LEVITATE: Automated Freight Transport

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In this article, we focus on some logistic concepts enabled by connected automated transport systems (CATS) and what disruptive changes we can expect from them. Freight transport is one of the three use cases in the LEVITATE project, beside urban transport and passenger cars. The overall goal is

- to identify how each area of impact (safety, environment, economy and society) will be affected by the introduction and transition of CATS in freight transport,
- to assess its impacts, benefits and costs,
- to test interactions of the examined impacts of freight transport, and
- to prioritise considerations for a public policy support tool to help authority decisions.

The impacts are classified into short-, medium-, and long-term impacts, following a previous deliverable "A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation" by Elvik et al. (2019).

- **Direct impacts** are changes that are noticed by each road user on each trip. These impacts are relatively short-term in nature and can be measured directly after the introduction of intervention or technology.
- **Systemic impacts** are system-wide impacts within the transport system. These are measured indirectly from direct impacts and are considered medium-term.
- **Wider impacts** are changes occurring outside the transport system, such as changes in land use and employment. These are inferred impacts measured at a larger scale and are result of direct and system wide impacts. They are considered as long-term impacts.

In the following, we present the work in progress for the freight transport use case and showcase three applications or so-called sub-use cases:

- **Automated urban parcel delivery**
- **Hub to hub automated transport**
- **Platooning on bridges**

Automated urban parcel delivery

This sub-use case compares the performance of parcel delivery in urban areas via manual delivery personnel and (semi-)automated concepts. Studies show that using smaller, electrified vehicles and robots addresses several acute problems: emissions, navigation in confined inner-city areas and the limitation of working time for manual parcel delivery (Jennings and Figliozzi 2019). Based on the current manual delivery process, the envisioned automation technologies and concepts that will emerge in the next decades, we consider these delivery scenarios:

- **Manual delivery** (status quo) is used as a base scenario for comparison.
- **Semi-automated delivery** assumes that the delivery process is not fully automated yet. While the delivery van is automated, personnel is still doing

the delivery task. However, since he does not need to switch between delivery and driving task, time can be saved during each stop.

- **Fully automated delivery** is the most interesting one where small autonomous delivery robots replace all service personnel and operate beyond the road (pavement, pedestrian area, etc.). They use an automated van as mobile hub where they perform short delivery trips to end-customers, i.e., a hub-and-spoke setup with moving hubs. This human-less delivery process can be carried out during night where traffic is lowest and during off-peak hours.

Figure 1: Example of mothership concept where a van serves as hub for up to eight autonomous delivery robots. Source: Daimler https://www.roboticsbusinessreview.com/supply-chain/daimler-invests-robotic-delivery-starship-technologies

For the full-automation scenario, our assumptions on the van and the delivery robots are based on the Starship Robovan concept, see Figure 1. Compared to conventional delivery where the delivery capacity is usually limited by the 8 hours of working shift of service personnel, the Robovan is limited by its parcel capacity due to the delivery robots. Also, we assume that necessary infrastructure on the customer side for contactless handover is given. This can be established through physical internet boxes (on the supplier side) or white label parcel boxes (on the customer side). It is not unrealistic to assume that these technologies will experience the breakthrough before the fully automating the delivery process. The data we use is based on parcel delivery in city of Vienna. Using available data such as overall parcel volume, market share of the logistic operators and their delivery capacity, we make reasonable assumptions on the operational logistic process.

For assessing the impacts, we apply a hybrid method based on micro simulation and operations research. We use micro simulation to capture the traffic impacts of a typical delivery tour of one delivery vehicle. These impacts are then scaled up using operations research, where we compute the delivery tours, see Figure 2.

