Opportunities and Barriers for Truck Platooning on Norwegian Rural Freight Routes

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ABSTRACT
Truck platooning can potentially make road freight transportation safer and greener. Technological readiness, business opportunities and acceptance of truck platooning have mainly been studied for multi-lane highways with ample truck volumes. Less is known about truck platooning in areas with low traffic volumes, challenging roads and weather conditions. This paper investigates opportunities and barriers for truck platooning on Norwegian rural freight routes through stakeholder interviews and realistic case examples. Given modest freight volumes, dispersed industry clusters and challenging road conditions, this study identifies several prerequisites to deploy platooning and achieve economic savings. The paper discusses future steps to organize platooning across carriers, ensure appropriate infrastructure and gain acceptance among truck drivers, motorists and other road users.

Keywords: truck platooning, wireless truck convoys, rural freight routes, stakeholders, two-lane roads, road freight, public acceptance, driver workload

INTRODUCTION

Truck platoons are convoys of virtually linked trucks that travel together with small headway distances *(1)*. As such, platoons consist of one lead truck, and one or more following trucks, driving closely behind each other as a train on the road. Truck platooning is forecast as one of the earliest applications of road vehicle automation to become commercially viable *(2)*. The operation of platooning trucks can be structured along the Society of Automotive Engineers (SAE) levels of automation (3), based on the allocation of tasks between a human driver and the driving automation system. The levels range from No Driving Automation (level 0), in which the *human* performs all driving tasks, to Full Driving Automation (level 5), where the *system* performs all driving tasks without requiring human intervention. In intermediate levels, the human driver and automated system share vehicle control. This paper assumes that a human driver is present in the first truck, having operational control of the platoon. The presence and role of drivers in following trucks depend on the level of automation and the state of cooperative technology. Additionally, platooning can be classified based on use-cases ranging from restricted areas, dedicated lanes or roads, to entire public road networks. This is often referred to as the operational design domain (ODD), denoting environmental and roadway conditions under which an automated driving system is designed to function *(3)*. Furthermore, platooning can be deployed within a single carrier, organized across carriers, with trucks of the same or different manufacturers. The term platooning is also used in the context of passenger vehicles, although the truck application dominates *(4)*. In this study, *platooning* refers specifically to *truck platooning* using heavy goods vehicles.

The expected benefits of truck platooning include fuel savings, reduced emissions, increased operational efficiency, and improved safety. Shorter gaps between trucks reduce aerodynamic drag, lowering fuel consumption 5-15%, depending on headway distance, mass, and other vehicle configurations (*1, 2, 5)*. Platooning may increase traffic throughput by reducing inter-vehicle spacing, freeing up capacity for other motorists, and by homogenizing or smoothing out arterial speeds *(6)*. Platooning may thus reduce infrastructure investments for accommodating predicted traffic volume increases *(7)*. Platooning-related hazards are cut-in situations, as well as the risk of following truck(s) running into the preceding vehicle. As long as platoons are manned, issues also exist relating to driver workload and possible decreases in situation awareness for following drivers while monitoring automated systems *(4)*. Poor rest quality, underload effects, and sustained time-on-task due to longer monitoring periods may cause fatigue and reduced performance *(4, 8)*. Sensors, communication, and centralized traffic control may mitigate these risks *(4)*. When fully automated, platooning is expected to enhance safety by reducing reaction times, human errors, and the frequency of rear-end collisions *(9)*.

Platooning has been tested and evaluated on ideal conditions elsewhere, with promising results *(e.g., 10, 11, 12, 13)*. Furthermore, acceptance studies have been performed for platooning on multi-lane highways *(e.g., 14, 15)*. Opportunities and barriers for platooning have also been investigated from a business-case and organizational perspective *(e.g., 16, 17)*. Due to dispersed industry clusters, adverse weather, low road standard and small traffic volumes, previous findings are not directly transferrable to Norway *(18)*. This study investigates prerequisites for introducing platooning on Norwegian rural freight routes, identifying opportunities and barriers expected by involved stakeholders. Local road conditions, regulations, freight volumes and stakeholders are outlined below.

THE NORWEGIAN CONTEXT

The Norwegian public road network is classified into national, county, and municipal roads, organized under the jurisdiction of three different public agencies. While national roads are owned and operated by the Norwegian Public Roads Administration (NPRA), county and municipality administrations are responsible for the two latter categories, respectively. Due to scarce population and difficult topography, motorways make up 1% of the primary and secondary road network, while making up 1-12% for most European countries *(19)*. Norwegian motorway density is also generally lower than for the other Nordic countries *(20)*. The Norwegian road network is mostly comprised of two-lane roads, many of which are demanding with respect to curvature, road width and roughness, with sparse use of medians and rumble strips, necessitating low speed limits (*21*). Furthermore, Norway has numerous tunnels and ferry connections, traversing mountains and fjords, compared to most other countries.

Norwegian regulations allow for the general use of heavy goods vehicles with a maximum length of 19.5 meters and an upper weight threshold of 50 metric tons. The current paper studies platooning considering vehicles in this category. The NPRA is gradually allowing for longer and heavier configurations on qualified roads. Specifically, the European Modular System (EMS) refers to configurations of tractors, trailers and trolleys restricted to a total length of 25.25 meters and 60 metric tons.

To reduce fatigue among truck drivers, hours-of-service regulations have existed for many years in developed countries. Although variations exist between countries, such regulations focus on limiting maximum hours on duty during a 24-hour period and regulating breaks during the workday and between work periods. In Norway, truck drivers are required to comply with European rules *(22)*: Essentially, daily driving periods shall not exceed 9 hours, with a break of 45 minutes after maximum 4 ½ hours of driving. Daily overnight rest periods must be at least 11 hours. Total daily on-duty time, including driving and non-driving tasks, cannot exceed 13 hours.

The presence and role of drivers in the lead and following trucks may change in the future, enabling new business opportunities and ways to organize road freight. In the future, only lead trucks may require attentive drivers, allowing rest or administrative work to take place in following trucks while moving. The order of trucks could be switched to utilize driving time for each driver, facilitating around-the-clock operation. This would require amendments to the regulations to allow currently forbidden in-vehicle overnight rest while moving. When only the lead truck is manned, while followers are unmanned, platooning could alleviate the worldwide shortage of professional truck drivers *(2)*. Eventually, lead vehicles may also become driverless. The Norwegian Truck Owners Association estimates that 10 000 new drivers are needed over the next 8-10 years for its member carriers to retain current market share *(23)*. This shortage stems from a growth in transport demand, the current workforce aging, and low recruitment.

