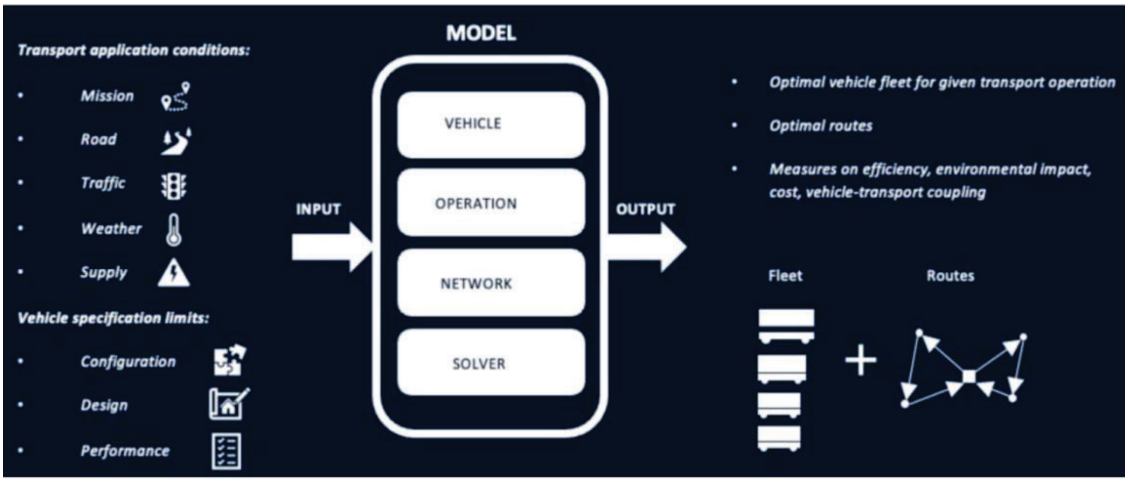
System understanding surrounding Driverless Multipurpose Vehicles

Public report



Project within FFI Transport and Mobility services

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Fordonsstrategisk
Forskning och
Innovation

Content

1. Summary

The global road transport sector is currently undergoing a transformation to decarbonize its activities to meet climate mitigation goals, while providing mobility of people and goods in a manner that is safe, affordable, accessible, efficient and resilient. This transformation is driven by technological trends of electrification, automation and connectivity. New vehicle concepts and transport solutions, such as driverless multipurpose vehicles (DMVs) and goods robots are enabled by these trends. DMVs are an emerging modular heavy-duty vehicle concept for cities that can transport people, goods and waste, or be used for other applications during daily transport operations. This type of on-the-road-modularity enables both intensified vehicle-use and flexibility throughout a vehicle's life cycle but also the possibility to adapt the transport supply to the current transport demand in a city, potentially leading to lower energy use, more circular resource management and a more resilient system. While these potential benefits are promising, there is insufficient knowledge about how DMVs along with their local last metre delivery systems influence efficiency, resilience and accessibility in urban road transport systems.

Another system aspect to these vehicles that needs to be solved is the loading and unloading as well as other goods handling that the driver carries out today. In earlier research carried out in HITS project, concepts of autonomous last-metre delivery or goods robots for short could be one attractive solution. However, further work needs to be done to understand operational concepts of these robots in relation to DMV systems as well as how their actions should be coordinated for optimal efficiency of the operations.

This pre-study has continued to explore the area surrounding DMV systems in urban transport through several meetings, benchmarking activities and literature review activities. The project has identified promising themes to further develop; these are multi-disciplinary themes in themselves that required further work in this pre-study to be able to set-up a larger research application with the right scope.

2. Sammanfattning på svenska

Den globala vägtransportsektorn genomgår för närvarande en omvandling för att avkarbonisera sina aktiviteter för att nå klimatmålen, samtidigt som man erbjuder mobilitet för människor och varor på ett sätt som är säkert, prisvärt, tillgängligt, effektivt och motståndskraftigt. Denna omvandling drivs av teknologiska trender inom elektrifiering, automation och uppkoppling. Nya fordonskoncept och transportlösningar, såsom förarlösa multifunktionsfordon och godsrobotar, möjliggörs av dessa trender. Förarlösa multifunktionsfordon är ett framväxande modulärt tungt fordonskoncept för städer som kan transportera människor, varor och avfall, eller användas för andra ändamål under dagliga transportoperationer. Denna typ av modularitet möjliggör både ökad fordonsanvändning och flexibilitet under hela fordonets livscykel, men också möjligheten att anpassa transportutbudet till den aktuella transportefterfrågan i en stad, vilket potentiellt leder till lägre energianvändning, mer cirkulär resurshantering och ett mer motståndskraftigt system. Även om dessa potentiella fördelar är lovande, finns det otillräcklig kunskap om hur förarlösa multifunktionsfordon tillsammans med deras lokala sista meter-leveranssystem påverkar effektivitet, motståndskraft och tillgänglighet i urbana vägtransportsystem. En annan systemaspekt av dessa fordon som behöver lösas är lastning och lossning samt annan godshantering som föraren utför idag.
I tidigare forskning som genomförts inom HITS kunde koncept som självkörande sista-metersleveranser eller godsrobotar i korthet vara en attraktiv lösning. Ytterligare arbete behöver dock genomföras för att förstå de operativa koncepten för dessa robotar i relation till DMV-system samt hur dess åtgärder bör samordnas för optimal effektivitet i verksamheten.
Denna förstudie har fortsatt att utforska området kring förarlösa multifunktionsfordonssystem i stadstransporter genom flera möten, benchmarking-aktiviteter och litteraturgranskning. Projektet har identifierat lovande teman att vidareutveckla, dessa är tvärvetenskapliga teman i sig som krävde vidare arbete i denna förstudie för att etablera en bra och större forskningsansökan.
Följande teman har identifierats:

