack foods from warehouses to retail shops that sell these products. The task shares for snack delivery are based on data from Hanowski et al. (2000). The largest share of working time is spent on delivering goods (stocking shelves and merchandising) at 40%, followed by loading and unloading at 30%, and driving at 20%. Unproductive waiting time accounts for 6.4% of working time, while the remaining 3.6% is unspecified.

Operational challenges and savings for automated trucks are both low. For automated trucks, delivery and loading/unloading tasks must be performed by available personnel at the warehouses and stores. Personnel are assumed to be available and therefore do not constitute an operational barrier. However, operational savings are also low because wage costs will shift only from the driver to personnel at the site. Assuming personnel at warehouses and stores are already working at full capacity, additional personnel are required to handle delivery and loading/unloading tasks. In this case, operational cost savings are restricted to driver wage costs during driving time, i.e., 20% of overall working time. In reality, store personnel might have spare time to perform delivery and loading/unloading tasks when there are only a few customers in the store, leading to lower additional personnel costs and higher operational savings from automated trucks. At the same time, the technical requirements for automated driving are high, as driving takes place over short distances in urban and rural areas, which constitute challenging traffic environments. Early stages of automation, such as automated highway driving, do not benefit snack delivery operations.

Although the operational barriers for using automated trucks in snack delivery are low, the high level of technical maturity required for automated driving, combined with potentially low operational savings, makes the use of automated vehicles for snack delivery unappealing early on. Snack delivery may not warrant the case for the development of automated driving, but rather for profiting later, once automated driving is well established.

The fact that local delivery jobs offer better working conditions than trucking jobs and are typically performed by experienced drivers is another reason against the push to use automated vehicles for local deliveries. Local delivery jobs offer a regular schedule and do not require drivers to be away from home for prolonged periods. According to Scott and Davis-Sramek (2023), companies in local delivery can therefore choose their drivers and opt for experienced ones. In contrast, long-distance truckload jobs are often viewed as entry-level positions.

Parcel delivery

Parcel delivery is the transportation of parcels from warehouses to private homes. The parcel delivery task shares are based on data from Sanchez-Diaz et al. (2020). The largest share of working time is spent on the delivery process at the customer site (39%), followed by driving (36%) and tasks at the warehouse (24%), with only 1% of working time remaining unspecified. Time at the customer site includes unproductive waiting time, at 6.9% of working time.

Operational barriers to using automated trucks in parcel delivery are high, but the potential operational savings are significant. As in the case of snack delivery, loading/unloading tasks at the warehouse, are performed by available personnel, offering easy implementation but low savings potential. Tasks at the customer site, on the other hand, pose an operational challenge: no personnel are available to perform them, so a technological solution must be implemented. The operational savings, in turn, can be high. Driving and tasks at the customer site account for 75% of working time, offering significant savings in driver wage costs to offset the additional costs associated with the automated driving system and its delivery solutions, e.g., lockers or micro-vehicles. The technical requirements for automated driving are again high, because driving takes place over short distances in urban and rural areas.

Parcel delivery is the most challenging vocation to automate, as it involves the most complex driving environment for automated vehicles and additional operational challenges that require further technological solutions for the delivery process. Nevertheless, the potential operational savings are high, making it an appealing target area for automated trucks. Parcel delivery, therefore, is a case to push the development of automated driving solutions.

Poor working conditions can be a further reason to push for automated driving solutions. The *European Labour Authority* raised concerns about the working conditions in parcel delivery in a recent report (Haidinger and Rème-Harnay, 2025). The report focuses on un- and underreported work. Pressure to meet delivery targets leads drivers to reduce their rest time and potentially exceed labor time restrictions. Growing freight volumes are seen as exacerbating the situation, with employment numbers struggling to keep pace with their growth rate.

Dedicated lane

We assume dedicated lane transport concerns the transportation of goods between two warehouses within a single company. The dedicated lane task shares are based on data from Soccolich et al. (2013). The largest share of working time is spent on driving (74.3%), followed by loading and unloading (4.6%), and 21.1% is unspecified.

Operational challenges for automated trucks are low, while potential savings are high. For automated trucks, loading/unloading tasks must be performed by available personnel at the warehouses. Personnel are assumed to be available and therefore do not constitute an operational barrier. Again, operational savings from these tasks are low because wage costs will be shifted from the driver to warehouse personnel. However, even if operational cost savings are restricted to wage costs during driving time, this constitutes a major share overall wage costs with driving time making up 74.3% of overall working time. Additionally, the technical requirements for automated driving are relatively low, assuming warehouses are located near a freeway, so that driving mainly takes place on freeways.

Operational and technical challenges in dedicated lane transport are low, enabling early deployment of automated trucks. Considerable savings in driver costs can further incentivize the fast adoption of automated vehicles. Dedicated lane transport can, therefore, be an early application for automated driving solutions.