Norwegian industry clusters, with export-oriented businesses such as petroleum and fish farms, are dispersed along the coastline. Many road freight shipments start or end at facilities located along rural roads. Frequently, goods are transported from rural industry sites to the Oslo capital district for domestic distribution and export. Similarly, most of the imported goods arrive at terminals in the capital district and are distributed to consumers country-wide. Shippers and receivers depend on the ubiquity and flexibility of road freight, connecting rural and urban areas. The total Norwegian freight demand is expected to increase from 530 to 760 million tons in 2050, with minor changes in modal shares for road (53 to 55%), sea (40 to 37%) and rail freight (8%, unchanged). Thus, volumes are forecast to increase by 50% for both road and rail freight, and by 33% for sea freight (*18*). For many years, however, the Norwegian government has set national policy objectives to shift modal distributions away from road, towards rail and sea. As such, current forecasts do not support these political goals.

Figure 1 shows main stakeholders and their roles in the road freight transport system. Carriers are presumably the main direct beneficiaries of platooning, saving fuel and personnel costs, and possibly reducing future staffing requirements. 42% of Norwegian carriers are owner-operators, 48% operate 2-10 trucks, while the remaining 10% operate more than 10 trucks (*24*). The dominance of smaller carriers suggests between-carrier cooperation to make platooning viable. Platooning may also improve shipper competitiveness by delivery cost reductions and by increasing their ability to maintain production in rural regions. These cost reductions may also benefit receivers through lower pricing. While also being a national road owner, the NPRA acts as an authority across all road categories, having several roles and responsibilities for ensuring a safe, efficient, and environmentally friendly road system for all road users. Residents, workers, tourists, and others may encounter platoons on the road, and may also benefit from infrastructure changes needed to accommodate them. Although their involvement in the road freight transport system is indirect (*25*) their interests should be considered, as public acceptance and willingness to cooperate with platoons is a prerequisite for deployment (*26, 27*). Policymakers aim to make regions attractive to businesses and residents, while balancing private and public interests (*28)*. They may also need to decide on frameworks for permitted platooning technologies, and regulate aspects such as allowed weight, number, and distance between trucks. Moreover, authorities and policymakers should decide on licensing requirements and trucking regulations, as well as on which roads platooning could be permitted. Original equipment manufacturers (OEMs) should clarify capabilities and limitations of installed technologies, their ODDs and requirements for monitoring and manual intervention. This impacts the legislation and infrastructure requirements for enabling platooning.

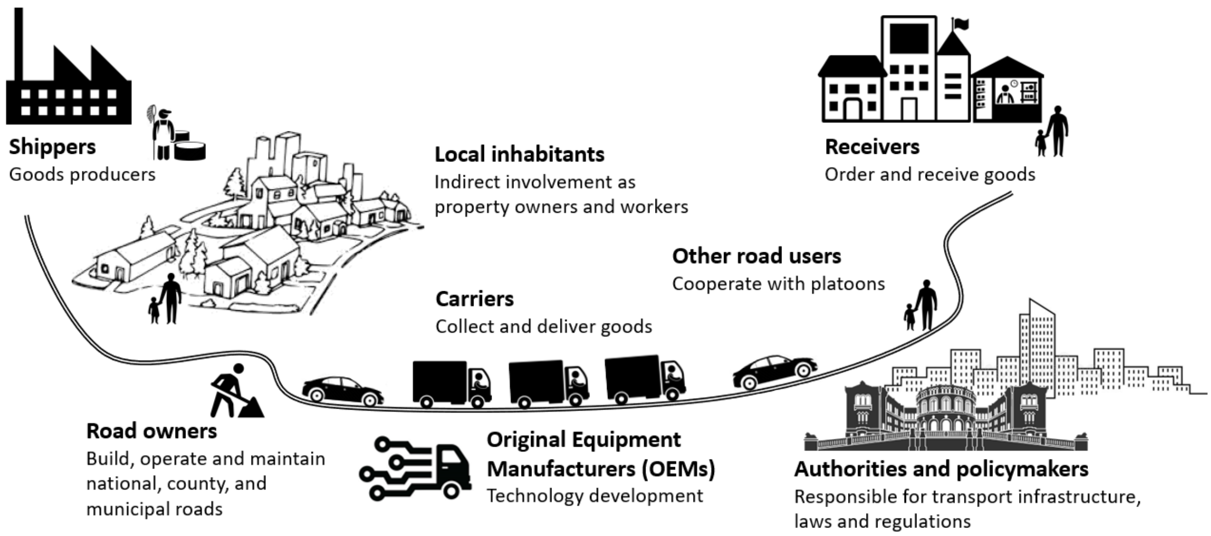

Figure 1: Main stakeholders in the road freight transport system.

METHODS

This study identifies opportunities and barriers for platooning in Norway through semi-structured stakeholder interviews *(28, 30)*. Realistic case examples were used to facilitate discussions of business opportunities, acceptance, organizational means, and the level of infrastructure readiness needed to accommodate platooning on rural freight routes.

Stakeholder interviews

Purposive and snowball sampling techniques were used to recruit 21 interviewees, 4 women and 17 men, based on their knowledge about either or both freight transport and Norwegian road infrastructure. Some were also familiar with vehicle automation technologies. They represented carriers (n=4), shippers (n=4), researchers (n=4), the NPRA (n=3), county administrations (n=2), interest organizations (n=2), railway terminal owners (n=1), and OEMs (n=1). Shippers included a seafood corporation, a furniture manufacturer, and a natural gas distributor. Two interviews included two participants from the same company. The other interviews were conducted with participants individually. 7 interviewees were former truck drivers. To some degree, shippers may also be considered representing receivers, as they order and receive raw materials for production.