1. Optimeringsverktyg för hög- och lågnivåsimulering av multifunktionsfordon.
    a. Koppla optimering av fordonets moduler och beskaffenhet till optimering av urban logistik. Utöka simuleringsmetod genom att hitta nya sätt att ta med mer fordonsmodelleringsdetaljer.
2. Koordineringsaspekter kring självkörande sista meter leverans.
    a. Ta fram och analysera ett antal scenarion där självkörande fordon behöver stöd av sista meter lösningar/godsrobotar, hur interaktion mellan fordon och robot samt kund och logistikoperatör kan tänkas fungera, vilka tekniska problem och hinder som finns för implementation av olika tekniska lösningar.
3. Systemanalys, resiliens och urban logistik för multifunktionsfordon.
    a. Förstå, givet en implementation av självkörande multifunktionsfordon, hur systemet påverkas jämfört med dagens scenario sett till effektivitet, hållbarhet och resiliens.

3. Background

Road transport systems around the world are going through a major change, moving away from fossil fuels and human drivers toward electric and self-driving vehicles. This shift creates chances to rebuild transport systems in ways that support global goals for a greener future while meeting future transport needs (Kumar & Alok, 2020; Lin et al., 2023). However, because transport systems tend to follow certain paths, small choices made early in this change can have a big effect on where things end up. Once a certain technology or business model becomes common, systems tend to stay locked in, much like what happened when fossil-fuel transport took over in the last century (Åhman & Nilsson, 2008). To avoid getting stuck with outcomes that are not good for the environment, decisions need to be based on a real and complete understanding of long-term system effects.

Driverless multipurpose vehicles (DMVs) are a new type of electric heavy-duty vehicle made for city transport. They can switch between or do several transport jobs at the same time, such as carrying people, goods, or waste, all without human drivers (Lin et al., 2023; Ulrich et al., 2019). The main type of DMV considered in this study has a driving module and a separate payload module that can be taken off. The payload module can be swapped to handle different kinds of demand, including passenger transport, freight delivery, and recycling services. The effects of these vehicles on transport systems are still not clear, and there is a lack of methods that look at both the vehicle level and the transport system level at the same time. Table (1) lists all the representative DMV concepts identified in industry.

Table 1. An overview of DMV concepts identified in the industry.

Concept	Year	Coutry
NExT	2015	IT
Vision URBANETIC	2018	DE
Toyota e-Palette	2018	JP
Volvo Vera	2018	SE
Rinspeed Snap	2018	CH
Renault EZ-PRO	2018	FR
DLR U-Shift	2019	DE
Scania NXT	2019	SE
REE FlatFormer	2019	IL/JP
Rinspeed Metrosnap	2020	CH
Dromos ANT system	2020	UK/DE
PIX Moving space	2020	CN
REE Leopard	2021	IL
DANNAR 4.00	2021	US
EVIE 2.0 pods	2023	SB/SBPA/IRPA
Pods4Rail	2023	EU

Most DMV concepts emerged between 2015 and 2023, with a strong concentration between 2018 and 2020. The field is predominantly European-led, complemented by a few initiatives from Japan, China, Israel, and the US. Figure 1 shows visual representation of the concepts listed in Table 1.

