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# The impacts of automated urban delivery and consolidation

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## Abstract

Automation in urban freight transport is an important milestone for city logistics, but it will most likely be challenging due to the complex traffic situations. The aim of the present paper is to provide an insight in the impact assessment method used and the results related to parcel delivery in Vienna. While the parcel volume is soaring due to the popularity of e-commerce – and especially accelerated by COVID, cities are thinking about the future delivery system. Automation and consolidation are expected to bring disruptive changes to the system we know today. By applying analytical methods, we show which impacts at what magnitude we may expect from the changes brought by automation in freight transport. We consider the direct impacts consisting of fleet size, freight mileage and fleet operation costs, as well as the wider impacts consisting of parking space, public health and road safety.

*Keywords:* CCAM; city logistics; impact assessment

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## 1. Introduction

The technological advancements in the field of cooperative, connected and automated mobility (CCAM) have risen the expectations with regards to their potential impacts on safety, environment, society and economy. In the Horizon 2020 project LEVITATE, an impact assessment methodology has been developed in order to identify the impacts, benefits and cost of introduction of CCAM on urban transport, passenger cars and freight transport. The impact assessment results will be implemented in the LEVITATE Policy Support Tool (PST) in order to assist relevant stakeholders in the analysis of urban policy scenarios and targets.

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With the introduction of CCAM, new business models and operational concepts will emerge that bring large changes. One of the major cost factors today is the driver or personnel in general. Automation in urban freight transport is an important milestone for city logistics, but it will most likely be challenging due to the complex traffic situations. The aim of the present paper is to provide an insight in the methods we use to forecast the impacts of automated parcel delivery. While the parcel volume is soaring due to the popularity of e-commerce – and especially accelerated by COVID, cities are thinking about the future delivery system. Automation and consolidation are expected to bring disruptive changes to the system we know today. Studies show that using smaller, electrified robots addresses several acute problems: emissions, navigation in confined inner-city areas and the limitation of working hours (Jennings et al. 2019, Baum et al. 2019). In addition, consolidation via white-label city-hubs is expected to decrease the freight mileage, which is a primary factor for evaluating freight transport (Allen et al. 2012, Quak et al. 2016). Other impacts such as congestion, ecology, economy and safety are in direct relation to the mileage. In this paper, we compare the following delivery scenarios:

- **Manual delivery** (status quo) is used as a baseline scenario for comparison.
- **Automated delivery** uses so-called robo-vans and small autonomous delivery to replace the service personnel. The fully automated robo-vans function as mobile hubs while autonomous delivery robots perform short delivery trips to end-customers[*]. This human-less delivery process can be carried out during off-peak hours when road traffic volumes are lower and be extended to evening or night-time delivery. For this concept, we assume that the parcel capacity of the van will be significantly reduced. The main reason is that it has to carry the delivery robots and the necessary equipment to load them.
- **Manual consolidated delivery** uses bundling at white-label city-hubs, i.e., the delivery vehicles are not bound to a specific delivery company but operate the service for all companies. This removes the redundancy in the delivery system nowadays. In this scenario, both the servicing of city-hubs and the delivery to end-customers are done manually.
- **Automated consolidated delivery** is the final scenario that combines the automated delivery via robo-vans and the city-hubs for bundling.

In all automated scenarios, we assume that the delivery is done during day and night, whereas the transport from distribution centers to city-hubs is done during the night via automated trucks. Solutions or prototypes for automatic loading and unloading already exist for packages and pallets (Cramer et al. 2020).

In the remaining paper, we demonstrate on a case study for Vienna how these delivery scenarios would perform. A full list of impacts and assessment methods, such as microsimulation, operations research and Delphi panel are provided by Elvik et al., (2019).