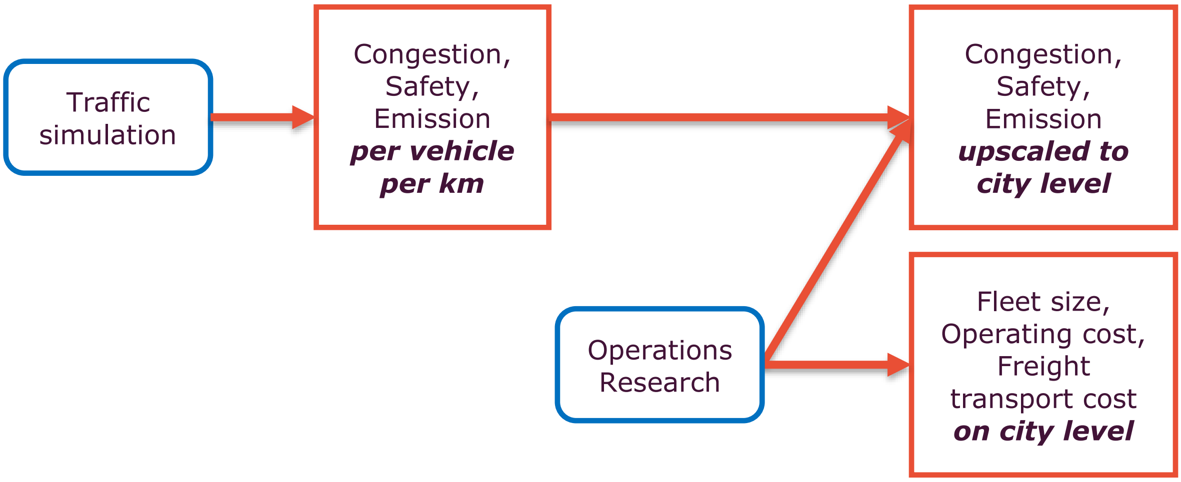

Figure 2: Flowchart for the impacts assessed by the two methods.

We compare the impacts of the different delivery scenarios and assume that the same level of service (parcel volume per day) must be achieved. Compared to manual delivery (MD), the required vehicle fleet size can be reduced by around 20% for the semi-automated delivery (SAD) and the fully automated delivery (FAD). The increase of total driven km for FAD to 242% over MD is frightening at first glance. However, we should take into account that only one third of the mileage is done during the day and two third is performed during night. When silent, electric vehicles are used, this drawback is less critical. For operating cost, we forecast a significant reduction of 16% when adopting SAD and 44% when moving to FAD, caused by personnel savings.

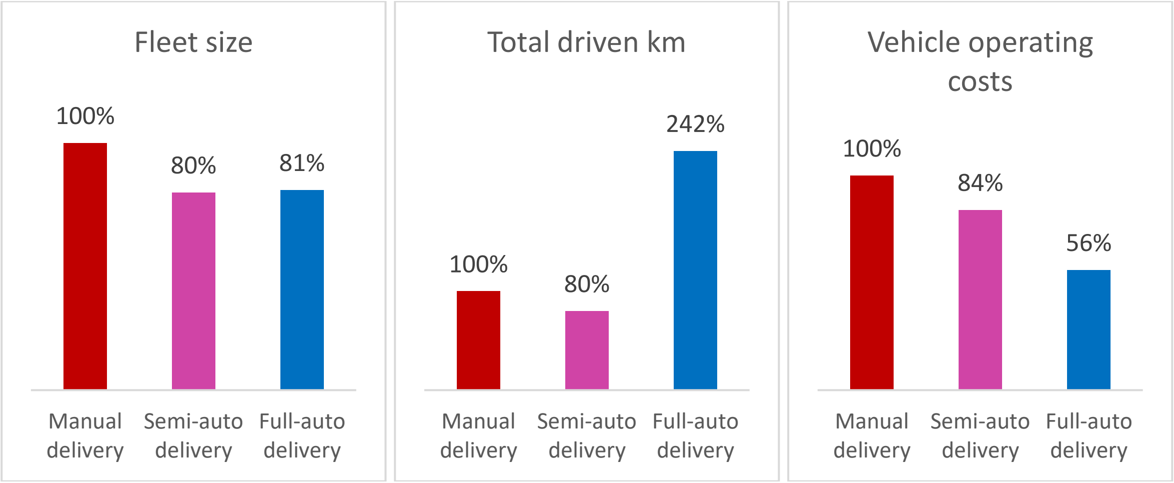

Figure 3: Results on automated parcel delivery.

Hub to Hub Automated Transport

This sub-use case studies the impacts of AV truck terminals. The goal of these terminals is to facilitate the operation of level 4 automated trucks that can operate on highways but not in urban environment. It is assumed that outbound freight containers from the city are passed to AV trucks at the terminal, which then take over the long-haul highway segment. At an AV truck terminal of the destination city, the container is passed to a manually operated truck again to bring it to the destination. An ideal location for such a terminal is at the city border with direct or good access to the highway. Figure 4 shows a sketch for the functionality of the AV truck terminal.