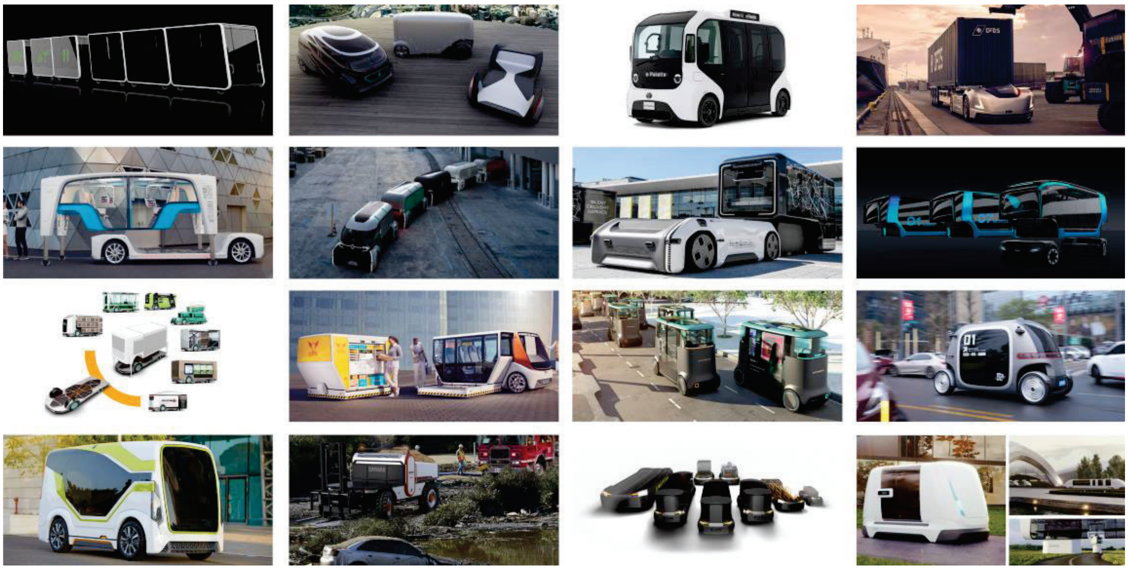

Figure 1. Visual representation of the concepts listed in Table 1.

The transport system presents significant complexity in urban environments, where rarely two transports are alike. In a future where the driver no longer accompanies the truck, tasks such as unloading, loading, and delivery work need to be automated. Research indicates that in urban distribution, drivers spend more time handling goods than driving the vehicle (Chiara et al., 2021). During a work shift, drivers are involved in and responsible for a variety of labour-intensive activities throughout the service flow, including managing multiple systems and apps, handling keys and packing slips, and performing various quality controls (*HITS 2*, 2025). The activities that have the greatest impact on efficiency in the delivery flow include ensuring recipient availability, finding available loading zones, verifying correct stowing, maintaining temperature for refrigerated goods, and minimizing distance between vehicle and delivery point. The factor with the greatest negative impact is handling errors such as wrong or missing goods.

Optimization Tool for High- and Low-level DMV Simulation

Different tools exist to analyse how new vehicle fleets and transport operations work across different areas, such as cost, environmental impact, system strength, and how well operations run. Vehicle Routing Problems (VRPs) are of great interest in both industry and research. A VRP is a math problem first brought up by (Dantzig & Ramser, 1959), where the main goal is to find routes for a fleet of vehicles that lower the total cost of travel while serving all customers from one depot (Koç et al., 2016). VRPs are used by transport companies for daily route planning in logistics (Vidal et al., 2020). However, VRPs are not just for daily planning. They can also be used for bigger-picture planning, as shown in

recent work that introduced a VRP form to check how DMVs compare to regular manually driven fleets in city transport.
Recent work has led to a two-stage way of solving these problems that includes a new VRP type called the Fleet Size and Mix Electric Vehicle Routing Problem with Simultaneous Pickup and Delivery (FSM-EVRP-SPD). This method puts together a detailed energy use model with a way of looking at both the vehicle level and the transport system level at the same time (Andreolli et al., 2026). The first stage builds a network through finding the best paths for each trip. The second stage solves the FSM-EVRP-SPD based on this smaller graph to get the best fleet size, mix, and routes. The method has been tried across many settings including different cities, goals, and types of vehicles.
The energy use model in this method uses real details that matter, such as vehicle total weight, speed, speeding up and slowing down, vehicle efficiency, extra power use, road slopes, speed limits, and traffic rules. This gives an energy use rate that changes along each road section. When checked against real electric-truck data, the energy model showed that it gave slightly higher values on average but correctly ranked which routes used more or less energy. The method works for both planning ahead and for daily routing, with a key strength being that it can find the best answer on detailed real-road maps for problems that are not too big. However, being able to handle bigger problems and work with more complex DMV designs remain the main limits (Andreolli et al., 2026).
A recent review paper looked at 80 articles on modular vehicles in freight and passenger transport. The review found that eleven used methods that look at things like system design, business models, and policy at a high level. Most of these studies put forward and explore different vehicle and system ideas. The other 69 studies used number-based methods. Forty-six of them focused on passenger transport, ten looked at both passenger and freight systems, and nine focused on freight only. The freight-only studies mainly looked at fleet size and routing problems, using different kinds of search methods. Generally, the studies found that modular vehicles lead to smaller fleets, lower costs, and better service (Liao et al., 2025).

