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Methodology for Determining Charging Strategies for Freight Traffic Vehicles based on Traffic Simulation Results

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Abstract

The decarbonization of transport is one major challenge in the upcoming years. One possible solution is the use of battery electric vehicles (BEV). While electric passenger cars and their charging strategies are already in series production, battery electric trucks and their charging strategies are still mostly in the prototype stage. The range limitations of battery electric trucks represent a new challenge for logistics. Therefore, we introduce a methodology for determining charging strategies for freight transport vehicles based on transport simulation results. We analyze the results of an agent-based transport simulation (MATSim) and evaluate different settings of normal and fast charging points. We found for a case study dealing with the food retailing in Berlin, that for a fleet with 279 vehicles in 16 depots 214 normal and 61 fast charging points are sufficient to complete approx. 90% of the tours with BEV. If the vehicles share their charging points, only 71 fast charging points with 400 kW are sufficient. With higher charging power the share of charged vehicles hardly increases. With 29 additional high performance opportunity chargers within the city, all tours can be operated by battery electric trucks. Due to the large variance in route lengths, the results of the case study can be representative for the entire delivery traffic.

Keywords: decarbonization; electrification; urban transport; charging; multi agent transport model

1. Introduction

To respond to the global climate crisis, the decarbonization of the transport sector is a priority task. Battery electric vehicles (BEV) are a promising solution. Currently, 35 % of the emissions from the transport sector in Germany are emitted by commercial vehicles [3]. Nevertheless, this sector represents a major challenge for electrification since heavy and expensive batteries are needed. Ewert et al. [5] show that urban areas with relatively short routes offer a

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good starting point for the use of battery electric trucks. They use a range constraint to plan only tours that are actually possible with BEV without recharging. However, they conclude that a significant share of the fleet (31%) have to be internal combustion engine vehicles (ICEVs), since the possible ranges for BEV are exceeded. It is obvious that suitable charging strategies are essential to enable 100 % battery-electric urban freight transport. Previous research has already dealt with both, modeling commercial road transport and the layout of charging infrastructure. A sensible and efficient charging infrastructure including the location, the construction, and the technical configuration is essential to convert all road transport to electric drives [9]. To provide the necessary charging infrastructure for complete electrification of road transport, it is required to develop and verify charging strategies. The following research was found: Micari et al. [15] extrapolate the number of charging points from motorway network data. Marquez-Fernandez et al. [13] use MATSim for their research, whereby charging possibilities are integrated into the transport simulation. This analysis refers to long-distance transport in Sweden and does not take into account difficulties in urban regions. A further analysis extrapolates registered trucks in Amsterdam with averaged distances to determine the required charging infrastructure based on energy consumption [4]. Chung [4] concludes that high charging powers of over 600 kW no longer offer any advantage in terms of the number of charging points. Libby Bradley [12] develop a charging strategy for electric trucks by analyzing truck travel pattern data from Southern California to determine the best locations for charging stations. Today, charging stations with 600 kW are already on the market [1]. Additionally, Kim et al. [10] is already testing charging stations with 1 MW on trains. This technology could also be used for trucks in the future.

Martins-Turner et al. [14] recently developed a case study on the electrification of urban freight transport with the example of the food retailing industry. They generate synthetic tours, the fleet size, and composition by solving a Vehicle Routing Problem (VRP). They simulate the tours with ICEVs and BEVs and calculate the total cost of ownership and well-to-wheel emissions. They found that with recharging one time a day, 90 % instead of 56 % (without recharging) of the tours can be operated by BEVs. Based on these findings, this study presents a methodology for charging infrastructure layout for freight vehicles. The aim of this article is to answer the following research question: How many charging points and which charging power is needed to enable a complete transition of urban logistics to BEVs?

2. Methodology

It is apparent that the charging strategy plays a major role in answering the posed research question. Therefore, this research focuses on designing the charging infrastructure for the respective MATSim scenario by Martins-Turner et al. [14] by applying and analyzing multiple different approaches to the charging of trucks. MATSim is an extensible, activity- and multi-agent based transport simulation, which enables the simulation of large scale scenarios. It follows an iterative process several times until a stable state is reached. Synthetic agents are modeled which have previously defined schedules for their daily activities. The executed plans result from the agent's choice of transport mode and from interactions with other agents (e.g. traffic jam). After the simulation period (one day), the agents' plans are analyzed and scored. In the next step, the agents can replan their daily schedule by changing the transport mode or route [7]. MATSim covers i.a. passenger transport [18] and freight transport [16, 19].