Informed consent was collected from all participants, and 90-minute semi-structured interviews were conducted during spring 2021. The interviewee information letter included a short explanation of platooning and examples of questions from the interview guide. Participants introduced themselves at the start of the interviews, immediately after which they were asked about their understanding of platooning. Subsequently, the authors reiterated the explanation provided in the information letter, to ensure common terminology. The interview guide included open-ended questions that allowed for subjective reflections and discussions about platooning in Norway. Participants were encouraged to speak freely about their experiences and insights relevant for platooning and freight transport, a suitable approach when exploring a topic for which there is limited knowledge *(28, 30)*. Interviews focused on expected opportunities and barriers for platooning in Norway, concerning economic benefits, infrastructure readiness, organizational and regulatory demands, acceptance, and road user safety. Shippers and carriers were also asked about their logistics organization, freight volumes and routes. All but two interviews included case-examples, described below, to facilitate discussions about platooning viability in Norway.

Interviews were conducted digitally, in Norwegian, and recorded for verbatim transcription. Transcriptions were anonymized, coded, and thematically analyzed in the software NVivo 12 (*31*). A combined deductive and inductive approach was used to identify 31 codes and distinct code definitions. The first and second author coded a subset of the data independently. Once a reliable coding scheme was agreed upon, the first author coded the remaining data. Codes were sorted and grouped into higher-order themes as presented in the results and discussion chapter. Interviewee quotations throughout the paper have been translated to English.

Case examples

Five realistic examples were presented during all but two interviews to contextualize the discussion. The cases facilitated discussion of economic savings, freight volumes and infrastructure readiness for platooning. Based on three different routes, the cases reflected rural and coastal challenges, particularly related to the idea of using ferry terminals as starting points for platooning. Once potential routes were found, average hourly traffic volumes were inspected to determine the extent to which platooning would be feasible. Truck traffic volumes were obtained through NPRA inductor loops and the National Ferry Database from 2019. As truck volumes are expected to increase, cases represent conservative estimates for platooning viability. The case examples considered only two-truck platoons. Cases were defined with GPS-coordinates for logistics terminals as start- and endpoints. Subsequently, the SINTEF Energy Module *(32)* was used to calculate route length, fuel consumption and trip duration for conventional, solitary truck driving. As opposed to using fuel savings upwards of 10%, as suggested by (*1,2,5),* savings were based on conservative 5% reductions of fuel consumption from the calculated SINTEF baseline. This is assumed to capture the effects of disadvantageous Norwegian topography and conservative following distances, potentially required for traffic safety. All cases assumed that all platooning trucks are manned by a driver. Cases are described below and visualized in Figure 2 with respect to trip dispositions and geographical locations. As they were part of the interviews, case discussions were also transcribed verbatim and thematically coded in NVivo 12. Findings from case discussions were generalized and included in appropriate subchapters of the results and discussion.

Case 1: Short route, 84.8 km

A transport traverses a busy West-coast ferry connection. All daytime departures have at least two trucks. Terminals in Stavanger and Haugesund represent origin and destination for truck A. Truck B has the same destination. Trucks drive separately to the ferry, convene and platoon after disembarking. Thus, case 1 facilitated discussion on fuel savings for short routes.

Case 2A: Medium route, 280.7 km – 20% lower follower costs

A transport traverses a ferry connection in Northern Norway, where almost all departures include two trucks. Terminals in Narvik and Bodø, respectively, represent origin and destination for truck A. Truck B has the same destination. Trucks drive separately until the ferry, convene and platoon after disembarking. For the discussion, 20% reduced follower costs were proposed, under assumption that the driver partially rests during platooning. Route 2A is longer than route 1, yielding larger absolute fuel savings.

Case 2B: Medium route, 280.7 km – Linking and dissolving at hubs

Based on the same route as case 2A, trucks A and B platoon together between the ferry quay and a hub at which they disassemble and continue manually along different routes. The case introduced participants to the idea of linking and dissolving platoons at hubs.

Case 2C: Medium route, 280.7 km – Waiting for partner at hub
Based on case 2B, the platoon is dissolved at the hub. At daytime, the downstream stretch towards the destination of truck A, is traversed by 6 trucks per hour, on average. Thus, the follower waits 10 labor-minutes for a new partner. Waiting inconvenience, waiting effects on hours-of-service regulations, and value loss of onboard cargo were also discussed.

Case 3: Long route – 722.2 km – In-vehicle rest while moving
This case shows effects of alternating lead driver, while the driver in the following truck rests. The case presumes that “follower time” does not count towards daily allowed driving time but counts as working time. Two trucks start platooning at the hub, destined for an 11-hour drive to Alta. The hub represents the northernmost point of Norwegian rail service. As such, this case exemplifies using platooning as an extension to the public railway system. For simplicity, ferry time is assumed to count towards driving time, and resting drivers are paid driving wage. Truck-and-driver combinations switch at suitable locations when approaching their 4.5-hour driving periods, avoiding overnight rest, halving transit time from 23 hours to 11. Total labor-hours drops slightly, as 11 wage-hours for two drivers, totals 22. Shortened transit time was not assigned any value.