Coordination Aspects of Autonomous Last Metre Delivery

Loading and unloading operations, along with last-metre delivery for trucks and trailers, are key parts of freight logistics. These tasks used to be done by hand, and while there are now some ways to do them automatically, they are not used widely. Current efforts mainly focus on moving pallets to and from vehicles but often still need people at different steps. Usually, drivers do the loading and unloading themselves. With self-driving trucks becoming more common, there is more interest in having fully automatic loading and unloading systems. While earlier work has looked at different parts of making supply chains automatic, such as self-driving transport, warehouses, and cross-docking, the links between trucks and buildings, especially loading and unloading, have not been studied much. To work well with self-driving vehicles, these steps must happen without any people involved.
There are mainly two kinds of unmanned ground vehicles (UGVs) that can move pallets from truck beds by themselves: forklift UGVs (Li et al., 2015) and underride UGVs.

Forklift UGVs can reach right into truck beds, containers, or racks, making them good for fully automatic loading and unloading even when there are height differences or rough ground. They do cost more, take up more space, and need more safety steps. Underride UGVs are smaller, safer, and cost less. They work well for last-metre transport in warehouses or delivery spots where pallets are already at the same level as the UGV, which might limit what they can do on their own. Most research on moving pallets by themselves focuses on forklift UGVs because they can load and unload pallets from truck beds or racks directly, making them good for full automation.

The pallet pickup operation of a forklift UGV involves several steps: finding the pallet, figuring out where the forklift is compared to the pallet, making a path, getting close to the pallet, and putting in the forks to take the pallet from the truck bed. Cameras are often used to find pallets and figure out where they are. Some methods mix laser and camera data, which works well outdoors where light can change. Recent work has made pallet pickup systems that work outside on rough ground by using cameras to find pallets and automatically changing the angle of the forks (Iinuma et al., 2020).

After picking up a pallet, the UGV needs to be able to steer and control itself to take the pallet where it needs to go. Most current ways of doing this, such as using magnetic strips, QR codes, or floor marks, only work on set paths, with a central system usually handling overall steering. This is often linked with the factory's planning software (Berman et al., 2003). In these setups, each mobile robot follows paths already set through certain waypoints. However, these methods cannot adjust well. Even small changes in where things are, like moving pallet storage, means the vehicles need to be set up again. To handle places that change, overall planning is often paired with local planning. The overall planner figures out a full path from where the robot is to where it needs to go, usually using a map. For example, (Tsiogas et al., 2021) used an A* overall planner for pallet docking. Local planners then fine-tune this path in real time, letting the robot avoid moving things like people or other robots by using onboard sensors like cameras and LiDAR.

A related area of work looks at methods for making maps and finding position in robotic delivery systems, with a focus on last-metre delivery for self-driving trucks and robots working both inside and outside. For outdoor settings, work has looked at how delivery robots that already exist likely find their position based on public information. This shows that they rely on GPS or RTK positioning along with local sensing through LiDAR, cameras, and depth sensors. For indoor settings, setup methods have been grouped by how much work and changes to buildings they need, from making maps from building plans and SLAM-based mapping to line-following and wire-guided systems.

Regarding robot development for handling goods flows outdoors, most solutions so far have focused on vehicles that transport goods, rather than systems that can load and unload. A critical difference between various robot systems is their ability to handle varying terrain. Indoor robots are often limited to even and clean floor surfaces with high environmental requirements. The development of smaller robots for goods handling has progressed rapidly, particularly in warehouse and industrial environments, with this market maturing through more competitive solutions and increasing demand. However, this automation largely remains inside the warehouse; very few systems can load and unload goods at the truck dock today. In Europe, the Euro pallet and the European container are the main standards, and these will likely be normative for future automation in the region, though there is currently a significant gap between technological development and outdoor application areas.

System Analysis, Resilience and Urban Logistics of DMVs

The good points of DMVs come mainly from two things: their ability to change how much they can carry for different kinds of demand and being able to leave payload modules at different places. Because the driving module can only attach one payload module at a time, this design works best when the need for different payload types changes over time rather than happening at the same time. (Chen et al., 2022) talked about a setting where passenger, freight, and recycling needs have different busy times during the day and suggested a way to plan when to change payloads. DMVs let the payload module be left at a set place while the driving module goes on to do other things. This is especially useful for payload modules that do not need to keep moving.

