Institute of Transport Economics
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ENGLISH Summary

Automated vehicles for urban goods delivery

A system perspective

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- Highly automated vehicles for land-based urban goods delivery can be classified as pavement robots, following robots, vehicles for use on low-speed roads and vehicles for use on high-speed roads.
- For logistic actors automated vehicles can help improve the effectivity, productivity, traffic safety, social responsibility, environmental sustainability and customer friendliness of urban goods deliveries.
- Automated vehicles can also help logistics actors meet the challenges of accessing goods delivery points, increasing customer expectations, driver shortages and high driver costs.
- For society, use of automated vehicles for urban goods deliveries can help increase effectiveness, reduce energy use, increase road network capacity, assist in down-prioritizing cars in city centres, and improve universal design and working conditions.
- Limitations for i) vehicle technology and ii) goods delivery systems means that relatively few use areas will be realizable in the near future.
- The use areas most likely to be realizable first are delivery with pavement robots, transport along simple stretches from terminal to terminal, and use of following robots that increase driver capacity.
- To ensure that technology is implemented in line with societal goals, the Norwegian Public Roads Authority (NPRA) should consider eight different roles they can play; these include collaborating with private actors on testing, data sharing and infrastructure modification and remote control needs.

Background

Use of highly automated vehicles in last mile delivery is an exciting development that can help meet societal challenges related to driver costs, traffic safety, traffic flow and work conditions. Despite this we know little about how automated vehicles will influence the economic, environmental and social costs when or if they become integrated as part of complex urban goods delivery systems. Unanswered questions also remain concerning regulatory and infra-structural changes needed for automated goods delivery to function optimally.

As far as we know there is little documented knowledge about the societal value of automated vehicles as part of a system for urban goods delivery, for either Norway or other countries. There is need for more knowledge on how the use of automated vehicles in goods delivery could potentially influence achievement of societal goals. We also need to know what changes will be needed to enable their wider implementation – to surrounding logistic systems, to city or road infrastructure or to laws and regulations.

This report presents the results of a project that has set use of automated vehicles in goods delivery in a holistic societal value-perspective. The project has been financed by the Norwegian Public Roads Authority (NPRA) who wished to know whether emerging technology would promote or hinder goods delivery in line with societal interests. NPRA also wanted to know which roles they can play to help ensure that automated vehicles for goods delivery will be introduced in a way that is favourable for achievement of its own goals.

Methods

To answer the above questions we use the following data sources:

- Document analysis, including TØI reports on urban goods delivery
- Literature review on use of automated vehicles in urban goods delivery
- Interviews with
    - 7 representatives of logistic actors and public actors working with city logistics
    - 6 researchers and consultants from Nordic countries, with knowledge of automated vehicles for use in city logistics
    - 3 persons who deliver goods in urban areas using manually driven light electric freight vehicles
    - 8 representatives from different organisations who participated in a pilot study of a pavement robot for deliveries in the Aker brygge area of Oslo
- Field observations and interviews with vulnerable road users under testing of the pavement robot in Aker brygge.
- Participation in international seminars on man-machine interaction and standardization needs for pavement robots.

A foundational hypothesis has been at we can not understand the implications of automated goods delivery for society without first understanding why and how logistic actors will use these vehicles for good delivery. The report therefore starts by mapping essential functions that need to be carried out in order to achieve urban goods delivery, before going on to consider i) critical challenges that logistics actors face when they carry out these functions; and ii) challenges that society faces when logistics actors carry out these functions. After examining different concepts for use of automated vehicles in goods delivery, we look at the effects their use will have on the achievement of logistics actor goals, and if they can help meet some of the challenges of urban goods delivery today. We also look at limitations on the use of automated vehicles in urban goods delivery, and then use this as a basis for considering the most realizable use areas. Finally, we look at roles NPRA can play to help ensure that automated goods delivery is implemented in line with its goals.

Urban goods delivery today

Logistic actor goals

A system analysis of urban goods delivery suggests that logistics actors want goods delivery that is economical, efficient, safe, socially responsible, climate-/environment-friendly, good for its reputation and practical for its customers.

