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# What may automation cost? Activity-based costing for autonomous transport in urban logistics

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**Abstract**

A shift towards driverless vehicles in urban logistics will only happen if the use of the new technologies is economically beneficial. For this reason, this paper discusses the question of what autonomous shipment may cost in urban logistics. Using activity-based costing, the distinction between shipment with conventional trucks and autonomous transport robots is analysed. The calculation shows that the omission of the driver does not necessarily lead to a reduction of process costs. Only by also reducing technology costs, autonomous transport in urban logistics can gain economic benefits.

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## 1. Introduction

In 2021, the Act on Autonomous Driving became the new regulatory framework for autonomous motor vehicles in Germany which legally allowed autonomous vehicles, "to operate in regular public road transport in determined operational areas" (Federal Ministry for Digital and Transport, 2021). Autonomous driving describes the highest automation level (e.g. Gasser, 2012 or SAE International, 2016). A driver is no longer needed in the vehicle although a person (technical supervisor) has to monitor the operations in the vehicle or remotely. Where a driver is needed today, future autonomous systems could take over the driver's tasks which are necessary for lateral and longitudinal control of the vehicle, in all environmental conditions from start to finish.

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The purchase decision is mainly based on the question when it makes economic sense to use a driverless vehicle (Müller and Voigtländer, 2019). The driverless vehicle represents an attractive alternative to the conventional, manually controlled vehicle if there is at least cost equivalence. These economic effects, regarding the costs of autonomous driving, have been little studied so far.

Some research has been done on the effects of automated vehicles and, in particular, driverless vehicles in road freight transport (e.g. Flämig, 2015; Pernestal, 2020; Engholm, 2021; Tjaden, 2023). Looking at existing studies on the cost calculation of automated vehicles in freight transport, the focus has been on the total cost of ownership (TCO) (Wadud, 2017; Ghandriz et al., 2020; Engholm et al., 2020). Furthermore, Flämig (2015), Engholm (2021) or Tjaden (2023) stated that driverless driving might lead to relevant changes in the transport chain as well as in upstream and downstream processes of the transport chain. While standardised processes facilitate the use of driverless vehicles in long-distance transport, modified processes are to be expected for the far more complex urban logistics processes. In particular, value chains with service tasks, e.g. delivery to the customer, will have to be redesigned.

In order to automate last mile operations, the idea of using transport robots for the last mile of urban deliveries has become more popular in recent years. Automated guided vehicles have existed since the 1950s and 1960s in factories. Transferring these vehicles into the public spaces of dense cities is relatively new and still in a trial phase. It is still unclear if the integration of these technologies in 'the last mile' processes create an economical benefit for the delivering companies.

The aim of this paper is to determine the individual process costs and cost drivers of autonomous shipment processes for a comparison with conventional shipment processes. The cost calculation will be done by using the comprehensive method of activity-based costing (ABC).

To analyse the discrepancy between conventional and autonomous shipment from the shipper to the customer the findings of the TaBuLa-LOGplus project are used which are based on previous projects, ATLaS (Flämig et al., 2020) and TaBuLa-LOG (Gertz et al., 2022). These projects deliver the changes of activities in a combined shipment with an autonomous truck and a transport robot for the final mile. However, the ABC performed cannot be an exact forecast of costs as autonomous driving has so far only been used in test operations so only a trend estimate based on generic data and data from test operations is possible at present. Nevertheless, the calculation provides a basis for further economic discussion.

## 2. Literature Review

A systematic literature review on publications on automated and autonomous driving in freight transport following Fink (2010) shows that approximately three quarters of the publications are focused on technological aspects and only one quarter analyses economical, ecological or social topics (Tjaden 2023).