In almost all research and projects, DMVs are electric. DMVs are made up of a driving module and a payload module. Both can have batteries. The driving module should be used as much as possible because its driving parts are expensive. (Ulrich et al., 2019) pointed out that the battery of a driving module cannot work well for 24-hour use without charging. At the same time, charging for a long time will hurt how well the driving module works, while fast charging will shorten the battery's life. Instead, the driving module can use the battery of the payload module, though this needs a way to move energy between the two modules. There are three possible energy setups for electric DMVs: only driving modules have batteries, only payload modules have batteries, or both have batteries.

Because DMVs have separate parts, they can support common business models for electric vehicles, such as Vehicle-to-Grid (V2G), Vehicle-to-Building (V2B), and Vehicle-to-Home (V2H) by letting the separate modules send power back to the right places. A cost-benefit look at the U-Shift MV concept by (Österle et al., 2022) included estimates of effects on CO2 and air pollution. The results showed that CO2 went down by 30% compared to not using these vehicles. Air pollution went down by a similar amount. A life cycle study by (Ulrich et al., 2023) compared the U-Shift system to a single-purpose vehicle. The results showed that the U-Shift system led to a 3% drop in total CO2 output.

DMVs can change their payload modules based on different needs. This naturally helps them be ready for emergencies, letting the vehicles change their modules as needed to handle many different crisis situations. For example, during a serious health crisis such as COVID-19, the DMV fleet can attach medical modules to quickly grow medical service capacity, without needing to keep a large dedicated fleet of medical vehicles during normal times. Also, DMVs can add more capacity for a certain kind of demand during its busiest time by changing vehicles normally used for other jobs. (Hatzenbühler et al., 2025) tested many situations with different demand patterns on a large scale. It showed that driving modules can attach the right payload modules during busy times for a certain kind of demand, to add capacity and be ready for sudden increases in that demand.

Along with DMVs, another vehicle idea has been studied: Modular Vehicles (MoVs), which are made of several connected units. MoVs have one or more units that are the same or alike. Each unit can drive by itself and carry either goods or passengers. The units can connect to form a platoon, and the number or size of units in the platoon can be changed based on what is needed. The ability to change the size and type of modules in a platoon gives them their flexibility. Future DMVs may include features from both modularity and multimodality. This may help DMVs be used in many road transport or multimodal settings. However, how much these parts are used for DMVs should match the underlying business model. After all, more complex systems cost more, so complexity should only be added when needed.

Data Sharing in Urban Logistics

Cross-industry collaboration and data sharing require coordination between public authorities, private companies, and research institutes to coordinate efforts in urban logistics. Several international initiatives demonstrate this approach. In New York City, smart kerb technology is being introduced to meet the increasing demand for deliveries, waste management, and new transport modes, addressing data integration, compliance, and competing space needs (New York City Department of Transportation, 2025). The ColisActiv' programme in France subsidizes deliveries by bicycle and on foot in exchange for route data used to support local infrastructure investments (ColisActiv', 2025). Rotterdam's municipal administration has committed to taking action based on data-driven recommendations from the private sector, including zero-emission zones (Logistiek 010, 2025). In Madrid, an urban consolidation centre has been established, though the greatest challenges for effective collaboration remain trust, governance, and actors' opportunity for influence.

4. Purpose, research questions and method

This pre-study project has been managed through work package 1 (WP1 – Project management) and the main work has been conducted in WP2-4 that is further elaborated on below.

Work package 2 – Integration of High- and Low-level DMV simulation
TRATON and KTH, through a joint industrial PhD project, have developed a novel Vehicle Routing Problem (VRP) variant—Fleet Size and Mix Electric Vehicle Routing Problem with Two-stage Approach (FSM-EVRP-2S)—to analyse the impact of emerging modular vehicle solutions (Basso et al., 2019; Golden et al., 1984; Kopfer & Vornhusen, 2019).
Building on this and the work of (Hatzenbühler et al., 2023), the aim of this work package was to define future project scopes and research questions focused on understanding how Driverless Multipurpose Vehicles (DMVs) impact urban transport systems. A state-of-the-art literature review has been conducted on DMV concepts and their effects on urban mobility.
The project has had a holistic approach, considering both vehicle- and transport system-level impacts. It explored new methods and tools to simulate the complex interaction between modular vehicle configurations and higher-level transport system tasks.

Especially, focus on methods that can handle larger networks, multiple transport tasks as well as integrating optimisation of the vehicle platforms themselves.

Work package 3 – Autonomous last-metre delivery and its coordination

This work package focused on autonomous last-meter delivery, where large vehicles transfer goods to smaller delivery robots or drones, enabling seamless, unmanned delivery to customers.

The objectives were to:

- Understand the needs and obstacles in efficient goods and waste transport, including impact of the last delivery point on the overall goods flow, the DMV, and last-meter vehicles.
- Identify use cases that meet customer demands and are suitable for automation.
- Explore how to set up a cost-efficient test environment to simulate and validate technology and business models.