System functions

The extent to which logistic actor goals are achieved depend on successful execution of 17 system functions. Two of these are central in the sense that they have a large influence on the achievement of logistic actor goals:

1. **Dispatch** is a procedure where operations and goods delivery are coordinated with available drivers and vehicles. Dispatch depends on the time window and place ordered for goods delivery, the number and type of goods that can be combined, and type and availability of vehicles in the delivery fleet. Dispatch influences the time of day of goods delivery, the number of vehicles and goods that are sent out, the streets and roads the vehicles pass through (route choice), mass and volume transported, and density of addresses for delivery or collection.
2. **Driving and navigation** of the vehicle that is sent out is also a central function, as it helps decide vehicle speed, total time used on goods delivery, distance to other vehicles and road users, vehicle placement in the road (which also has land use consequences), emission levels, energy use, vehicle noise and predictability for other road users (traffic safety). Driving also influences other system functions like "localization" of delivery or collection points.

System components

How system functions are executed influences goal achievement. Execution of functions in turn depends on which system components (vehicles, technology, data…) are available, which are selected for use, and how they are used in practice—which again depends on how people, technology, infrastructure, and work are organized in the goods delivery system. Figure S1 summarises goals, functions and components identified.

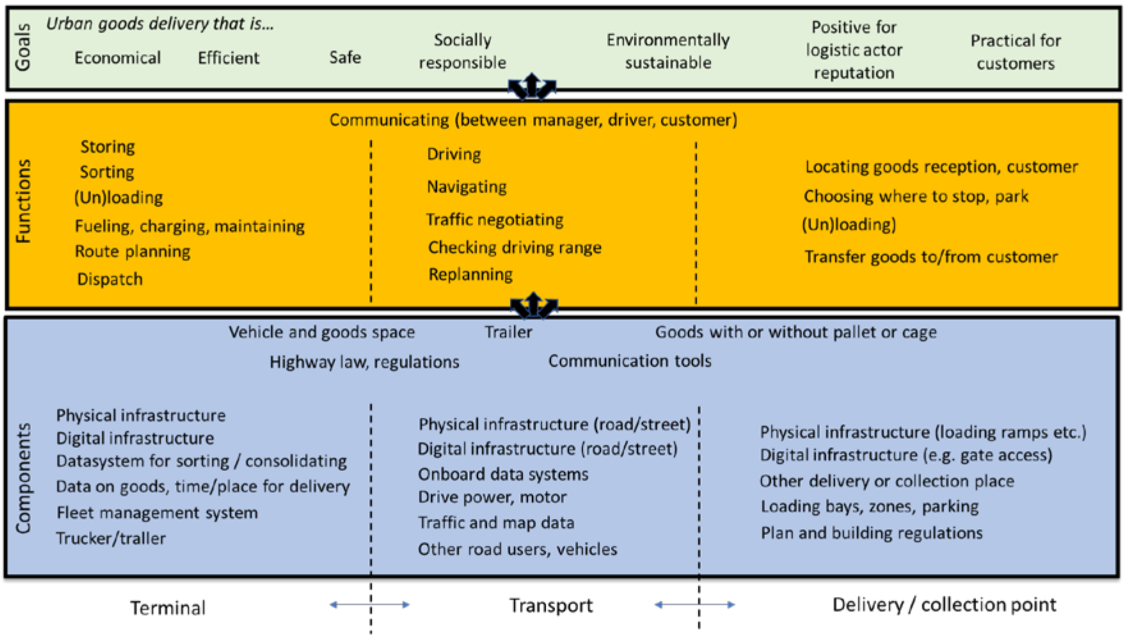

Figure S1: System components and functions influencing urban goods delivery

The vehicle is a central component of a complex system for goods delivery

Through its influence on other components and functions, choice of vehicle affects each logistic actor goal. Choice of vehicle also has a large influence on the two central functions of dispatch and driving.