The technologies already researched and partially applied are mainly platooning as well as other vehicle-to-vehicle communication (e.g. Flämig, 2015; Chan, 2017; Martínez-Díaz and Soriguera, 2018). Those publications that address economical, ecological or social aspects analyse advantages as well as challenges of automated and autonomous driving. The expected benefits of autonomous driving includes increasing safety, efficiency and productivity as well as reduced resource consumption and costs (e.g. Fagnant and Kockelman, 2015; Milakis et al., 2017). Martínez-Díaz and Soriguera (2018) name the challenges: human behaviour, ethics, policies, liability and technology. Hjälmdahl et al. (2017) specifically examine the effects of platooning on driver workload, trust, acceptance and performance. Other publications focus on the development of a framework for further tests with autonomous vehicles, especially trucks, e.g. Elgharbawy et al. (2019) or Kalra and Paddock (2016).

The existing literature on economic effects focus on the total costs of the vehicle and its operations or on the transport system. Wadud (2017), for example, carried out a TCO calculation that compared different vehicle sizes of conventional vehicles and automated vehicles. Engholm et al. (2020) did a comparable TCO study for driverless trucks. Lunkeit et al. (2019) examined the effects of increasing market penetration of automated vehicles on transport costs by using a system-dynamics approach. Furthermore, Tjaden (2023) identified and analysed the effects of driverless vehicles particularly in the comprehensive logistics system and simulated these effects for a period of 30 years with a system-dynamics model. She also included a costs analysis using a TCO.

So far, a detailed analysis of the costs for each activity of an autonomous shipment is still missing. There are different types of cost analysis used in the context of freight transport and supply chain management (SCM). A lot of literature already addresses activity-based costing (ABC) in the supply chain environment. Some publications summarize and analyse the evolution of ABC in SCM, e.g. Lin et al. (2001) or Hofmann and Bosshard (2017). Lin et al. (2001) focuses on logistics activities and the specific costs of these activities to gain a better understanding for management decisions. Hofmann and Bosshard (2017) present the previous findings on ABC and SCM based on a detailed literature analysis. Others develop their own framework or model for ABC and use a case study to evaluate it, like Bokor (2009) or Baykasoglu and Kaplanoglu (2007).

As part of the ATLaS project, Flämig et al. (2020) identified different scenarios for autonomous shipments with driverless trucks for long haulage as well as for the last mile in cities and used an ABC to identify economic effects of the new technology.

Cost calculations for smaller vehicle sizes like transport robots are rare. In the TaBuLa-LOG project a transport robot was developed and tested for delivering mail between local authority sites in Lauenburg/Elbe (Germany) (Gertz et al., 2022). Tjaden et al. (2022) used these finding and discussed potential costs for a combined passenger and freight transport of a shuttle and a transport robot. The analysis is based on a TCO calculation and an ABC to identify which costs might occur due to a combined passenger and freight transport. Furthermore, a comparison of activity-based costs of a conventional and an autonomous shipment as a combined scenario like a truck and a transport robot in urban logistics is missing.

## 3. Activity-based costs of conventional and autonomous transport in urban logistics

In the following the common term activity-based costing (ABC) is introduced and used. The methodological approach of ABC is based on process costing (PC) which is more common in Germany (Horváth and Mayer, 1995). The main difference is that ABC focuses on activities as a more detailed level whereas PC is based on processes as a collection of activities. Both methods enable greater cost transparency in the company as well as improved planning and control of costs for each activity or process (Cooper and Kaplan, 1988; Wöhe and Döring, 2013).

For the cost calculation an activity analysis is required first to identify the relevant activities within the processes. The processes combine activities, so the second step is to aggregate. That is made possible by identifying cost driver reference values for each single activity cost. The total fixed costs can then be allocated based on the cost drivers. Resource costs can be examined by identifying resources used in the single activities. Based on the identified activities and the required resources by each cost driver, the total costs of the processes can be calculated.

In this section, ABC is performed for two scenarios: The first scenario shows the activities and costs of a regular, manually controlled transport from a shippers' goods despatch area to the customer, whereas the second scenario shows an autonomous transport in which the driver is no longer included in the calculation as an autonomous truck and a transport robot will carry the parcels.