## 2. Case study for Vienna

We apply our assessment methodology on the for analyzing the automated delivery scenarios to, for which we have a good availability of demographic and parcel data. In 2020, the six logistic providers in Vienna delivered a total of 272,000 parcels per day from a total of nine logistics centers (Fig. 1). In general, these centers are located either on the outskirts of the city or outside of Vienna, where there is a good connection to the highway. In addition, the possibility of implementing 7-8 white-label city-hubs were the basis for the consolidated delivery scenarios.

### *2.1. Methodology*

For assessing the fleet composition, freight mileage, and fleet operation costs, we use operations research (OR) methods (Lagorio et al, 2016). For the sake of simplicity and applicability of assessment methods, it is assumed that

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[*] https://www.starship.xyz/press_releases/robovan-by-starship-technologies-and-mercedes-benz-vans-future-proof-local-delivery/

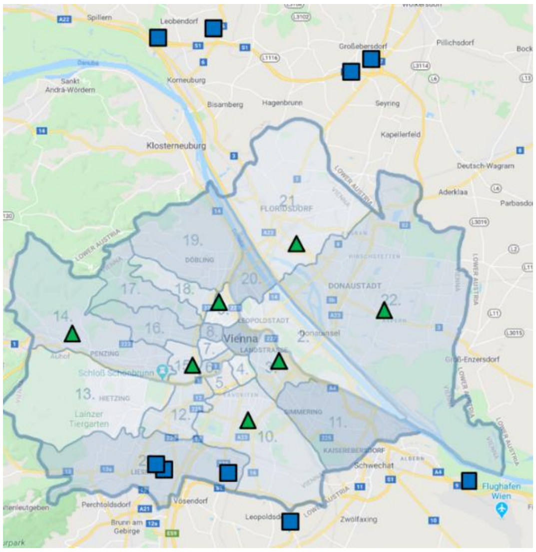

Fig. 1. Distribution centers (blue squares) and potential city-hub locations (green triangles) for Vienna.

for the appropriate level of automation, adequate infrastructure exists (e.g., for receiving parcels at night). It is also assumed that the pure technological obstacles are solvable and do not hamper the operations. The road safety impact is handled both qualitative and quantitative aspects. For the driving behavior and the interactions of delivery robots with pedestrians, there are only few studies. Therefore, they are handled in a qualitative manner. The quantitative results for the number of potential crashes are based on micro-simulation and surrogate safety assessment model (SSAM). For a detailed description of the road safety assessment methods, we refer to Weijermars et al. (2021).

For the wider impacts such as parking space and public health, we use the Delphi method. This is a process used to arrive at a collective, aggregate group opinion or decision, by surveying a panel of experts. This concept was developed by the RAND Corporation for the military in order to forecast the effects of new military technology on the future of warfare, and then continued to make multiple practical applications of this method (Dalkey & Helmer, 1963). The Delphi methodology is based on a repetitive interview process in which the respondent can review his or her initial answers and thus change the overall information on each topic (Hsu & Sandford, 2007).

The parcel volume was taken from a parcel industry report (Wirtschaftskammer Wien, 2020). Based on that, delivery addresses were generated and randomly distributed but weighted according to the population density of the respective districts in the city of Vienna, see Fig. 2a. The delivery addresses were grouped into clusters of 200m diameter, which represent the stop points of the delivery routes, see Fig. 2b. The underlying assumption is that the courier can walk to several delivery addresses per vehicle stop. The underlying assumption is this is that under manual delivery, the courier walks to several delivery addresses per vehicle stop: The vehicle is parked, and parcels are delivered to addresses within 100m of the vehicle, sometimes the delivery person is aided by a hand truck, dolly or trolley. In case of automated delivery, the robo-van would act as a mobile hub where autonomous delivery robots would swarm out to deliver the parcels to final address. Two cluster variants are used:

- **Unconsolidated clusters**: delivery addresses of the logistics providers are considered separately. This results in between 5500 and 22500 clusters per logistics provider, depending on their market share, with a potential demand of about 2 parcels per cluster.
- **Consolidated clusters**: All delivery addresses are considered together. This results in a total of approximately 27700 clusters, with a potential demand of approximately 8 parcels per cluster.