Despite the salience of the vehicle's role, the system analysis shows that urban goods delivery depends on many other components. To understand potential use areas for and possible effects of automated vehicles in goods delivery, we need to consider not only the new vehicle technology but the road network the vehicle will be used on, the physical and digital infrastructure at the terminal, the location of terminals in relation to delivery/collection points, the surrounding logistics system, the charging infrastructure, regulatory framework, the infrastructure at the goods reception. How the vehicle is organized as part of the larger logistics system has a lot to say – for example, whether routes are planned before delivery starts or whether they are developed as delivery progresses or which factors are considered when organizing dispatch.

Automated vehicles for urban goods delivery

Most highly automated vehicles for goods delivery that are available today have level 4 automation technology. This means that the vehicle can drive autonomously on delimited stretches under certain conditions, but that it needs a human operator to be available to take over control of the vehicle or make decisions in the event of unexpected or complex situations.

Different categories for automated vehicles in urban goods delivery are summarized in Figure S2.

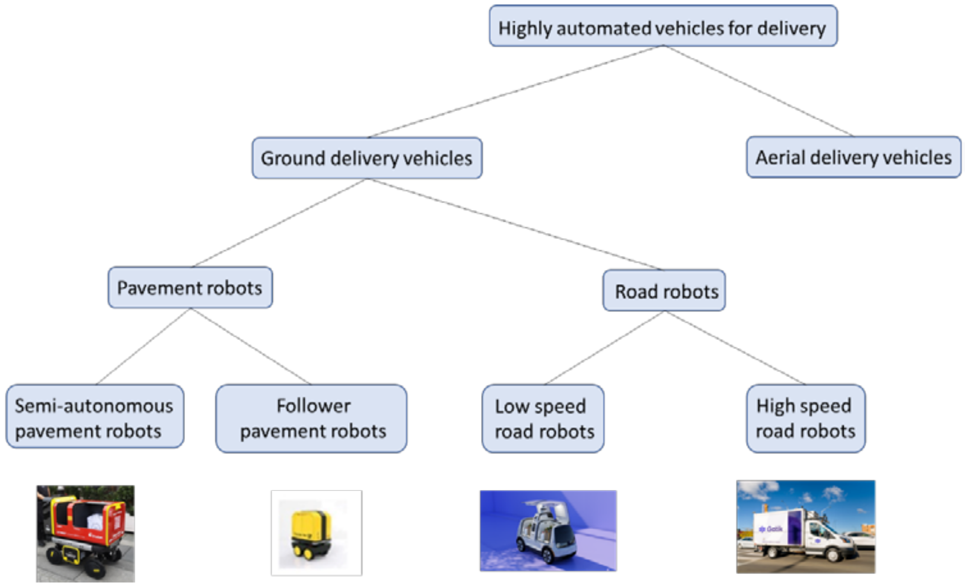

Figure S2: Categories of highly automated vehicles, adapted from Buldeo Rai et al., 2022.

Pavement robots with level 4 automation technology are being tested increasingly in pilot projects in larger cities across the world, for deliveries on short, simple stretches. Due to their low speed, they are simpler to implement from a regulatory and safety perspective when compared with aerial robots over cities or normal ground delivery vehicles fitted with automation technology. Smaller automated vehicles that can be used on roads with lower speed limits have more capacity than pavement robots, so can make more deliveries over a larger area. On the other hand, access to all parts of the road or path network will be lower than that of robots that can travel on pavements. Automated vehicles that can be used on high-speed roads have limited potential for delivery to city centres but can be useful for highly routine transport of large volumes of goods from terminals outside the city to ring road distribution centres. Due to their relatively high weight and speed, however, the regulatory demands are higher.

Use concepts and business models

From the literature we have identified four main concepts for use of automated vehicles in urban goods delivery:

1. **Direct**: Goods loaded at terminals and transported direct to the customer.
2. **Fixed proximal distribution centre**: Automated vehicles deliver out from a permanent hub close to the delivery area.
3. **Mobile distribution centre**: Larger automated vehicles are used as mobile distribution centres to transport parcels and/or smaller automated vehicles to the delivery area.
4. **Following robots** ("city platooning"): Automated vehicles linked in a virtual chain follow a single leader "vehicle", which is itself automated or manually driven; if the leader is a person walking or cycling, the automated following vehicles increase the capacity of people in the system in a flexible way.