Therefore, it is necessary to connect two autonomous areas of application: On the one hand the shipment by an autonomous truck up to 7.5 tons gross vehicle weight (GVW)) and on the other hand the shipment by a robot for the last mile. The scenarios for these applications are based on Flämig et al. (2020) and Gertz et al. (2022).

## 4. Assumptions

The activity analysis results in a list of activities of the different processes. Flämig (2015) as well as the German Ordinance on the Implementation of the Professional Driver Qualification Act ("Berufskraftfahrer-Qualifikations-Verordnung") named typical activities of truck drivers. These activities are used as a basis for the processes as these are generic activities for professional drivers in general. Specific processes for urban logistics can be found in DHL (2018), which describes typical activities for parcel deliveries.

The activities for the parcel delivery can be divided into three processes: preparation, delivery and follow-up. The activity analysis lists the following 11 typical activities: Loading vehicle, capturing each package with handheld scanner and securing the load are part of the preparation. Complying with rest periods, driving to the delivery area, driving between recipients, handing over the packages, obtaining receipt confirmation from the recipient and driving to the delivery base belong to the main process delivery, unloading returned packages and calculating collected 'cash on delivery' amounts are follow-up processes.

The identified cost driver is a parcel. In the following, costs per parcel are calculated for each of the named activities. For the calculation of the costs per parcel, the following basic assumptions are made:

- The number of working days' amounts to about 250 days per year for the conventional scenario (according to the regulation (EC) No 561/2006 of the European Parliament and of the Council of 15 March 2006) and 300 days for the automation scenario, as Sundays are excluded.
- An electrical truck up to a maximum of 7.5 tons GVW with a capacity of 200 parcels is considered for the tour to and from the delivery area.
- Two electrical transport robots with a capacity of two parcels each are considered for the short distances within the delivery area.

Activity quantities per day and specific activity times per working day could be assigned to each activity. They are defined for the conventional and the autonomous scenario based on DHL (2018) and Hoyndorff (2010), who collected key figures for logistics centres in the fashion industry as well as on expert interviews and the author's own assumptions. The values determined were collected for the Federal Republic of Germany. The assumptions for the ABC are listed in Table 1.

Table 1. General assumptions for the scenario calculation

| Process | Activity | Activity quantities per day | Activity time per working day [min] |
|---|---|---|---|
| Preparation | Loading vehicle | 200 parcels | 40 |
| | Capturing each package with handheld scanner | 200 parcels | 35 |
| | Securing the load | 1 truck | 3.33 |
| Delivery | Driving to the delivery area | 1 truck | 20 |
| | Complying with rest periods | 1 truck | 45 |
| | Driving between recipients | 120 stops | 50 |
| | Handing over the packages | 120 stops | 150 |
| | Obtaining receipt confirmation from the recipient | 200 parcels | 150 |
| | Driving to the delivery base | 1 truck | 20 |
| Follow-up | Unloading returned packages | 50 parcels | 10 |
| | Calculating collected cash on delivery amounts | 10 parcels | 5 |

Furthermore, the total costs per year and the personnel costs of an electrical truck up to 7.5 tons GVW as well as the costs for the transport robot are required for the calculation. The total vehicle costs for the truck are based on ifeu (2023) with around 0.82 € per kilometre. With 37,000 annual vehicle kilometres travelled the total costs for the truck amount to 30,340 € per year plus approximately 40,000 € personnel costs (KE-CONSULT Kurte & Esser GbR, 2018; Verdi, 2023). The costs for the transport robot are based on Tjaden et al. (2022). A transport robot with optimized costs of components amounts to 14.29 € per kilometre. It is assumed that the transport robot travels around 10 kilometres per day, so 2,500 annual vehicle kilometres in total.

The total cost per year (for the conventional scenario 70,340 €, for the autonomous scenario 114,590 €) are broken down proportionally to the activity time per working day to obtain the cost per year for each activity. These costs are afterwards divided by the activity quantities, so that the costs per parcel can be determined.