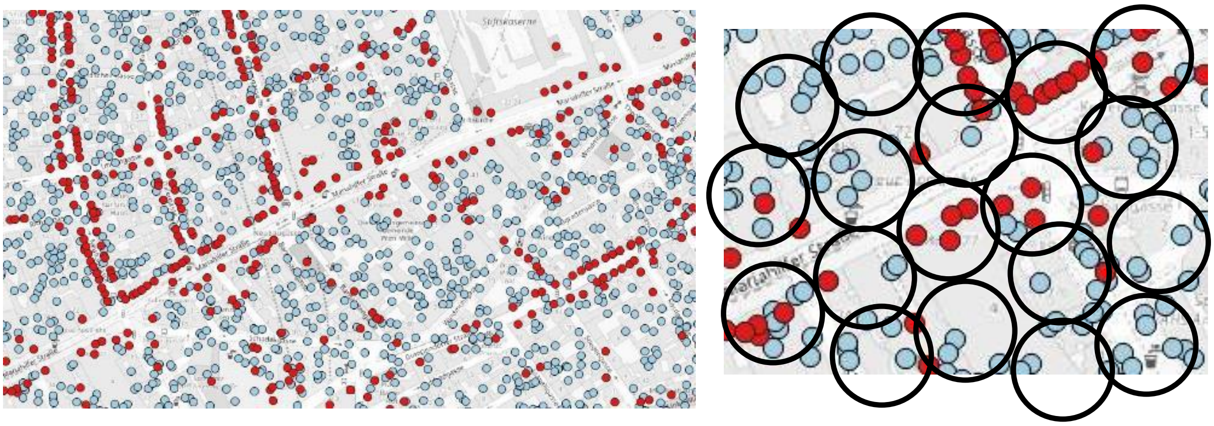

Fig. 2. (a) Delivery address generated for Vienna: residential addresses (blue) and business locations (red); (b) clustering the addresses via circles with 200m diameter.

The algorithm for calculating the delivery scenarios is based on optimizing the routing of the delivery vehicles. It is commonly known as the vehicle routing problem (VRP), where the goal is to calculate the optimal route or set of routes at the lowest possible cost (and often also the shortest possible time) from a given depot to a number of customers (Toth and Vigo, 2014). In all delivery variants considered, the delivery points are assigned to a depot from which the parcels are delivered. Depending on the delivery scenario, this depot can be a logistics center or a city-hub (in case of consolidated delivery). Subsequently, a problem instance of the VRP is generated for each depot, with the delivery addresses acting as so-called customers. Finally, these instances are solved using the Savings algorithm (Clarke and Wright, 1964). This algorithm is able to handle large size problems which is the case here when the full city is considered. Finally, the required consolidation trips between the individual depots are calculated. If the demand for parcels at a delivery address exceeds the capacity of a single delivery vehicle, we divide it into multiple virtual delivery addresses at the same location, with each of these having a maximum demand for parcels equal to the capacity of the delivery vehicle.

For the unconsolidated delivery, the unconsolidated clusters are used as customers. The nine logistics centers serve as depots. The assignment of addresses to depots is made according to districts. For logistics providers with two logistics centers, all addresses in the northern districts (2, 19, 20, 21 and 22) are assigned to the northern logistics center, all other addresses to the southern logistics center. For logistics providers with only one logistics center, this center is responsible for all addresses in Vienna. Consolidation runs are not necessary with this variant. The difference between manual and automated delivery is mainly the vehicle capacity.

In the case of consolidated delivery, consolidated clusters are used as customers. The seven city-hubs in Vienna function as depots. The assignment of addresses to depots is performed by solving the capacitated facility location problem (Laporte et al., 2019), where the city-hubs are the facilities, and the districts are delivery areas. The assignment costs of an area to a depot are calculated using the average distance of delivery addresses within a delivery area to the depot. Consolidation trips are made separately for each logistic provider: all parcels of one provider are directly delivered to a specific city-hub via trucks from the nearest logistics center. For servicing the city-hubs, we assume that trucks with a capacity of 800 parcels are used. They are either manually operated or automated. For the delivery vans, we assume a capacity of 150 parcels for manually vans and 100 for robo-vans. Each city-hub is assumed to have a capacity to handle 36000 parcels per day, so that the demand for Vienna is met. For a detailed description of the OR methods, we refer to Hu et al. (2021).