Urban goods and waste transport are complex and challenging to automate. Previous studies (*HITS*, 2025; *HITS 2*, 2025) suggest that transport flows in automated systems must be more standardized than in current urban logistics. This pre-study will conduct a state-of-the-art analysis to address these challenges.

Key design questions include; Where should robots be managed, and how should they receive orders? Should there be a centralized fleet management system? What infrastructure and workflows are needed at delivery locations?

Work package 4 – System analysis of DMVs

This work package explored the broader potential of integrating driverless multipurpose vehicles (DMVs) with autonomous last-meter delivery. The focus was on assessing system-level impacts across sustainability, resilience, and circular business practices.

Key areas include the potential of modular, multipurpose vehicles to:

- Provide tailored, efficient solutions for specific customers.
- Enable more efficient resource use.
- Offer greater flexibility and adaptability in uncertain futures.

Depending on priorities, different system designs can be developed. Understanding viable business models are crucial for creating sustainable solutions for customers, manufacturers, service providers, policymakers, and planners. DMVs allow a single platform to offer multiple services—goods, waste, and passenger transport—potentially by different providers. By adapting to temporal demand variations, vehicles can be repurposed and redeployed, increasing utilization and reducing parking needs. Combining larger and smaller vehicles, along with modular capabilities, can enhance resilience to short- and long-term disruptions (e.g., events or economic crises). The project has examined current barriers and future enablers and reviewed state-of-the-art methods and case studies on autonomous urban transport. Insights will be gathered from literature, ongoing projects like (*ACUMEN*, 2025) and (*SYNCHROMODE EU Project*, 2025), and expert input.

5. Objective

The goal of this pre-study project was to explore the area surrounding Driverless Multipurpose Vehicle systems in urban transport through different themes.

- **Emerging vehicle concepts and approaches for simulating them**
- **Autonomous last-metre delivery and its coordination**
- **Sustainability and system analysis**

These are multi-disciplinary themes in themselves which makes it difficult to setup and design suitable research scopes and research questions, hence a pre-study was needed to more broadly work on the different themes and how the themes interact with each other and how one or more potential larger projects could be structured.

6. Results and deliverables

The project has through several workshops, meetings and different literature reviews started to draft a research proposal for a larger project. This project at the time of writing currently has KTH, TRATON, LiU and H&M as potential partners and are looking for other potential partners as well.

This new project proposal will stem from already ongoing TRATON/KTH industrial PhD project and extend this research more broadly with funding for another PhD student and senior researchers as well as possible part-time postdoc funding. Focus will be on the DMV concept including last meter delivery system in an urban setting to confine the project scope and keep a focused group with clear interactions.

Both literature reviews and state-of-practice have been done in the three work packages of this project as intended, and the result of these separate works are summarized in this report under background and conclusions and future research.

In work package 2 a research paper has been finalised and sent to the journal Transportation research Part D. Figure 2 and 3 below shown some of the results of this work finalised during the pre-study in work package 2. Figure 2 shows the two-stage optimisation framework developed using the method “Fleet size and mix electric vehicle routing problem with simultaneous pick and delivery” FSM-EVRP-SPD.

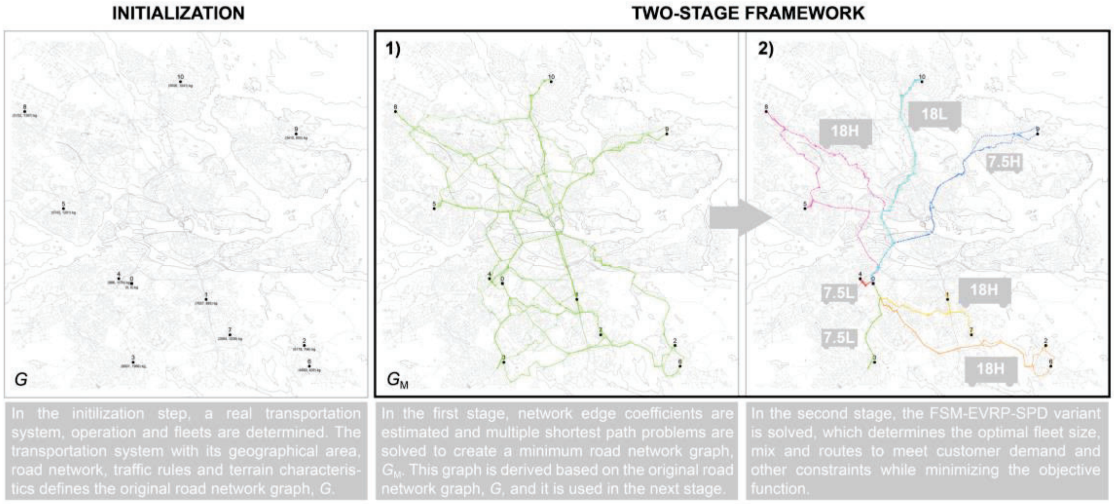

Figure 2. The two-stage optimization framework follows the initialization step. Notation: G= original road network graph, GM = minimum road network graph. Abbreviation: 7.5= 7.5 metric ton; 18= 18 metric ton; L= Low performance level; H= High performance level; FSM-EVRP-SPD= Fleet size and mix electric vehicle routing problem with simultaneous pick and delivery.