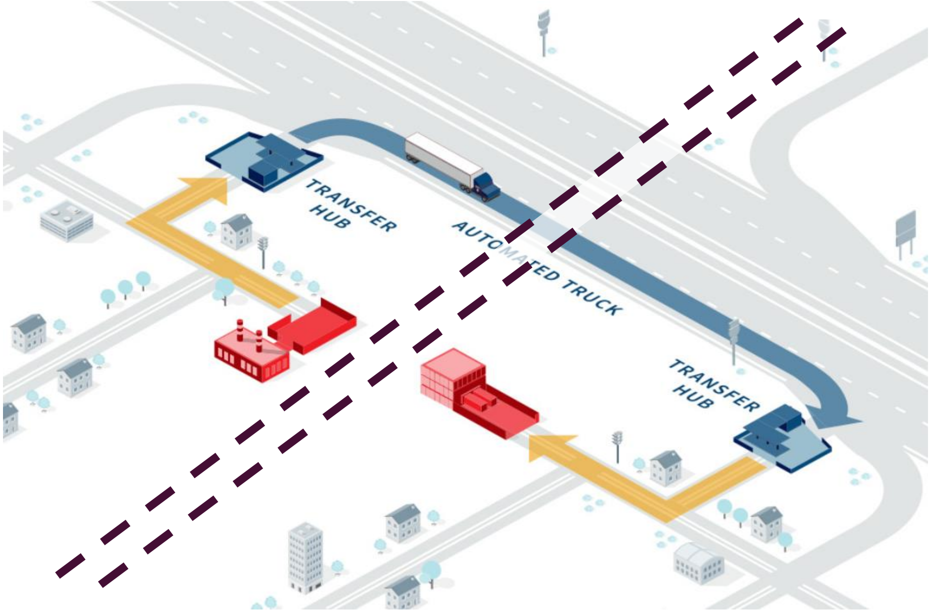

Figure 4: Sketch for an AV truck terminal. Routes of manual trucks are marked in yellow, and AV trucks in blue.

The main benefit of this approach enabled by AV truck terminal is that

- Long-haul freight transport is the most unappealing part for truck drivers, but the first thing that can be automated. Besides social benefits, the cost reduction is a significant factor. This concept supports the usage of AV trucks.
- For the urban highway, it is possible to reduce the usage during daytime and shift the freight transport towards night. This can be achieved by coordinating AV trucks to only depart during night hours.

For a case study we consider a small area around a potential AV truck terminal including an urban highway segment with ramps. Two scenarios are compared:

- **Status quo** where manual container trucks are operating between their origin and destinations directly across the day.
- **Operation via transfer terminal**: During the day, manual trucks deliver their freight from origin to the AV truck terminal. During night, AV trucks ship the containers from the terminal to the destination terminals. Similarly, AV trucks from other terminals arrive across day and night, while the further transport into the city via manual trucks happen during the day.

We use micro simulation to assess the direct impacts on the road traffic such as congestion, emission, and road conflicts in the area around the transfer terminal. For the scenario with transfer terminal, we use an updated OD traffic volume demand according to the description of the scenario.

Figure 5 shows some example results on congestion in the considered area based on micro simulation. We observe that on the one hand, the congestion decreases gradually with the increasing AV penetration rate when no transfer terminal is used. This is because of increased road capacity due to AV vehicles requiring less headway. On the other hand, the congestion decreases when the transfer terminal is used by a rate of up to 60%, but then increases. The reason for this strange behaviour is that with the assumed traffic redistribution to the night hours, congestion for AV trucks during night occurs. We point out that this phenomenon can easily be removed with a more intelligent traffic redistribution for the AV trucks.

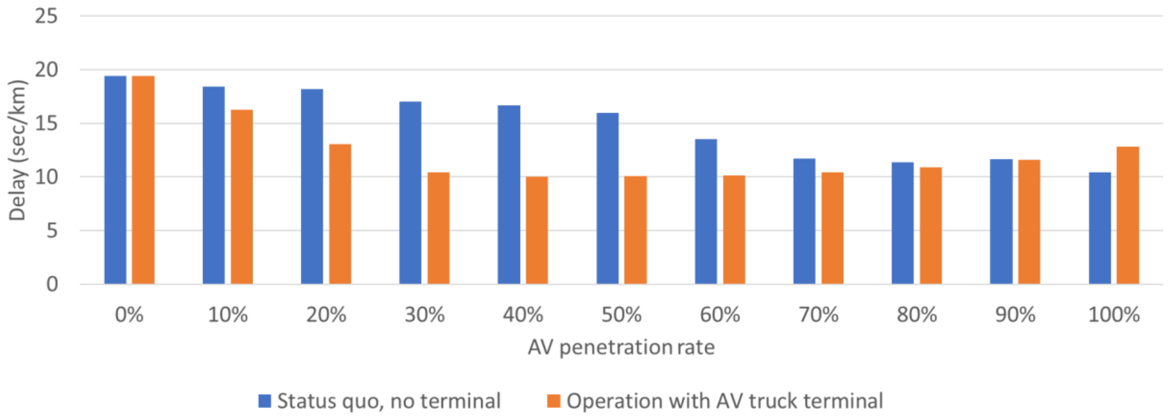

Figure 5: Simulation results for congestion, w.r.t. AV penetration rate.