## 3. Results

For automated delivery and automated consolidation, the primary factors for the impacts are the fleet size and the driven km. They are fundamental for freight operations since other impact indicators are directly based on them, such as annual fleet cost, freight transport cost, $CO_2$ emissions and congestion.

### 3.1. Fleet size and driven km

Table 1 shows all delivery variants with respect to their fleet composition and driven km per day. The columns show the number of delivery trips, fleet size, average number of stops (parking operations) per trip, average trip length and mileage of all delivery trips. This is followed by the mileage of the consolidation trips by trucks (i.e., trips for delivering to parcels to the city-hubs), and finally the total mileage of all vehicles.

Table 1. Results for automated delivery and automated consolidation for Vienna

| | Delivery via van / robo-van | | | | Consolidation trips by trucks | |
|---|---|---|---|---|---|---|
| | No of trips | Fleet size | Ø Trip length | Van km | Truck km | Total driven km |
| **No consolidation** | | | | | | |
| Manual delivery | 1,799 | 1.799 | 44.7 km | 80,389 km | - | 80,389 km |
| Automated delivery | 2,692 | 898 | 39.4 km | 10,6177 km | - | 106,177 km |
| **Consolidated delivery** | | | | | | |
| Manual consolidated delivery | 1,806 | 1,806 | 13.7 km | 24,675 km | 10,445 km | 35,120 km |
| Automated consolidated delivery | 2,716 | 906 | 11.9 km | 32,347 km | 10,445 km | 42,792 km |

We observe that on the one hand, the mileage is significantly shortened by the consolidated delivery via the centrally located city-hubs, and on the other hand, mileage increases due to the lower capacities of the robo-vans for automated delivery. However, with automated delivery being able to operate in three shifts (two during the day and one at night), we require fewer vehicles in the fleet to achieve the same delivery capacity. This has the potential to reduce the operating costs significantly.

For the environmental impacts, the driven km can be directly translated into $CO_2$ emissions which is not listed in this paper due to space reasons. A typical delivery van with combustion engine emits around 300g $CO_2$ per km, and a truck with combustion engine emits around 570g $CO_2$ per km. In this regard, consolidated delivery has a significant contribution towards reducing $CO_2$ emissions. In addition, the overall reduction following automation will be driven by the parallel change to electric engine drive that is assumed for all automated vehicles.

### 3.2. Fleet operating costs

For assessing the vehicle operating cost, we make the following assumptions.

- **Manual delivery**:
  - For a conventional delivery transporter, we assume acquisition costs of EUR 30,000 (model of Mercedes Vito). With a linear deprecation over 10 years, the costs are EUR 3,000 per year.

  - Costs for insurance, maintenance and fuel are assumed to cost EUR 5,000 per year.
  - The average salary of a driver for parcel delivery is around EUR 35,000 per year[†], and the employer pays EUR 45,500 per year due to additional tax and insurance.
  - The total costs for a conventional delivery vehicle are therefore EUR 53,500 per year.
- **Automated delivery**:
  - For the robo-van which needs further equipment for handling the delivery robots, we assume the costs to be 70,000. With a linear deprecation over 10 years, the costs are EUR 7,000 per year.
  - Costs for insurance, maintenance and energy will be cheaper than a conventional vehicle. We assume a cost of EUR 3,000 per year.
  - The costs for the delivery robots (e.g., Starship) are highly speculative. According to Starship's Head of Data, one robot might cost around USD 5,500[‡]. Adding service costs and assuming a linear depreciation over 3-4 years, we come to a cost basis of EUR 2,000 per year. We assume that one robo-van operates with six robots, therefore the total costs for the delivery robot fleet is EUR 12,000 per year.
  - The robo-van operates completely without driver or delivery personnel. However, remote monitoring personnel will be necessary where it is assumed that one person can cover five delivery vans (ITF 2017). With an estimated annual salary of EUR 60,000, we obtain EUR 12,000 per year per robo-van.
  - Applying these costs, we get EUR 34,000 per robo-van per year.