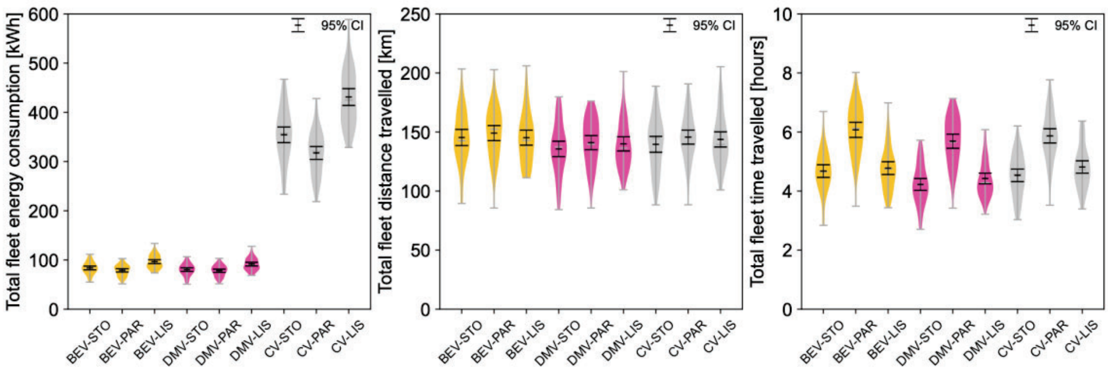

Figure 3. Results shown as violin plots of total fleet energy, distance, and travel time for DMV, BEV (Battery Electric Vehicle), and CV (Combustion Vehicle) fleets over 50 trips in Stockholm (STO), Paris (PAR), and Lisbon (LIS).

Figure 3 shows one of the many analysis results done in (Andreolli et al., 2026). Here, a comparison is made between Combustion Vehicles, Battery Electric Vehicles and Driverless Multipurpose Vehicles for three different city topologies. Showing the differences that the city topology has on the results (total fleet energy, distance and time) depending on fleet type.

Work package 3 conducted a detailed analysis of driver challenges and automation needs in urban goods transport. The analysis identified key efficiency factors at the depot level, including: inefficient layout or workflow leading to long walking distances and double handling; paper-based or outdated IT systems requiring manual input; lack of real-time information about truck arrivals and departures; mismatch between order size and load capacity; time pressure combined with limited staff or equipment; and poor ergonomics from repetitive tasks and heavy lifting. The findings indicate that experienced drivers can quickly determine how the load should be stowed to achieve road safety and correct

delivery order—knowledge that must be transferred to automated systems. Results summary can be seen in background section and future work.
Work package 4 results summary can be seen in background section as well as future work. Here, it is clear that some real-life concepts do exist, but the concepts differ and have different characteristics in terms of transport system and vehicle system implementation. This highlights the need to develop methods to analyse these concepts in more depth to understand their impact and potential benefits.
Objectives of FFI-Programme that this project have contributed to is the following:

- FFI demonstrates solutions that make society's road transport fossil-free, safe, equal and efficient.
    - This pre-study aimed to create a larger application able to address this objective which is also currently being written. Here, the solutions that will be demonstrated is the DMVs and its system of last metre delivery solutions.
- FFI develops sustainable solutions that are implemented and accepted by users and society.
    - This prestudy have a focus on DMVs as a new transport solution and will develop a larger project that will also analyse the sustainability, efficiency and resilience of such solutions.
- Through innovation, partnership and collaboration, FFI contributes to the development of skills, infrastructure, new technologies, regulations and business models for the road transport system.
    - The pre-study in itself has already initiated and established partner collaboration and will further do so in the larger research application.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	Project has through different literature review works created content for a future application. Project have through its literature review work also contributed to a scientific journal paper that has recently been sent to a journal for review.
Be passed on to other advanced technological development projects	X	The pre-study will result in an application to FFI involving several partners and include work packages with themes identified in this application.
Be passed on to product development projects		
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

7.2 Publications

The following publication (Andreolli et al., 2026) was finalized during the pre-study project and the work in WP2.