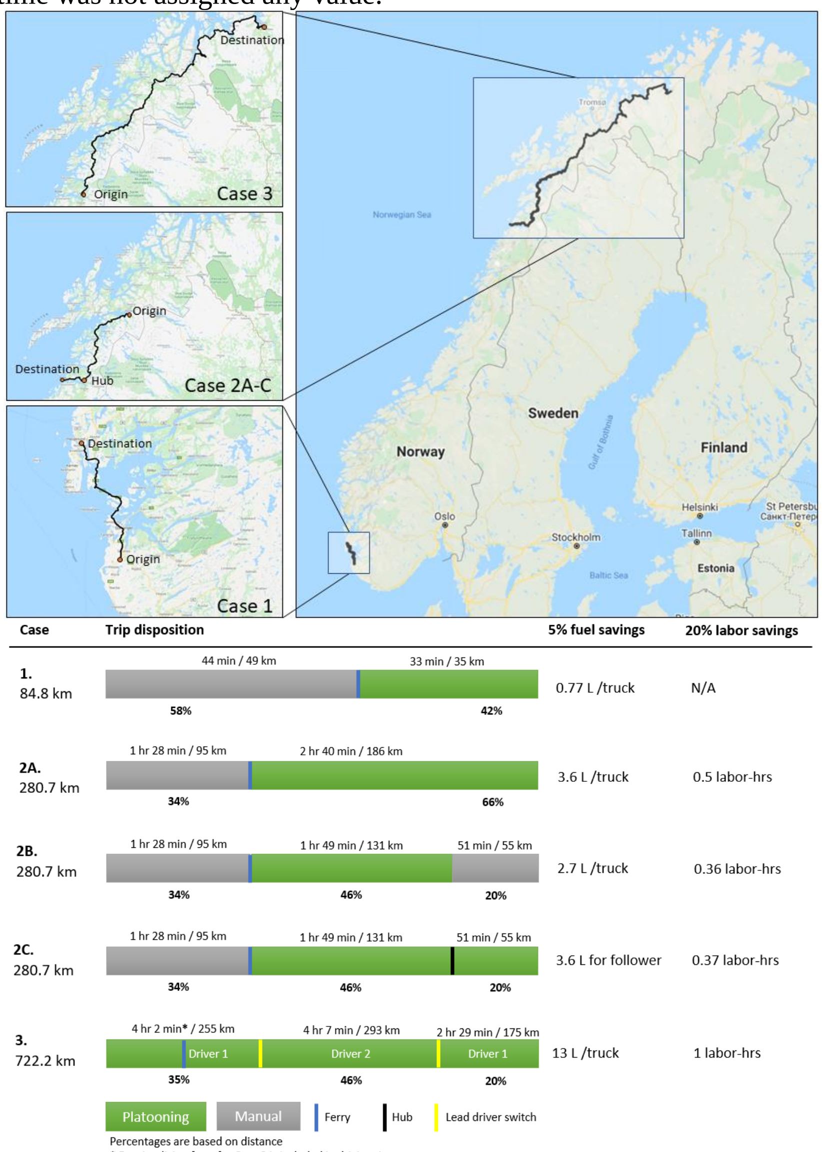

Figure 2: Simplified overview of cases

RESULTS AND DISCUSSION

This chapter contains a synthesis of participants' viewpoints on platooning in rural Norway, including discussions evoked from case examples. Study findings are grouped under six higher-order themes: Understanding of truck platooning (1), Impacts on truck drivers and hours-of-service regulations (2), Societal impacts and public acceptance (3), Logistics, organization, and cooperation (4), Economic considerations for shippers and carriers (5) and lastly, Infrastructure readiness, investments, and maintenance (6).

Table *1* provides a summarized overview of the opportunities and barriers discussed for themes 2 through 6, followed by suggestions for deployment and future research needs. The first theme, exploring participants' understanding of the truck platooning concept, is documented in a separate paragraph, and not included in the table. The subchapters following the table describe results and discussions for themes 2 through 5 in further detail.

Table 1: Results overview

	OPPORTUNITIES	BARRIERS	DEPLOYMENT SUGGESTIONS	RESEARCH NEEDS
TRUCK DRIVERS	• Safe and economic driving • Better utilization of driver competence • Improved workload management, trust, and comfort • Enable drivers to perform non-driving tasks or rest while moving • Enable drivers to return home at night	• Added demands for driver monitoring of platoon system and boundary conditions (ODD) • Diverging driving styles preferences between lead and following drivers • Reduced independence and freedom for drivers	• Designated leaders on challenging routes akin to skilled marine pilots in ports • Rotate truck positions to optimize driver workload • Small-scale introduction within companies • Form agreement about driving behaviors prior to platooning • Gradually extend driving periods	• Perceived usefulness and ease of use • Impacts on driver role, workload, and job satisfaction • Trust in technology and lead driver • Basis for changing hours-of-service regulations
SOCIETY	• Optimize handling of present freight volumes • Make existing tailgating practices safer • Improve intermodality • Ensure reliability of supply • Improve safety and accessibility for other road users • Reduce need to overtake • Prevent speeding and risky driving	• Changes in perceived control for shippers and receivers • Threat against political objectives for goods transfer from road to rail and sea • Public concerns about platooning safety • Public concerns about encountering platoons • Other road users' willingness to cooperate with platoons	• Clarify societal objectives • Incremental introduction to foster public acceptance • Communicate benefits to local inhabitants • Inform other road users • Introduce platooning for electric trucks	• Public acceptance • Traffic implications • Other road users' cooperation with platoons • Objective risks and safety effects

	OPPORTUNITIES	BARRIERS	DEPLOYMENT SUGGESTIONS	RESEARCH NEEDS
ORGANIZATION	• Complement directional freight balance • Simplify logistics planning • Regulate and sanction unfair behavior • Improved efficiency at terminals	• Inadequate truck volumes • Carriers not willing to cooperate • New scheduling demands • Waiting times • Cargo security • Data-security • Terminals becoming bottlenecks	• Target cargo that has high volumes and/or regularity • Target origin-destination pairs with high road freight volumes • Target ferry-dependent areas • Utilize infrastructure at low-intensity time windows • Matchmaking tool for carriers • Organize platooning in-house or cooperate with others • Platooning on fixed schedules	• Viable routes • Responsibility for organizing platoons • Matchmaking tool requirements • Data-sharing issues • Interface with other transport modes and terminal handling
ECONOMICS	• Reduced transport times and labor costs • Fuel savings • Improved utilization of driving, working and rest periods	• Start-up costs • Potentially limited fuel savings compared to other measures • Inadequate labor savings if drivers are needed in all trucks • Waiting time costs • Contrary views of being platoon leader (costs vs. job motivation)	• Conduct trials and pilots • Subsidies or marketplace exclusion • Software system for fair distribution of costs and savings	• Transport time reductions • Cost-benefit of waiting time • Fuel and labor savings • Models for co-financed R&D programs
INFRASTRUCTURE	• Address current road shortcomings for all users • Improved road capacity • Enable highly automated driving • Reduce interaction with other road users	• Lack of uniform, high-quality road infrastructure • Lack of truck stops • Winter conditions • Narrow, steep, and winding roads and tunnels	• Start in greater Oslo-area • Start on roads approved for EMS road trains • Alternating 2+1-lanes will enable overtaking and support emergency vehicles • Remove bottlenecks • Build more roadside pockets and climbing lanes	• Evaluation of road parameters • Impacts on road capacity • Winter operation demands • Basis for changing regulations (speed limits, overtaking)