The resulting total annual fleet costs are shown in Table 2, which indicates huge costs savings by using robo-vans.

Table 2. Estimated annual fleet operating cost for Vienna.

| | Fleet size | Annual fleet cost (Million EUR) |
|---|---|---|
| Manual delivery | 1,799 | 96.2 |
| Automated delivery | 898 | 30.5 |
| Manual consolidated delivery | 1,806 | 96.6 |
| Automated consolidated delivery | 906 | 30.8 |

While the costs of the vehicle fleet can be approximated by these assumptions, it is very hard to estimate the costs for the city-hubs, which are required for the consolidated delivery. According to estimations, the costs for building a standard warehouse or distribution center ranges from $35 to $100 per square foot (NewStream, 2020). This heavily depends on the land cost and the level of technology. In this paper we do not want to make an accurate calculation on the costs, but we expect them to be on the higher end of the estimation since land plots within Vienna are relatively expensive and the technology cost for an automated consolidation center will be high.

### *3.3. Wider impacts*

Wider impacts are broader changes occurring outside the transport system, such as parking space required and public health. These are inferred impacts measured at a larger scale and are the result of direct and system wide impacts. Wider impacts are considered to be long-term impacts and are shown in Table 3, which is based on the project deliverable (Goldenbeld et al., 2021). The columns show the considered impact, the delivery scenario, and the results grouped by the automated vehicles (AV) market penetration rate given in percentages. In all scenarios, the market penetration rate of automated vehicles in the entire network vehicle fleet increases from 0% AVs (100-0-0) to 100% 2nd generation AVs (0-0-100), together with either manual delivery or one of the automated delivery systems.

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[†] https://www.stepstone.at/gehalt/Paketzusteller-in.html

[‡] https://sifted.eu/articles/starship-robot-delivery/

According to expert consultation, in the baseline scenario (manual delivery), parking space requirements will be reduced by nearly 12% once human-driven vehicles are reduced to 20% or lower. However, in both automated delivery scenarios the impact is smaller than in the baseline, implying that the automated delivery van SUCs will require more parking space than the scenario with automation but without a fully automated, unstaffed delivery van system. Regarding public health, a negative estimate implies a decline in public health. In the expected baseline scenario, a small deterioration in public health is expected during the transition phase, followed by a small improvement in public health (4% to 5%) as the penetration of second generation CAVs increases. Automated consolidation is anticipated to bring a substantial additional improvement to public health once the entire vehicle fleet is automated.

The road safety is predicted to initially take a turn for the worse when the first generation of automated vehicles is introduced and there is a lot of interaction between human-driven vehicles and (two types of) automated vehicles. Due to different driving styles of human drivers and automated vehicles, some extra risks in mixed traffic are an expected development during the transition from human to non-human-driven vehicles. However, this improves once no human-driven vehicles are left in the simulation (from a 60% penetration of 2nd generation vehicles and above), resulting in roughly half as many crashes per vehicle-kilometer when the entire vehicle fleet is made up of 2nd generation automated vehicles. Compared to the manual delivery scenario, the introduction of either automated delivery or automated consolidated delivery shows marginal additional benefits for road safety, especially at lower penetration rates of automated vehicles in the entire fleet.