Andreolli, R., Nybacka, M., Jenelius, E., O´Reilly, C., & Hede, M. (2026). "Two-stage Fleet Size and Mix Electric Vehicle Routing Problem with Energy Estimation". *In Review for TRB.*

8. Conclusions and future research

Several areas for future research have been identified across the reviewed work. These span optimization methods, autonomous delivery systems, and broader system analysis.

Optimization and Simulation Methods: One main limit of the current FSM-EVRP-SPD type is that it cannot show more complex DMV designs, such as self-driving pods or swap-body setups, without major changes to the math. Also, as with other VRPs solved by exact methods, there are limits to how big the problems can be, which limits working with larger real-world cases and more complex DMV designs. Future work may tackle this by using methods that find good but not perfect answers, such as the Adaptive Large Neighbourhood Search (ALNS) algorithm (Andreolli et al., 2026). The work package continues to develop the 2-step VRP to further improve goods transport efficiency through detailed simulation of DMV setups and how they work with transport tasks. Work is needed to understand the needs and challenges to describe what use cases are relevant and identify potential customer partnerships for further project steps such as design, manufacture, demonstration, and testing in pilot operations.

Autonomous Last Metre Delivery: Based on the gaps found, several future directions have been proposed for developing last-metre delivery of pallets from truck beds. First, a combined use of forklift and underride UGVs may offer a good solution for different scenarios. For instance, when no ramp is available between the truck bed and ground level, the forklift UGV can unload pallets directly from the truck bed, while the underride UGV can move pallets deeper inside the truck to help forklift access. Second, there are very few studies that formally ensure safety and collision avoidance during autonomous pallet transport with moving obstacles. However, many collision avoidance methods have been developed for mobile robots that could be adapted to this context. Third, to achieve fully human-free autonomy, a UGV must be capable of higher-level task specification and execution. An automatic synthesis process is required where, when a UGV receives a task via communication, it must be able to translate this high-level instruction into a low-level implementation that defines how the task will be performed.
Future research should also address depot-level automation challenges identified in this study, including:

- developing systems that can replicate experienced drivers' knowledge of optimal load stowing for road safety and delivery order,
- integrating fragmented IT systems currently requiring extensive manual input,
- and creating real-time information systems for truck arrivals and departures.
- Additionally, research is needed on robots capable of handling varying terrain outdoors and bridging the gap between indoor warehouse automation and outdoor dock operations.

System Analysis and Use Cases: Various DMV system concepts face similar challenges coming from modularity. These include: efficiency that is highly affected by both real-time and pre-booked demand, depending on where docking stations are, which can affect overall system performance, difficulties in the docking process especially during in-motion docking, and the need for reliable real-time fleet control. The study will scale its analysis to include large cities in different countries and geographical settings, looking at how innovations at the vehicle and system level can spread benefits across different areas. This includes checking infrastructure needs, being able to work together, and regulatory effects. The project will consider a diverse range of transport scenarios, including city deliveries and from close city transfer hubs. By addressing multiple use cases, the research will ensure that proposed solutions are robust, scalable, and can be applied across different parts of the goods transport sector.

Mapping and Localization: The review concludes that no single method can cover all operational scenarios well. Instead, a tiered approach using different systems optimized for specific environments is presented. Using, for example, simple line-following robots for structured indoor sites and sensor-rich autonomous platforms for complex or outdoor spaces offers the most practical and cost-effective path forward. For outdoor environments, it is often impractical to create detailed maps over the entire operational area. GPS-based maps, similar to Google Maps, are typically used, with platforms such as Mapbox offering high-quality map data and support for navigation between GPS coordinates. These systems also enable customized layers, such as geo-fences, no-go zones, or temporary obstacles. For indoor environments, where GPS is unavailable, SLAM techniques are used instead.

Additional Research Items: Other items for parallel research can be to analyse the environmental benefit in terms of LCA and CO2 contribution of DMVs compared to classic BEV in urban transport. Several open questions have been identified including: studying more complex DMV concepts such as swap body architecture, joint high and low level approaches, impact of DMV especially automation and multipurposeness in logistics, understanding and implementing new solution methods as computation sizes grow, connections to autonomous last metre delivery, suitable applications and use cases, and broader analyses based on multiple goals such as total cost of ownership, total cost of energy, and energy consumption.
A particularly innovative research direction is the use of Large Language Models (LLMs) for robot installation and navigation processes. Such a system would eliminate the need to create a predefined map, allowing operators to give verbal instructions that the robot interprets and follows using built-in sensors (LiDAR or cameras) in combination with semantic classification models. The robot could simultaneously map its surroundings while

following instructions, building maps successively for future use. However, critical questions remain regarding how today's requirements for testing and safe operation can be met if a robot system is given the ability to self-learn and operate in new, previously unknown environments.

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