From comments of branch experts and researchers it is likely that automated vehicles will result in new business models for goods delivery. Rather than using a third-party transporter, larger shippers and wholesalers, for example, will be able to work directly with vehicle manufacturers who will be able to offer new fleet services. Total cost of ownership (TCO) will also influence how use of automated vehicles is organized.

Can automated vehicles help logistic actors achieve their goals?

Table S1 shows that automated vehicles can help logistic actors achieve their goals in several ways. The table shows that in order to assess the extent to which the potential contribution of automated vehicles can be realized, there is a need for more testing and development of vehicle technology and supporting systems.

Table S1: How automated vehicles can help logistic actors achieve their goals.

Goal	***How can automated vehicles help?***	***Questions / Challenges***
Economical and efficient delivery	**Reduce driver costs**	Drivers and cyclists carry out many other tasks than driving. New roles will be necessary.
	Increased productivity: With no need for a driver, more vehicles can be operated for longer, increasing fleet capacity.	People will still be needed in the system, how many staff per vehicle will there be?
	Optimal organisation: With no need for a driver, different types of vehicles can be combined for optimal dispatch.	What will it cost to purchase or rent vehicles and operate an automated fleet? Can goods be delivered at around the clock if people are needed for monitoring or in case of remote operations?
	Save on material costs: With smoother, safer driving there will be fewer material damages in traffic and at terminals.	Still uncertainty about system effects. Purchase costs will be higher. There may be new material costs e.g., from theft or vandalism if vehicles do not have driver deterrent.
Traffic safety	The vehicles will become lighter and carry **less weight** in a collision. If the driving is safer and consistent across vehicles, **less chance of collisions**. «Driver» behaviour could also be more predictable for other road users.	Depending on the safety of driver technology, data quality, cybersecurity, standardisation and communication, type of road used, time of day (visibility, traffic volumes), choice of stopping place, infrastructural adaptations.
Social responsi-bility	**Improve work conditions** in goods delivery: less stress in traffic, new and more varied jobs that demand more skills and qualifications.	Not known whether staff want to see automation.
Environ-mentally friendly	**The shift to electric vehicles will be facilitated** by driverless vehicles, if the shift to electric vehicles means more vehicles and drivers. **Contribute to energy savings** as part of more seamless logistics.	Goals and measures already working to stimulate use of electric vehicles in urban goods delivery. More seamless logistics only possible if systems for loading, unloading, fleet management etc. are also automated.
Practical for customers	Can save time (e.g., no need for driver breaks), lead to **reduced delivery costs**, and parcels that are delivered **closer to the customer**.	Saving time depends on much more than just the vehicle. Customers might need to take on new tasks (e.g., collect from vehicles).
Business reputation	Good for **business reputation** if new technology used to improve goods delivery.	Customers and society must trust the technology.

Based on the results of interviews and system analysis we identified challenges that logistics actors can have when they use automated vehicles to carry out functions in order to achieve their goals. The analysis shows that automated vehicles can help solve some of these challenges, but not all (see Table S2).

Table S2: Can automated vehicles help meet the challenges logistics actors have when they deliver goods in urban environments?

Poor access to customer's goods delivery and collection areas	✓
Customers demand more flexible choice of collection point and delivery time	✓
Driver shortage with challenges for recruitment and turnover	✓
Mobility and traffic flow for goods delivery vehicles	?
Predictable traffic (roadworks, queues etc.)	✗
Experienced drivers solve many frontline challenges by adapting and communicating	✗

A special challenge for implementation of automated vehicles is how to account for the many "hidden" tasks, workarounds and shortcuts that drivers normally carry out to "get goods delivery done". Transfer of goods from the vehicle to the customer, collecting goods from the customer and customer relations are examples of tasks that will be difficult to automate.

How can use of automated vehicles in urban goods delivery influence societal goals?