Over-the-road

Over-the-road transportation is the transportation of goods in a single vehicle over long distances, typically requiring multiple days of driving. The task shares for over-the-road transportation are based on data from Belman et al. (2004). The largest share of working time is spent driving (62.7%), followed by unproductive waiting time (26.7%), and 10.6% is unspecified.

Operational barriers to using automated trucks for over-the-road transportation are moderate to high; however, operational savings are substantial. The primary operational challenge is the diversity of customers and the wide range of transported goods. In contrast to dedicated lane transport, personnel are not guaranteed to be available at pickup and delivery sites to perform non-driving tasks. In such cases, a driver could take over the vehicle at a transfer location close to the freeway to perform both local driving and on-site tasks. Driver wage costs could still be spared for a large part of the trip in such a case. In addition to driving time, eliminating driver wage costs for unproductive waiting times offers cost savings for automated vehicles. Lastly, delivery times for over-the-road transportation can be substantially reduced by using automated trucks. Over-the-road transportation trips, as recorded by Belman et al. (2004), have an average driving time of 14.8 hours. This exceeds the driving time limits for truck drivers in the US, which limit driving to 11 hours before requiring a 10-hour break (FMCSA, 2025b). For a human driver, completing 14.8 hours of driving therefore takes at least 24.8 hours. Automated trucks are exempt from complying with driving time limits. Completing the same trip could therefore save at least 10 hours, which is a 25% overall time savings, assuming driving time makes up 62.7% of total working time. Such time savings can enable higher vehicle utilization, thereby reducing the need for a larger vehicle fleet. Alternatively, some of the time savings could be traded for lower driving speeds to reduce energy consumption (Jungblut et al., 2023). The technical requirements for the automated driving system are low, assuming driving mainly occurs on freeways.

Operational and technical challenges are moderate, while potential operational savings are huge. In addition to operational cost savings, automated trucks offer major incentives such as reduced delivery times and increased vehicle utilization. Therefore, over-the-road transport is not only a case for early deployment but also for rapid adoption of automated driving solutions.

Driver shortages can be a further reason to advocate for the use of automated trucks in over-the-road transport. In Germany, substantially more drivers are retiring each year (30,000) than are being trained as new drivers (17,000), resulting in a driver shortage (BMVI, 2020). According to the International Road Transport Union, driver shortages are increasing worldwide (IRU, 2023), with a projected 130% increase from 3 million drivers in 2023 to 7 million in 2028. Reducing driver demand for over-the-road transportation is particularly effective because these are entry-level jobs in trucking (Scott & Davis-Sramek, 2023). Therefore, the number of new drivers who need to be trained can be reduced, while experienced drivers can keep their jobs.

The exemplary analysis of four selected vocations showed that task shares dictate the utility of automated driving for individual freight vocations. The decision to use automated vehicles is based on whether they can provide cost savings. While operational characteristics may determine the difficulty of automation, they do not determine the potential savings. Comparing the cases of snack and parcel deliveries reveals that operational barriers are lower for snack deliveries; however, the potential benefits of automation are lower as well. Because of the significant technical challenges of city driving, both require advanced automated driving technology and will only become a use case for automation when its technology is well-established. However, parcel delivery can drive the development of automated vehicles through its significant potential for cost savings. These cost savings depend on the additional costs of the respective delivery solutions, which are subject to ongoing development and require further study in future cost analyses. Hub-to-hub and over-the-road transportation can be early use cases for automation due to their low operational and technical barriers to automated vehicles. Especially over-the-road transport can be a case for rapid adoption of automated vehicles, with significant benefits from shorter delivery times.