Understanding of truck platooning

Participants expressed varying knowledge about platooning. Three participants, one researcher and two shipper representatives, had no prior knowledge of platooning. The most common expressions used to explain platooning were connected trucks driving as a chain, or road train. There were uncertainties regarding the criteria for using the term *platooning*, related both to the minimum automation level, and to the number of connected trucks needed in order for them to be considered a platoon. One interviewee compared platooning to vehicle-to-vehicle (V2V) communication between passenger cars, proposing that the main difference is that platoons have a "*lead sheep.*" Some emphasized the role of the lead truck in controlling following trucks, citing prospects of driverless followers. One interviewee saw platooning as "*a way of reducing the complexity of automation on road by having a driver in front, while increasing the freight volume and making it more dynamic.*" Several participants, representing interest organizations, an OEM, carriers, shippers and the NPRA, spoke of platooning as an exciting prospect. Some researchers and carriers, however, were skeptical. "*My first thought was Australian, enormous heavy goods vehicles, a mountain of vehicles.*"

Impacts on truck drivers and hours-of-service regulations

Several interviewees believed that all platooning trucks would require human driver presence for many years to come. They stated that this will depend on the extent to which technology can cope with everything that platoons can encounter on rural roads, e.g., curvature, tunnels, overtaking situations, vulnerable road users, wild animals, and adverse weather. While some uncertainties may be handled through regulations and infrastructure improvements, others will still require human driver intervention. Some suggested designated platoon leader roles. Experienced drivers familiar with local road conditions may enhance economical, defensive, and predictable driving, beneficial both for the platoon and other road users alike. To further utilize driver resources, non-driving tasks, such as loading and offloading, could be allocated to other roles. This would disburden the lead driver, who now carries responsibility for, and makes operational decisions for, the entire platoon while driving. Platooning could also introduce new work processes for drivers, such as operational maneuvers required to join and leave platoons. Strategical processes could also be introduced, such as trip planning and coordination with logistics dispatchers.

Increased automation could offer the opportunity for drivers to perform non-driving tasks while moving. However, drivers may experience increased mental demands if expected to monitor the driving operation for prolonged time periods. As far as drivers are required, platooning technology will add complexity to the driver-vehicle-environment system, in which the driver may be requested to intervene. Thus, interviewees were skeptical to scaling down training and licensing requirements for drivers in following trucks. If extended driving periods are permitted, or drivers can rest in-motion, some interviewees expressed concerns regarding performance of drivers in subsequent manual driving. On the flipside, fatigue may be alleviated by regularly rotating lead and follower positions. In this way, manual driving and monitoring tasks are evenly distributed between participants, as exemplified in case 3. Thus, the authors suggest that platooning could improve driver performance and traffic safety compared to individual driving, subject to the same automation level.

Some interviewees expected that challenging road conditions and diverging driving styles can evoke emotional and bodily responses, such as motion sickness, tension, and anxiety for following drivers. One participant suggested that platooning should first be introduced within smaller carrier subdivisions, where drivers know and trust each other, their cargo and equipment, before organizing platoons across business units or carriers. Forming agreements prior to platooning could also clarify expectations and increase predictability, trust, and comfort among drivers. Interviewees stated that some drivers may find driver team participation rewarding and possibly enjoy performing non-driving tasks while moving. Others, on the other hand, may feel constrained or pressured to platoon, appreciating the independence and freedom of solitary driving. Extended driving time may enable drivers to return home at night after long-haul trips but could also add to driver exploitation. Thus, platooning may have mixed impacts on job satisfaction, driver recruitment and staff turnover, as long as drivers are required.

Societal impacts and public acceptance

Stakeholders discussed barriers for public acceptance when introducing platooning on public roads. The OEM representative drew an interesting parallel between implementation of platooning in society, versus the process of continuous improvement in the industrial sectors. The industrial workforce is well acquainted with continuous negotiations between technologies and regulations to improve work processes. On the other hand, a step-change shift in mindset is required by society to accept platooning. Some interviewees stated that an incremental introduction, supported by good communication of positive effects for local inhabitants, would enhance public acceptance. Examples of such effects are traffic safety benefits and economic gains. Two interviewees pointed to conventional trucks driving closely today. Although tailgating practices are undesirable and prohibited, it appears to be socially acceptable in certain areas, and in certain driver populations. Therefore, platooning could be viewed as a means towards making current practices safer. According to one interviewee, public resistance towards platooning may be caused by erroneous predictions of increasing numbers of trucks, even if actual truck volumes were unchanged. Similarly, others posited that the total number of trucks one would encounter on Norwegian roads would not increase simply if platooning were to become feasible. Stated otherwise, platooning would *group* trucks together, causing motorists to encounter them *less* frequently. And even if road freight volumes were to increase, encountering a platoon of 5 trucks might not be too different from encountering one with three. As such, it is conceivable that platooning can absorb induced volume demands from a potential modal shift. The authors suggest that acceptance might be enhanced by ensuring that the public has a clear understanding of platooning and its traffic implications.

At large, the Norwegian public trusts its policymakers, who do not permit new technologies until proven safe. Still, several interviewees demanded more testing and knowledge of platooning safety effects. Two interviewees mentioned that motorists may feel overwhelmed when approaching truck platoons on narrow roads with limited sight distance, perceiving this as unsafe, although the objective risk may not differ from meeting conventional trucks, one by one. Nevertheless, this perception could weaken public acceptance of platooning. To gain public acceptance and promote safety, participants stated that motorists must somehow be informed about the presence of platoons, potentially by means of variable signage. While most were concerned with overtaking, others questioned the need for this, seeing platooning as a convenient opportunity to prohibit speeding and risky driving. These participants also alluded to a future where overtaking of platoons may have become banned and passenger vehicles are instead able to join them. Some interviewees stated that, over time, public perception may lead to a future where overtaking is no longer considered an issue: *"I think it's great if sometime in the future a family who are going on a holiday trip from Oslo to Trondheim can just connect to a platoon."*