Table S3 summarizes our assessment, based on survey analysis, of how use of automated vehicles in goods delivery can help achieve societal goals in the form of NPRAs top goals.

Table S3: Can automated vehicles in goods delivery help achieve NPRA's goals?

Goal	***Overall assessment of influence of using automated vehicles for urban goods delivery***	
«More bang per buck» from sustainability measures	✓	Goods delivery more economically sustainable Less energy needed for goods delivery (but see also below) Increased capacity on the road, street, and path network Free up city space currently occupied by large vans Reduce the need for cars in city centres
Effective use of new technology	✓	Help tackle driver shortage – a societal challenge Social sustainability through improved work conditions (less social dumping) Universal design through increased standardisation of the physical road infrastructure
Improved effects on climate and environment	?	Can use fewer resources per delivery but could lead to more vehicle km driven Optimal energy savings will depend on seamless logistics requiring changes to surrounding systems Measures for reduced emissions from goods delivery vehicles already having an effect *First-time delivery* could be more difficult without driver e.g., more wasted delivery trips?
Traffic safety for all road users	?	Remove limitations from having humans controlling vehicles e.g., reaction time, fatigue, distraction System effects and limitations of automation technology not fully known Effects of moving from 1 driver per vehicle to several vehicles per operator?
Traffic flow, access, and mobility for all road users	?	If automation leads to more vehicles on the road, traffic flow could be worse Uncertainty about how vehicle negotiations in traffic Can increase traffic flows by reducing distance between vehicles or increasing predictability in traffic

The potential advantages that automated vehicles have for achievement of the goals «more bang for the buck» and «effective use of new technology» cannot be taken as granted, and there are potential downsides not included in the table. One example is that automated goods delivery could lead to reduced physical activity among staff and customers, and therefore influence health in society negatively. The analysis is also based on assumptions that introduction of automated vehicles will not demand extensive upgrading and extra maintenance of urban road networks, which would for example affect achievement of "more bang for the buck" from sustainability measures. Another assumption is sufficient levels of accept of and trust in technology society.

We cannot be sure that automated vehicles will help improve traffic safety for everyone, because this depends not only on the vehicle technology, but on factors like sensor maintenance, data quality and data transfer speed. This implies that it will be important to manage the risks at a system level and assess how the rest of the traffic system will need to be adapted, and how new remote operators or terminal staff will intervene to take over the vehicle in a safe way as needed. A good deal of standardization will be needed in cases where highly automated goods delivery vehicles interact with other road users.

Future developments

Constraints in existing systems

There are constraints the systems that automated vehicles will be introduce into, which will affect how automated urban goods delivery will be in the coming years:

- Limitations of vehicle automation technology, limited automation in surrounding systems (loading, unloading, charging, coupling to terminal, access to gated terminal or customer areas) and constraints on remote operations (data speed, standardization, competence), meaning that:
    - Relatively simple use areas must be found for automated vehicles in goods delivery, whose operation is contingent on certain conditions such as time of day, weather conditions.
    - People must be available to intervene and operate the vehicle and to collaborate with people operating systems at nodes in the delivery chain
- Use of automated vehicles in goods delivery to customers will require customers to perform extra tasks or re-organisation of customer premises – whether for B2B or B2C deliveries
- Continued accept for technology requires the development of products and services to accommodate automated vehicles before they are introduced and operated
- Logistic actors using automated vehicles need to re-organise their physical and digital operations and recruit the necessary technological competence.

Realizable use areas

Given these and other limitations, we have identified the most realizable use areas for automated vehicles in goods delivery:

- Delivery of smaller / lighter freight at low speed with pavement robots
- Routine transport of high freight volumes from regional terminal to city distribution center along a simple and preferably dedicated stretch of road
- Other:
    - Following robots to increase the capacity of people who deliver
    - Aerial robots or drones for delivering out of city terminals over sparsely populated areas or water[2]

[2] Aerial drones have been outside the project scope. After increasing interest and several demonstrations of the possibilities that aerial drones give for goods delivery during the project period, we consider them to be relevant for limited goods delivery in or out from city areas.