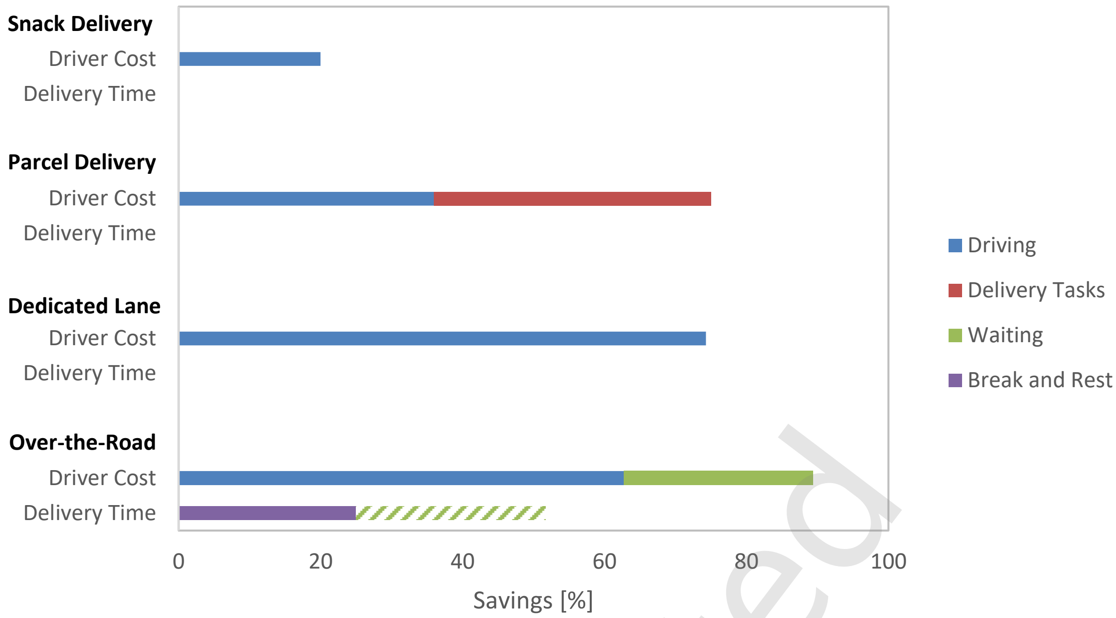


Fig. 3 Potential operational savings for the select vocations. Driver cost savings are based on the percentage of driving time in the total working time, assuming driving occurs without a human driver. Delivery time savings are based on the overall time savings that can be achieved by not taking a 10-hour rest period overnight during a multiday trip, as well as by eliminating drivers' unproductive waiting time.

8 Conclusion

Modeling studies so far fail to depict freight transport representatively in two regards. First, modeling studies mostly neglect non-driving tasks, except for loading and unloading. Interview studies, however, stress the importance of non-driving tasks for automated vehicle operation. Second, studies often make generalized assumptions regarding driving times, distances, and non-driving tasks, therefore failing to capture the diversity of freight transport vocations.

This study compiled an exhaustive list of road freight transport vocations and the corresponding tasks drivers perform in each. The study discussed the operational challenges of automating specific tasks and conducted a qualitative assessment of the benefits and challenges of automation in various vocations.

For the analysis, tasks are grouped into three task locations: Terminal/Depot, On-Route, and Customer Site. Tasks performed at the customer site are identified as a limiting factor for the use of automated vehicles, often requiring human intervention. Only in select cases, such as loading and unloading at warehouses, are personnel available to perform these tasks. In other cases, technical solutions must be developed, or a human driver must accompany the vehicle. From a technical perspective, automated driving is easiest to implement for yard transportation because it takes place in a controlled traffic environment. In contrast, automated driving is the most challenging to achieve for local deliveries, due to the often complex traffic environment in urban areas.

Analyzing the literature on task shares and time-use of truck drivers reveals three key aspects for the use of automated vehicles in road freight transport. First, automated trucks can reduce time-use inefficiencies. Second, automated driving can improve the compensation human drivers receive by reducing unpaid working time. Third, detailed task data is needed on a case-by-case basis, reflecting vocation and region, to determine the operational benefits of automated trucks.

Lastly, the exemplary analysis of four selected vocations showed that task shares dictate the utility of automated driving for individual freight vocations. The decision to use automated vehicles is based on whether they can provide cost savings. These savings depend heavily on the non-driving tasks and the additional costs of solutions for automating them. Vocations that promise large cost savings will drive the development of automated trucks. Operational barriers may determine which vocations automated vehicles are deployed in first; however, they do not play a significant role in the overall decision-making process for developing automated vehicles.

Based on our findings on time-use and operational characteristics, policy and planning should focus on two aspects to enable early benefits from automated vehicles in road freight transport. First, automated vehicle development should focus on long distance transport. Long distance trucking vocations offer significant benefits from automated vehicle use, potentially shortening delivery times. Additionally, the technical requirements for automation are relatively low, facilitating the introduction of automated vehicles. Second, efforts should focus on helping long distance drivers transition into regional transport jobs. Regional transport has higher operational and technical barriers to automation and will therefore take longer to be automated. However, further studies are needed to analyze the feasibility and labor impacts of this transition, including training demands, wage effects, and regional labor demands.

Author contributions

Edgar Jungblut: Conceptualization, Methodology, Formal analysis and investigation, Writing - original draft preparation. **Miguel Jaller:** Conceptualization, Methodology, Validation, Writing - review and editing, Supervision **Thomas Grube:** Conceptualization, Validation, Writing - review and editing. **Jochen Linssen:** Writing - review and editing, Funding acquisition, Supervision.

Acknowledgements

This work was supported by the Helmholtz Association under the program "Energy System Design". Open Access Publications funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 491111487. This study was partially funded by the National Center for Sustainable Transportation and the Sustainable Freight Research Program at the University of California, Davis. The authors would like to thank the State of California for their support of university-based transportation research, particularly for the funding provided for this study.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used DeepL for language improvement. After utilizing this tool/service, the author(s) thoroughly reviewed and edited the content as necessary and take full responsibility for the final content of the published article.

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