A two-step method is developed (Figure 1). First, the activity types and locations, the driven distances, and the number of vehicles, which are at the same time at the same location are derived from the respective MATSim scenario. We use current market data from series production and prototypes to define the battery capacity, the possible charging power, the consumption and the range of the vehicles. The charging demands result from the previously defined vehicle consumption and their simulated mileages from MATSim [8]. Thereafter, we differentiate public charging and depot charging. For public charging, an algorithm identifies the position and number of charging stations by locally resolving the charging demands from MATSim (presented in [8]). For depot charging, the location of the depot defines the position of the charging stations. The number of charging stations has to be defined afterwards. Commercial fleets usually perform charging in depots. The maximum number of charging stations is equal to the number of vehicles if each vehicle has its own charging station for overnight charging. Additionally, the installation of fast charging points enables charging during short-standing times in between tours. The number of vehicles that are simultaneously at the depot and require charging at daytime determines the number of fast charging points. The fast charging points can also be used at nighttime. The maximum number of normal charging stations can be obtained by subtracting the fast

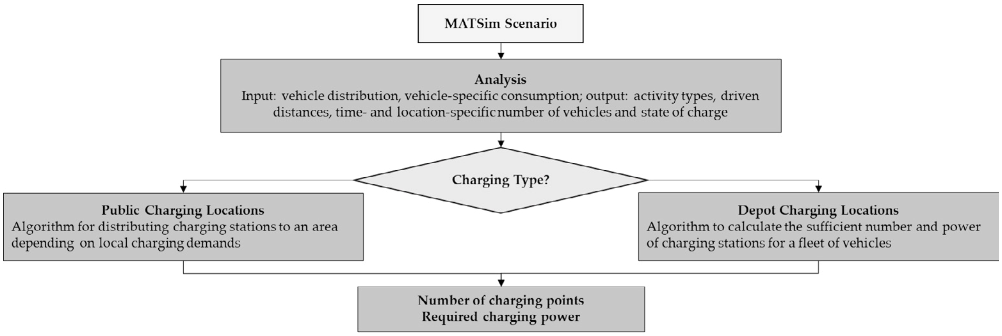


Fig. 1: Process diagram of the charging methodology [6]

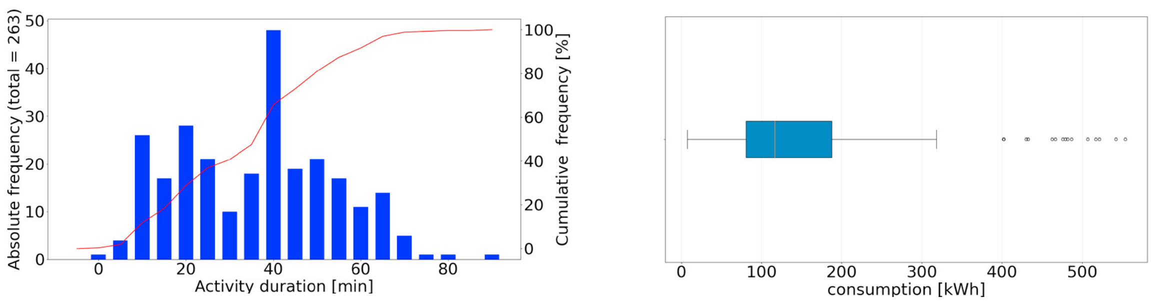
charging points from the number of vehicles at this depot (assumption: every vehicle has its own charging station). This number can be minimized by using each charger sequentially and charging several vehicles one after the other. For this purpose, the time that can be used for charging (vehicles are in the depot) is multiplied by the charging power of all chargers at the respective depot to derive the maximum possible charging capacity. Now the charging demands of all vehicles are analyzed and the vehicles are assigned to the charging points. While regarding maximum charging power and available time, the vehicles are charged in a way that the charging capacity is used sufficiently without exceeding it. This problem corresponds to the "subset sum problem", where a certain number of items should be selected from a set of items in order to reach a target value as high as possible without exceeding it [2]. The algorithm passes through the list of trucks and keeps all trucks in the list whose total consumption is less or equal to the possible charging capacity. In this way, a few trucks are distributed to the first charging station. The remaining trucks are distributed iteratively to the other charging stations. If the minimum number of charging points necessary for the sequential overnight charging is less or equal to the number of fast chargers for the opportunity charging in the day time, this is the final number of charging points. If not all vehicles can be charged on the fast chargers sequentially, slow chargers for all remaining vehicles are added. The total number of chargers is the sum of the number of chargers in all depots. As the cost of charging stations rises with the offered charging power, the definition of the minimal number and power of stations needed is of high economic value. Therefore, the state of charge (SOC) and the remaining tour lengths of the vehicles are analyzed. Thus, it is possible to determine the minimum energy demand for each vehicle arriving at the depot. Since the time required to pick up new goods is known, the required charging power for the vehicle can be determined. Since charging stations are available at certain power levels, we run through different scenarios with different charging power levels and check how many of the vehicles can be charged in this way.