Roles Norwegian Public Roads Authority can play

It is important that Norwegian Public Roads Authority (NPRA) and other public actors influence the development and introduction of automated vehicles for goods delivery in society. This will help avoid new systems developed solely by private actors who do not exclusively prioritize societal goals. NPRA should consider roles in the following eight areas:

1. Make clear the value for society of using automated vehicles in urban freight delivery.
2. Work with private actors to find out how road networks and pedestrian areas can be modified in simple and cost-effective ways to prepare for implementation of automated vehicles in goods delivery where this is desirable for society. Take a holistic approach to possible modification of the physical road/path network and consider together the needs of all types of automated vehicles for passenger and goods transport.
3. Continue to work with local and county municipalities and private actors on "proximal" physical infrastructure and concepts for goods deliveries (City Hub etc.) that is needed for more widespread use of light electric freight vehicles—and by doing so pave the way for automated vehicles.
4. Assess new ideas about shared infrastructure for freight deliverers, that private actors can use (e.g., "bus stop model").
5. Work with private actors and mapping agencies on development and exchange of map data that is needed for optimal operations of automated vehicles in goods delivery and other areas. Tackle challenges of data ownership.
6. Approval and certification of operations for remote monitoring and control of automated vehicles.
7. Contribute to developing the regulations concerning vehicle characteristics, classification and permitted use areas. Make clear which types of vehicles can travel where—this has consequences for city users and achievement of logistic actor goals. Regulations on types of goods that can be transported, traffic and road rules and liability also have to be developed.
8. Help develop standards that will improve predictability and road user understanding of the new vehicles. This is needed to maintain or improve traffic safety and universal design, especially when different manufacturers deliver vehicles that are operated in the same area.
9. To learn about the effects of using automated vehicles in goods distribution promote evaluation of the collective effects of goods delivery on critical parameters that influence achievement of NPRAs goals on energy use, emissions, land use and Vision Zero. Exploit the technology developers' need for NPRA's road data as a chance to increase open data sharing by private logistics actors.

Reflections and knowledge needs

Automated vehicles will take longer to implement for use in freight delivery than for public passenger transport. The latter has more routine and fixed routes that are often less complex. It is therefore easier to adapt the systems to automated vehicles, and the advantages are easier to see.

Both private and public actors see restricted mobility as a challenge for achievement of their main goals. For transporters the challenge is that it is hard to get the goods to where they need to get, not least because their drivers are forced to drive "unnecessarily" long distances at restricted times of the day; for public actors, however, the problem is that utility transport reduces the access that users have to the city. Illegal parking or the use of large vehicles that are poorly suited to the streets they drive on, or to mixed traffic with vulnerable road users, are some of the problems public actors see. They see that vehicles used to deliver freight cause problems, while private actors perceive that their vehicles and the functions they perform are not accounted for in city developments. Similarly, these two main actor types can perceive differently the potential advantages of automating goods delivery vehicles. While businesses see they can reduce the number of drivers needed and create new roles, public sector actors are interested in how automation can make vehicles more “city friendly” and obedient.

Before we know how urban goods delivery with automated vehicles will develop, logistic actors need to understand what it really means to remove frontline employees from delivering, especially as it concerns customer-facing tasks. New roles for existing and new employees should be identified and developed and competence is needed to operate and maintain new vehicle technology; data systems also need to be developed. Private-public collaboration on how road network capacity can best be used will be important to understand for logistic actors to invest in automation technology. Products and services that fit with automated goods delivery also need to be considered as part of customer acceptance. Logistics systems that exploit the potential that automated vehicles give for seamless freight logistics will be important in the future.

NPRA and other public actors need to understand how different use areas for automated vehicles will help or hinder achievement of their goals. Refection on possible roles for road owners, like those identified here, will help identify future research needs. Continued testing in ongoing pilots involving road actors, technology developers and municipalities will be an important arena for collaboration. Such pilots should eventually test whole fleets or logistics systems instead of isolated vehicles.