The impact on the freight transport cost can be directly taken from a study (Engholm et al. 2020). The authors state that the costs per 1000 ton-kilometre decrease by 45%, 37%, 33%, and 29% for 16-, 24-, 40-, and 60-ton trucks. These can be used in conjunction with traffic counting data on different truck sizes to estimate the cost-reduction of long-haul manual trucks that are being replaced. The cost reduction has to be further analysed though since setting up the AV truck terminal comes with infrastructure costs. In addition, this concept might become obsolete once AV trucks fully reach level 5, i.e. when they are also able to operate in urban environment.

Platooning on bridges

For truck platooning there is a good amount of existing work in the scientific literature, but so far, almost no research has been done on the effect of platooning on bridges. This topic is important because most of the existing bridges were built at a time where platooning did not exist. This rises the question if they are able to handle the increased traffic load and how it will affect the fault probability. Bridge collapses do not happen frequently. However, if they happen, the effects are disastrous.

The effects of truck platooning must go along with existing bridges and detailed investigation of different bridge types. Bhoopalam et al. (2018) stated that measures to fulfil the infrastructure needs could lead to restrictions on maximum weight or smart division of truck loads, or decoupling of truck platoons before entering critical bridges. Other measures could be temporary changes in the truck platoon speed or changes of headway distances, so that the bridge loads would not exceed the original design levels. Another option would be legal limitations on the total number of trucks in a platoon, as demonstrated in the lessons learnt of European truck platooning challenge. Among theses measures, we particularly compare the costs and benefits of two approaches:

- **Intelligent access control** that manages the headway and speed of truck platoons entering bridges depending on the size and load of the trucks, see Figure 6. This assumes that the necessary V2I infrastructure are present.
- **Structural strengthening** to enhance the capacity of existing bridges. This is a more permanent approach in the long run but requires high costs and cannot be completed for all critical bridges at the same time.

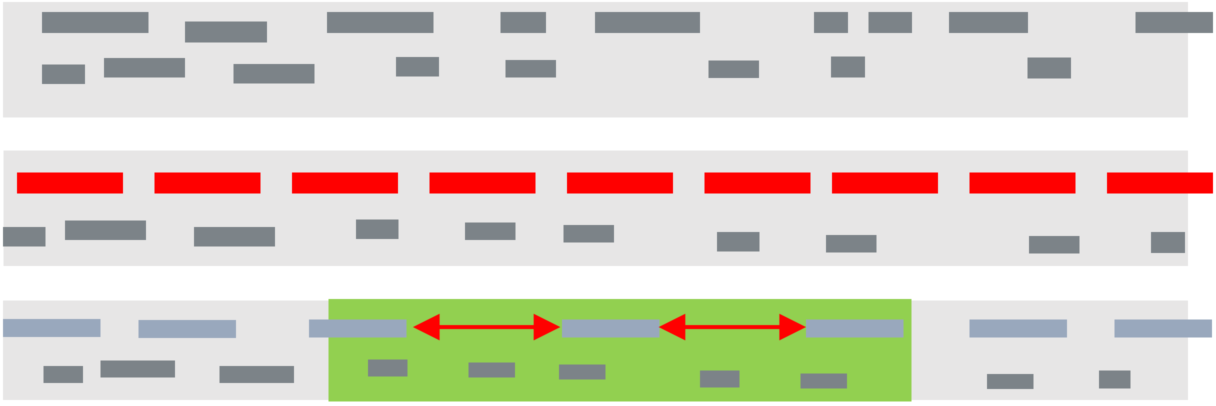

Figure 6: From top to bottom: (1) Random traffic on a bride. (2) The red vehicles form a platoon on a lane. (3) For a critical section, the platoon controller temporarily increases the headway.