## 5. Results of the ABC for the conventional and autonomous scenario

Using the above-mentioned parameters, the costs per parcel can be determined. The following ABCs show on the one hand the activities of conventional vehicles with a carrier and on the other hand an autonomous urban transport of parcels. For the latter, the driver costs are excluded from the calculation and the costs for the transport robots will be added. It is assumed that the truck drives autonomously, i.e. without human intervention, and therefore does not depend on the control by a driver as well as the transport robot. Furthermore, it is assumed that the preparation and follow-up processes are done by warehouse staff. The process of "complying rest periods" is no longer necessary for the autonomous scenario, but as an additional process the process "loading the transport robot" is integrated in the scenario with an amount of 200 minutes per working day and 0.02 € per parcel.

Table 2. Activity-based costing for the two scenarios

| Process | Activity | Conventional scenario [€] | Autonomous scenario [€] |
|---|---|---|---|
| | | Costs per parcel | |
| Preparation | Loading vehicle | 0.11 | 0.13 |
| | Capturing each package with handheld scanner | 0.09 | 0.12 |
| | Securing the load | 0.01 | 0.01 |
| Delivery | Driving to the delivery area | 0.12 | 0.07 |
| | Complying with rest periods | 0.05 | - |
| | Loading the transport robot | - | 0.67 |
| | Driving between recipients | 0.13 | 0.17 |
| | Handing over the packages | 0.40 | 0.50 |
| | Obtaining receipt confirmation from the recipient | 0.40 | 0.50 |
| | Driving to the delivery base | 0.05 | 0.07 |
| Follow-up | Unloading returned packages | 0.11 | 0.13 |
| | Calculating collected cash on delivery amounts | 0.27 | 0.34 |
| | **Total** | **1.74** | **2.71** |

Table 2 shows the costs per parcel for each activity for the conventional and the autonomous scenario. The calculation demonstrates that the scenario with a conventional truck and a carrier is approximately 1 € cheaper than the autonomous scenario. This is because the total costs for a truck and a carrier (70,340 €) are lower than for a truck and two transport robots (114,590 €).

Furthermore, it can be seen that the activity costs per parcel range between 0.01 € in the activity "securing the load" and 0.40 € in "handing over the packages" and "obtaining receipt confirmation from the recipient" of the conventional scenario. In the autonomous scenarios the costs per parcel are even higher. The activity of "loading the transport robot" amounts of 0.67 €. These activities are also the ones with the lowest and the highest amount of activity time per working day in relation to the amount of parcels handled. In other words, the most time consuming activity is also the strongest cost driver.

The total activity time in the conventional scenario is about 529 minutes per working day, so approximately 9 working hours. In this case 45 minutes are used for the activity "complying with rest periods", which costs about 0.12 € per parcel. With an autonomous truck no rest periods during a tour are required anymore as the vehicle does not need any resting times. But due to the operations of the transport robots the process "loading the transport robot" is integrated which is about 0.67 € per parcel. Although 45 minutes per day were excluded, around 200 minutes were added due to the new process of loading the transport robot. The total activity time per working day is therefore extended to about 684 minutes or 12 hours respectively. This is legally possible, as the autonomous vehicles do not have to consider resting periods.

Since the total costs are higher in the autonomous scenario the question arises how costs can be reduced to make operations with autonomous vehicles more attractive.

## 6. Discussion of the results

A scenario has to be determined which makes autonomous driving more attractive for delivery companies. For the ABC of the autonomous scenario driver costs were excluded from the calculation and two transport robots and a new activity were integrated. In sum, the costs are 1 € per parcel higher for an autonomous urban shipment. This result is highly connected to the assumptions made for the calculation. One transport robot costs approximately 14 € per kilometre. In the calculated scenario two robots were considered. In comparison, a truck up to 7.5 tons GVW and a carrier amounts of 1.9 € per kilometre. At the moment shipping with robots is much more cost intensive than with conventional trucks. Next to the robots, an autonomous truck requires additional technology for the driverless functions, resulting in additional costs of around 12,800 €. All in all, the automation costs for the two vehicle types are too high and therefore not economically beneficial.