Table 3. Estimated wider impacts, measured in terms of percentage change with respect to the baseline of manual delivery and 100-0-0 scenario (Goldenbeld et al., 2021).

| | | **Market penetration rate: AVs in Background vehicle fleet** (Human-driven vehicle - 1st Generation AV - 2nd Generation AV) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Impact** | **Delivery scenario** | 100-0-0 | 80-20-0 | 60-40-0 | 40-40-20 | 20-40-40 | 0-40-60 | 0-20-80 | 0-0-100 |
| Parking space requirement | Manual delivery | 0.0% | -1.4% | -1.3% | -5.0% | -11.5% | -11.6% | -11.6% | -11.6% |
| | Automated delivery | 0.0% | -7.9% | -4.6% | -6.8% | -5.1% | -4.0% | -4.0% | -4.0% |
| | Automated consolidated delivery | 0.0% | -4.3% | -2.8% | -2.8% | -4.2% | -3.8% | -3.8% | -3.8% |
| Public health | Manual delivery | 0.0% | -5.3% | -2.1% | 0.0% | 5.2% | 4.0% | 4.0% | 4.0% |
| | Automated delivery | 0.0% | 2.9% | 4.7% | 8.8% | 8.8% | 8.4% | 8.4% | 8.4% |
| | Automated consolidated delivery | 0.0% | 6.0% | 7.7% | 9.4% | 14.4% | 18.5% | 18.5% | 18.5% |
| Road safety | Manual delivery | 0.0% | 7.5% | 14.0% | 16.1% | 4.3% | -19.5% | -37.0% | -48.7% |
| | Automated delivery | -2.6% | -4.2% | 10.2% | 4.9% | 4.6% | -19.8% | -41.0% | -50.2% |
| | Automated consolidated delivery | -2.6% | -4.2% | 10.2% | 4.9% | 4.6% | -19.8% | -41.0% | -50.2% |

## 4. Discussions and conclusions

The results obtained by operations research indicate that the robo-van concept for automated urban delivery will increase the mileage of the delivery trips when compared to the current manual delivery situation. The main reason is the assumption that the vehicle capacity will decrease due to the delivery robots and additional equipment. By removing the driver who is the most expensive part of the manual delivery system, automated delivery has the potential to significantly reduce the costs which is in line with experts' estimations that delivery robots will reduce costs and delivery time (Jennings and Figliozzi, 2019). In general, the biggest advantage of automated freight transport is the possibility to deploy these when the demand for road capacity is low, for example at night. Without restrictions on working times, the road infrastructure can be utilized more efficiently by particularly freight transport by avoiding deliveries during peak traffic periods.

The current delivery system has a high redundancy since multiple delivery companies operate in the same area, thus one delivery address is often approached multiple times by different delivery companies. Therefore, consolidation through city-hubs is in the spotlight, especially white-label concepts where the infrastructure is shared among different logistics provider companies in order to reduce redundancy. While the mileage will decrease significantly, the implementation is very challenging: Beside the expensive upkeep for the city-hubs, the overhead in the freight operation and the additional personnel requirement is significant when the delivery system is operated manually. Without automation, adding the additional consolidation step means that freight must be transported to the city-hubs and then processed, before the actual delivery can begin. This alone causes a delay of several hours in the delivery process (which very critical for the B2B sector). Automated logistics solves this problem completely since servicing the city-hubs can be automated and shifted to the night, when all incoming parcels arrived. This can be seen as the critical enabler for freight consolidation. For the road safety, the results indicate consistently that with a higher AV penetration rate, the number of crashes per vehicle kilometer will decrease significantly when human driven vehicles are fully replaced by AVs. However, during the transition phase with a balanced mix between manual and automated vehicles, the crashes will rise temporarily compared to the status quo today.

Regarding policy recommendations, the results indicate that even without financial or operational incentives, automation in freight transport will gain popularity once the technology is mature and the operating costs become substantial cheaper than the transport operation nowadays. However, automation alone will most likely lead to an increase in freight mileage (because of smaller and cheaper freight vehicles), so corresponding policy measures in favor of freight consolidation should be considered to mitigate this trend. Fortunately, automation is expected to facilitate the consolidation process.

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