Figure 7 and Figure 8 show some intermediate results where we calculated the vertical bending load for two model bridges of length 20m and 90m. The traffic data and distribution of vehicles types are taken from Freundt and Böning (2011). Unsurprisingly, we observe that the vertical bending moment increases for traffic with platoons compared to standard traffic. Also, the vertical bending moment increases much more for the 90m bridge than the 20m bridge.

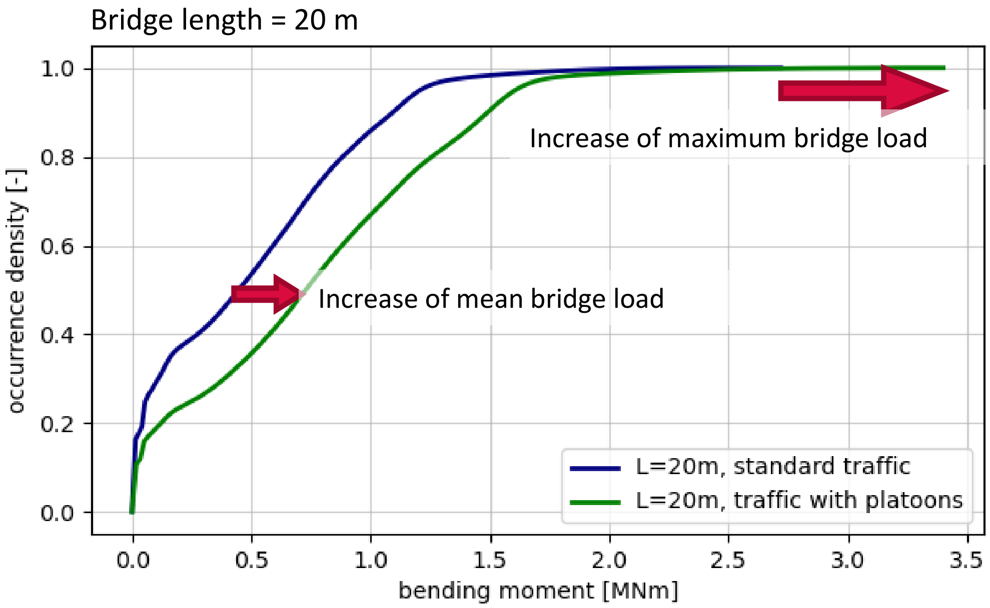

Figure 7: Vertical bending moments for a bridge with 20m length.

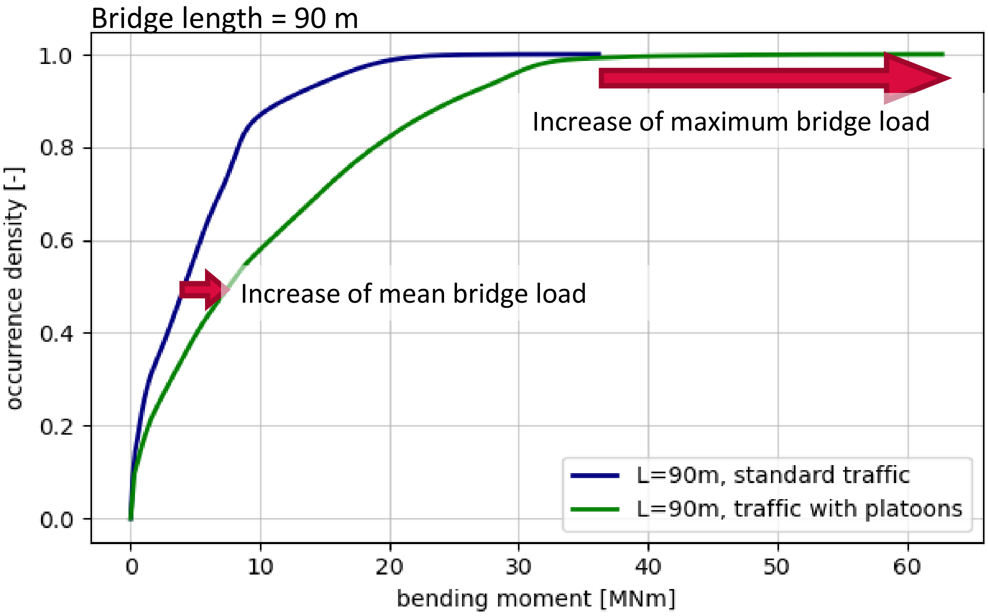

Figure 8: Vertical bending moments for a bridge with 90m length.

In the next step, we need to investigate the horizontal forces caused by synchronized acceleration and breaking.

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