Introduction of platooning were often discussed by interviewees in relation to other freight modes. Despite political objectives for goods transfer from road freight towards rail and sea, several interviewees pointed to increasing road freight volumes and sparse changes in modal proportions in recent years. Directly related to political ambitions, interviewees mentioned desires to improve traffic safety through reducing heavy vehicle numbers. Other stated ambitions were to stimulate business development in rail and sea transport, minimize ecological footprints and reduce emissions. Some acknowledged the unmatched efficiency and flexibility of road freight. As stated by several interviewees, electrification of trucks would weaken the sustainability argument underpinning the goods transfer objective. Two interviewees also mentioned the advantage of platooning in ensuring reliability of supply during emergency and peacekeeping situations, where the capacity and flexibility of other routes and freight modes may be constrained. Nonetheless, as the OEM representative suggested, a shift in mindset might be required. Platooning, although more flexible than rail and sea freight, will cause changes in locus of control of businesses and society: *"You can decide exactly when you want to send it and when it will arrive. (…). And we like to be in control. [Platooning] changes all of this. And that's hard.*"

The authors state that the motivation behind platooning may not be to expand road freight at the expense of other modes, but rather to optimize handling of present volumes and improve intermodality, as exemplified in case 3. As one interviewee highlighted, higher-level societal objectives could be clarified and current practices improved, while retaining ambitions for other modes. Some suggested that platooning on rural roads could maximize roadway uptime and availability, through infrastructure improvements facilitating platooning. It was postulated that such improvements would have positive effects on accessibility and safety for local road users and industries. This could possibly attract new citizens and contribute to economic growth in rural areas. Others, on the other hand, believed that efficiency gains would strengthen ongoing tendencies towards centralization.

Logistics, organization, and cooperation

To facilitate coordination of trucks meeting to form a platoon, one would ideally have sufficient volumes throughout the entire day, or at least during peaks from industry clusters. One participant suggested targeting high-regularity non-perishable goods, which are presumably less sensitive to wait times than goods with shorter lifespans. Others saw farmed fish as a good candidate, based on large current volumes, and forecasts of increasing production volumes in the future. Some suggested that carriers could organize platooning in-house if they have sufficient volumes, or they could cooperate with others. Many non-carrier representatives were skeptical to the realism of between-carrier cooperation, rooted in the competitive nature of the industry. According to these interviewees, small carriers may fear increased competition from larger ones. Larger carriers, on the other hand, might not want to cooperate since this could disproportionally benefit small carriers. Many emphasized that carriers do not fancy sharing, preferring to own the whole value chain. However, carrier representatives were mostly positive towards such collaboration. While this could indeed reflect their true intentions, it could also project a wish to present their company as overly forthcoming towards collaborative efforts. With respect to start-up costs, several interviewees suggest that platooning pilots could be organized by larger carriers, possibly supported by public funding. Later, subsidies or marketplace exclusion of non-platooning actors could force or motivate the industry to collaborate.

A representative from an interest organization stated that a matchmaking tool is needed for organizing platoons across carriers: "*one needs the Tinder of goods,"* referring to the popular dating app. The interviewee also stated that platooning will be most feasible if it can somehow complement directional freight balance between origin-destination pairs, which is a challenge in Norway. Although the need for matchmaking may first appear as a logistical barrier, one interviewee noted that such a system could potentially offload dispatchers and logistics planners. A matchmaking tool resonated with many interviewees, as it would embrace small carriers and could be organized to prevent unsportsmanlike behavior. An interviewee knowledgeable in roadside heavy vehicle inspections, suggested an example: A lead driver could deliberately slow down a platoon of trucks from competing firms, allowing another representative from his company to arrive first at a terminal.

Interviewees from most stakeholder groups noted that data-sharing should be independent of truck brands and fleet management systems. It was also suggested that carriers may exchange scheduled departures and destinations, along with truck weights and equipment status. This could be done in real-time, through a system akin to shipping and airline AIS (Automatic Identification System). To what extent location-sharing and platooning should be allowed for dangerous goods, such as natural gas shipments, remains an open question. Matchmaking could also include a scoring system where drivers rate the leader, or driving behaviors are objectively recorded. Data security was stressed, some suggesting the use of authentication protocols to validate participant integrity. Ideas were discussed as to who should own the matchmaking system, e.g., the Norwegian Truck Owners Association, the NPRA, carriers or even shippers involved in platooning agreements. Others drew parallels to the Norwegian state-owned rail freight company, suggesting organizing platooning in the same way, or even as a subsidiary of this public entity. Some felt that platooning would be better organized by the transport industry itself, emphasizing that it should have multiple owners to avoid monopolistic tendencies. The system owner could regulate and sanction unfair behavior, as well as accept trucks and drivers into the network. The authors suggest that a public system owner could either create and operate the matchmaking software in-house, or specify its workings, procure it, and regulate its use through a private entity. Regarding regulatory approval on the NPRA level, some suggested that platoons could be organized as a vehicle class or subcategory under the EMS framework.

Platooning could be organized in advance, through timetables and fixed agreements. Coordination hubs, as suggested in case 2, could be established and agreed upon, from which platoons would depart on fixed schedules. Platooning could also happen in a spontaneous, ad-hoc fashion while driving, or a combination of both. Some regions may not have enough goods flows, being constrained by infeasibly long wait times at hubs. "*Once you have to wait for 5 minutes, I think it becomes less relevant. But if you can get a match while driving, I think it will work much better*." Platooning in such areas may require more upfront coordination. Wait time variability is also an important aspect, especially for remote hubs. Given high variability, drivers and carriers might be less inclined to wait.

Before introducing the cases, a county representative suggested looking at ferry-dependent areas, where travel is already contingent on departure frequency and often involves waiting. Some objected based on infrastructure quality, as roads with ferries typically have lower standard due to adverse topography. Others objected due to small volumes on such routes. Some also stated that ferry prices are expensive for trucks, carriers preferring alternate routes if available. Nonetheless, as the case examples indicate, several locations in Norway have ferries as the only option. Many of these also have sufficient truck volumes for platooning.