First of all, the vehicle costs have to be reduced. Even if just one transport robot is included in the autonomous scenario, the total costs will be higher than in the conventional scenario with 1.86 € per parcel as the activity "loading the transport robot" is highly cost intensive. Plus, if just one transport robot is included, the activity time per working day needs to be extended as the delivery will take much longer. This can be a problem as the delivery time is already extended to 12 hours per day in comparison to the conventional scenario with 9 working hours.

By reducing the vehicle costs to 5 € per kilometre an optimized scenario can be calculated with total cost per parcel of 1.62 €. Table 3 shows the optimized autonomous scenario with costs per parcel for the different activities. So if we assume that two transport robots will be delivering the parcels the costs per robot have to be reduced to maximum 5 € per kilometre. The total costs for the delivery are approximately 68,140 € with about 12,500 € per transport robot a year and the assumptions made for this scenario.

Table 3. Activity-based costing for the optimized autonomous scenarios

| **Process** | **Activity** | **Cost per parcel [€]** |
|---|---|---|
| Preparation | Loading vehicle | 0.08 |
| | Capturing each package with handheld scanner | 0.07 |
| | Securing the load | 0.01 |
| Delivery | Driving to the delivery area | 0.04 |
| | Loading the transport robot | 0.40 |
| | Driving between recipients | 0.10 |
| | Handing over the packages | 0.30 |
| | Obtaining receipt confirmation from the recipient | 0.30 |
| | Driving to the delivery base | 0.04 |
| Follow-up | Unloading returned packages | 0.08 |
| | Calculating collected cash on delivery amounts | 0.20 |
| | **Total** | **1.62** |

## 7. Conclusions

Real potential for the use of driverless vehicles in urban freight transport are forecasted such as increasing safety, reducing transport costs or reducing the shortage of drivers. However, driverless vehicles are only purchased if they are at least cost equivalent to conventional vehicles or even more cost-effective. This paper deals with the question of how much autonomous transport in urban logistics may cost.

To answer this question, an ABC was carried out to identify the process costs of the individual processes and to analyse the changes in the use of a conventional vehicle to an autonomous vehicle. ABC offers the advantage of increasing cost transparency and identifying possible cost-drivers. The ABC used was able to demonstrate that cost reductions are not simply realized by just removing the driver in an autonomous transport scenario and replacing the person by a transport robot as the costs increased in the autonomous scenario.

Only when the vehicle costs of the transport robots are optimized the costs will be lower than in the conventional scenario. Moreover, the ABC shows that the highest process costs occur in the delivery processes as these have the highest process times in relation to shipped goods. In the conventional scenario personnel costs are the main cost-driver in the delivery process, while the transport robot is the most expensive part in the autonomous scenario.

At this stage the calculated additional costs that could arise from the use of the new technology are made under many assumptions. Based on the underlying assumptions the costs of a transport robot have to be less than 5 € per kilometre to be economically beneficial. This is a reduction of around 10 € per kilometre in comparison to the existing prototype with 14 € per kilometre. It is questionable if this is realizable with future technology development.

The ABC based on the processes of the TaBuLa-LOGplus project is just an exemplary calculation. Since costs have been very dynamic to date, this calculation represents a potential development but must be continuously adjusted to stay up to date.

Nevertheless, this paper worked out that the evaluation of autonomous driving should go beyond the saving of the driver costs. The driver's activities must be taken over by other means, which can lead to a restructuring of the urban logistics chain and additional costs may occur. We integrated this change by removing the process of “complying rest periods” and adding the process “loading the transport robot" to the cost calculation. Concerning further research, we suggest carrying out further sensitivity analyses on the costs of the technologies taken from other sources. It is planned to anticipate further changes on the organizational (activity, technologies) level in that research (e.g. maintenance, software provision, adaptation of equipment).

It therefore remains questionable whether the predicted economic gains from autonomous transport in urban logistics can be realized. In any case, further research would need to apply a holistic view of the logistics chain. This would allow for identifying both direct and indirect effects on costs for all players involved in urban logistics.

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