An interviewee knowledgeable in rail terminal operations, stated that terminals may need to be scaled up to handle platoons, as these might currently represent bottlenecks. He suggested it would be easiest to operate trucks separately at terminals, linking them on the outside. Moreover, he suggested using formal agreements to incentivize carriers to stick to their drayage agreements. Monetary penalties could be used to avoid excessive build-up of terminal inventory, which is a current challenge. Fearing market share transfer, some proposed allowing platooning only as part of intermodal chains, combining road, rail, and sea. Some researchers suggested reorganizing the structure of driving jobs: Most truckers could operate as local feeders between production facilities or terminals in one end, and hubs located adjacent to arterials in the other. One researcher referred to this model as "*a public transport trip for goods*." Platooning could be organized at specific times-of-day, during seasons where passenger transport is limited, or during periods void of problematic winter conditions. Platooning could even be restricted to one arterial direction during certain weekdays. In Norway, a handful of origin and destination pairs exists which are connected by parallel, high-volume routes. The two roads between Oslo and Trondheim provide a good example. Conceptually, platooning could be allowed in one direction along one of the routes, and in the other direction along the other route. Moreover, the directions could alternate daily to limit the burden on commuters and local inhabitants. It could be communicated to the public whether motorists should expect meeting platoons or catching up with them. A researcher pointed out that data on actual origin-destination pairs for truck trips would be beneficial for understanding where platooning would work from a volume perspective.

Economic considerations for shippers and carriers

Stakeholders agreed that platooning will only be viable if it improves carrier competitiveness. Carrier representatives, in particular, stated that fuel savings are unlikely to be sufficiently appealing to adopt platooning, and that these might even be outweighed by simple measures such as speed restriction or maintenance optimization. Labor cost and lead time reductions were regarded as more important: "*I really think [platooning] will not be profitable until you can remove driver number 2 and 3.*" As long as drivers are required in all trucks, carriers could utilize driving, working and rest periods across several drivers on the same route. As exemplified in case 3, saving may arise from switching order in the platoon if drivers in following trucks can rest while in motion. This could significantly reduce transit time for longer trips, allowing carriers to take on subsequent assignments earlier, while increasing asset allocation and allowing operation of a smaller vehicle fleet to obtain the same delivery numbers. Some participants stated that owner-operators are often paid fixed prices based on volumes and distances, regardless of the time required to complete assignments. Reduced transit times, however, might lead to "*(...) more urgent assignments where the transit time is important.*" One interviewee suggested that this might increase the number of high-margin assignments, perhaps at the expense of decreasing carrier ability to plan operations in advance, making planning a more expensive task. The authors suggest that this could be alleviated by a responsive matchmaking system.

The idea of paying followers lower hourly wage, introduced in case 2A, was opposed based on labor practices and the possible rotation of driving tasks towards other tasks such as coordinating upcoming assignments. Excluding owner-operators, it is unclear how drivers will be incentivized towards forming platoons. There might even be contradictory views between drivers and executives: "*The same company may not want to drive first all the time. At least not the business owner, because doing so is more costly. While the driver may want to drive first*." A software solution would likely be needed, where platoon savings are distributed fairly between participants. One solution could be that some of the savings from platooning could accrue to the driver. One interviewee stated that platooning would be a clear example of platform economy, transforming it into more of a cooperative activity than it currently is. She continued by stating that platooning is likely to remain unprofitable as long as fuel savings is the parameter optimized for, suggesting optimizing for safety or traffic flow instead. Others stressed that the software must facilitate payment between carriers of multiple nationalities, considering the international nature of the industry. In addition to studying specific case routes for platooning, one interviewee suggested establishing a more rigorous framework for investigating economic matters. He proposed that such a framework could include, among other aspects, platooning distance, number of vehicles, number of drivers (dependent on the automation level in each truck), transit time, hours-of-service regulations, and inter-vehicle headway.

Waiting at coordination hubs entail economic costs. Carrier representatives mentioned driver salary, carrier profit margin, and depreciation of the vehicle and cargo. They also pointed out that drivers are constrained by hours-of-service regulations, running the risk of depleting their daily allowed working hours due to waiting, since shipments are currently planned to fully utilize working time. Drivers might also be late with respect to scheduled delivery time, and thus prevented from waiting. One interviewee pointed out that waiting might not necessarily constitute a cost if the wait at the hub were to coincide with breaks required by hours-of-service regulations. As such, metrics pertaining to breaks and remaining driving periods of each driver, could also be included in the matchmaking algorithm.

Infrastructure readiness, investments, and maintenance

Most of the Norwegian road network constitutes two-lane roads with large topographical variations. Interviewees expected that platooning will require high-quality, uniform infrastructure standard and consistent geometric alignment, including horizontal curve radii and sight distance. Many stated that platooning would be feasible only on newer multi-lane roads, as opposed to two-lane roads. Some suggested that platooning would gradually be allowed on the secondary road network when proven sufficiently safe and reliable. To mitigate infrastructure shortcomings along main corridors, interviewees focused both on general features and removal of bottlenecks on specific routes. Avoiding abrupt changes in road quality was mentioned as important for minimizing the need for manual intervention by drivers in following trucks. This would also prevent unwanted interaction with other motorists. Some participants suggested that the NPRA could explore whether road sections approved for EMS road trains could be applicable also for platooning. In this way, future expansions of the EMS network could account for both vehicle classes simultaneously.

Inspired by deployment scenarios in other countries, one interviewee suggested dedicating one highway lane for platooning. This seems infeasible, however, due to generally low truck volumes and few multi-lane roads. One interviewee suggested looking at platooning use-cases starting in the greater Oslo-area, as this region has large motorway proportions and an extensive terminal structure for goods consolidation. Most interviewees were skeptical towards motorists overtaking platoons on two-lane roads. At the same time, potential positive effects of platooning on road capacity were discussed. Truck platoons could reduce speed variability while occupying less longitudinal space compared to manual driving. Some interviewees questioned the Norwegian standard of building two-lane roads that, they stated, do not adequately address bottlenecks such as narrow and steep segments. Three-lane highways, or so-called alternating 2+1-roads, were seen as a minimum to enable frequent overtaking both for motorists and for emergency response vehicles. For existing two-lane roads, interviewees proposed establishing roadside pockets and increasing the number and length of climbing lanes at narrow passages and steep grades. This would overcome current issues related to passing lanes, many having inadequate length, being too short to allow a convoy of trailing passenger vehicles to overtake platoons.

Some stated that platooning would demand more comprehensive road maintenance and operation, citing this also as economic and organizational barriers. Conversely, others saw this as a traffic safety benefit that would accrue to local inhabitants and other road users. Some questioned platooning in winter from a public safety perspective. Two interviewees proposed that criteria for operation and maintenance contracts should reflect freight volumes to a larger extent than is the case today. One interviewee discussed the effects of platooning on the road substructure, pointing to knowledge gaps as to how platooning might require additional reinforcement. Some pointed out the usefulness of hubs and proposed expanding, or otherwise adding such functionality to existing truck stops. A recurring theme in carrier interviews, was lack of truck stops along Norwegian roads. Some mentioned that truck stops are inaccessible during winter due to lacking snow removal. Expanding the number of truck stops in strategic locations and improving winter operations, might both address current carrier needs, and facilitate meeting places where platoons can form and dissolve.

Figure 3 visualizes specific road-stretches most frequently mentioned by interviewees as viable for platooning. Note that *viability* in this case denotes a multifaceted aspect, including freight volumes, organizational ease, road standard, operational demands, and impacts on others. As such, platooning will only be possible on the displayed routes if all viability aspects meet certain minimum criteria. These criteria, however, need further specification. Figure 3 includes some of the routes from the case discussions, in addition to other routes that were freely explored by participants. Several individuals stated that platooning should be most easily achievable on stretches with national road standard. Routes in the Eastern part of Norway generally seem most suitable, as these have the highest motorway proportions and largest truck volumes, while being far less impacted by adverse topography compared to Northern and West-coast routes. The two parallel Oslo-Trondheim corridors were most frequently mentioned. Routes to and from smaller coastal seafood industry destinations, e.g., Hitra and Rørvik, and the greater Oslo area, were seen as viable from a volume perspective. The route between Oslo and Narvik, traversing Sweden, was also mentioned. Truck shipments between Southern and Northern Norway often traverse through Sweden, due to better road standard and higher speed limits. In general, such long-haul routes could benefit greatly if hours-of-service regulations would allow for continuous operation. This would require the creation of a formal hub structure to facilitate platoon coordination along the route. Naturally, the same is true for other domestic origin-destination pairs which currently require overnight rest.

Figure 3: Routes with domestic origins and destinations most frequently mentioned by participants as viable for platooning. Line thickness indicates relative frequency of mentions.

Another issue in Norway is the prevalence of road tunnels. A few interviewees state that while many are in good condition, some are old and narrow, falling below requirements for e.g., maximum grades and lighting levels. In steep tunnels, platooning trucks should have similar ratios between weight and engine power. If headway distances are quite small, cooling of combustion engines might also be an issue for uphill tunnel grades. The authors underline that it is unclear to what extent platooning should be allowed in tunnels, with respect to brake and transmission components overheating, as the severity of platoon accidents might be larger than for individual trucks.

Although generally seen as vital, interviewees were uncertain as to what type of digital infrastructure platooning might require, and the extent of such infrastructure. A county representative stated that all new roads in his jurisdiction are built with cable conduits for expected power and fiber cables. Some brought up cellular coverage and broadband connection, pointing out that there are "*substantial cellular dead zones*" across large parts of Northern Norway. These, however, are likely to get resolved during upcoming 5G network implementation. It is also unclear to what extent roadside communication is required for connectivity between platooning trucks.

Some interviewees, particularly researchers, stated that cost-benefit analyses should be carried out to assess which routes deserve infrastructure improvements. Routes which might be generally well-suited, but have patches where investments are needed, should be prioritized above those where comprehensive work is required.

CONCLUSIONS

The present study investigated opportunities and barriers for platooning in a rural context with modest freight volumes, geographically dispersed industries, and challenging road conditions. Through their freight transport expertise, interviewed stakeholders identified several prerequisites for platooning in this context. While some carriers may have sufficient demands and regularity to enable platooning on their own, a matchmaking system could expand the potential to carriers and areas with lower volumes. While fuel savings seem insufficient for profitable platooning, reduced transit times and driver costs present economic opportunities. The extent of such savings will depend on readiness and harmonization of vehicle technology, infrastructure, and organization. Additionally, lower speed variability could reduce accident numbers. Platooning may require certain road alignment, sight distances, climbing lanes, traffic separation and digital communication features. If so, such characteristics should be considered today in long-term infrastructure planning and investments.

As with any novel technology, acceptance is a prerequisite for adoption. This implies that truck drivers, other road users and the public find platooning favorable, safe, and easy to use or cooperate with. Currently, many see overtaking as a barrier for platooning, which could justify increased operational spending and investments towards multi-lane roads. However, technological advances and organizational means could diminish motives for overtaking. Technology may also, to some extent, counteract infrastructure shortcomings and coordinate road users. For instance, speed limits for opposing traffic may automatically change to facilitate safe meeting of platoons, avoiding bottlenecks on the road. Similarly, Cooperative Intelligent Transport Systems (C-ITS) applications may assist trailing motorists in overtaking when there is limited sight distance. Moreover, platooning is developing alongside rapid advances in passenger vehicle automation. In the future, it is conceivable that motorists are able to join truck platoons.

We have identified several barriers to overcome. Platooning will require re-evaluation of road parameters and infrastructure management. How to make a matchmaking system beneficial for platooning, also in low-volume areas, needs further investigation. The demands for platoon drivers to monitor and intervene in challenging road and weather conditions should be clarified to justify regulatory changes. Platooning may have mixed impacts on truck drivers, both relating to the driving task and job satisfaction, geographical work patterns, cargo management, and terminal handling. A framework for studying platooning viability should consider multifaceted metrics, such as freight volumes, organizational ease, road standard, operational demands and impacts on others. Analyses of real-world carrier shipments could complement modelling of future deployment scenarios.

This paper showcases the need for a holistic approach that captures all aspects of platooning on challenging freight routes. Further efforts should pay attention to public and private stakeholder needs by involving them in study planning and evaluation of findings. Real-life testing is imperative for acceptance, and thereby also for successful adoption of new technologies. Previous platooning trials on public roads have been performed mostly on motorways. These roads have homogenous speeds and forgiving roadway alignment. Testing on two-lane roads would showcase the state of platooning technology, while indicating the current level of infrastructure readiness. Such field-studies would also provide insights into economic, organizational, and safety-related impacts of platooning in a rural context. The authors suggest iterative field-studies as part of long-term research efforts to better understand the conditions under which platooning is viable and beneficial for society.

Truck platooning is forecasted as one of the earliest applications of road vehicle automation to commercialize. For Norway to benefit from this advancement, with its conditions and rural contexts, timely and coordinated action is needed on multiple areas.

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