3. Case Study

Martins-Turner et al. [14] include different vehicle types for which we define specific properties such as the battery capacity, and the consumption (see Table 1). To investigate the effects of high power charging, the maximum charging power for all vehicles is set to 1,000 kW. This might not reflect the manufacturer's data of the reference vehicles. However, it reflects the current state of the art and research for heavy BEVs [17]. First, we analyze the transport simulation in terms of activity duration and charging demands. We define that charging infrastructure is only available at the depots of the carriers. For this reason, we consider the standing time of the trucks in the depots as the possible time span for (re)charging (Figure 2a). Next, we quantify the energy consumption of the trucks before they reach the depot. Depending on the traffic situation, a specific consumption is considered in the calculations. The maximum speed allowed on the link is compared to the simulated average speed. This ratio allows a statement about the traffic situation. The consumption is adjusted accordingly. If the average speed is much lower than the maximum speed, this indicates stop and go traffic, and increased consumption by 30 % on this link is assumed. A similar conclusion was reached by Li et al. [11], who analyzed stop and go traffic and its effects. The consumption distribution of the different vehicles is shown in Figure 2b. The optimum charging power is determined by analyzing what percentage of vehicles with a certain charging power can manage their route. For complete electrification, we assume that the trucks are able to charge at high performance opportunity chargers (HPOC) at strategic points in the city (access to city highways etc) if they are not able to complete their routes otherwise. The number of chargers and their charging power is determined by using the above-mentioned method for public charging.

Table 1: Vehicle specifications [14]

Vehicle type	Light Duty	Medium Duty	Medium Duty	Heavy Duty
Weight [t]	7.5	18	26	40
Battery capacity gross (net) [kWh]	87 (60.9)	122 (85.4)	286 (200.2)	443 (310.1)
Energy consumption [kWh/m]	0.00061	0.00106	0.00150	0.00180



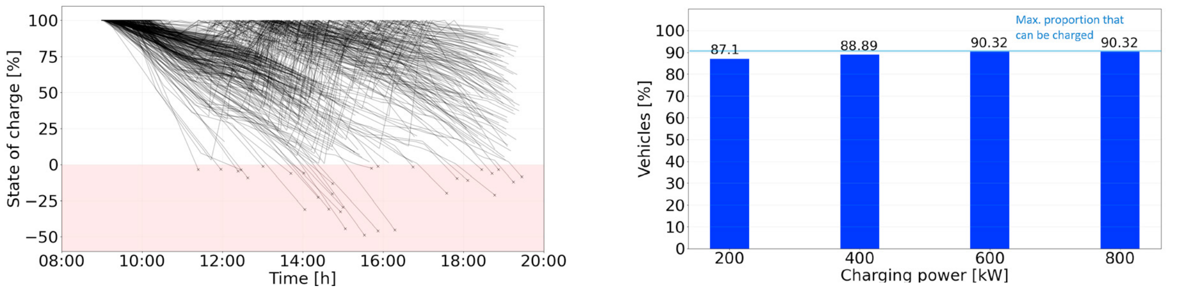
(a) Distribution of pickup duration for reloading goods

(b) Distribution of consumption of electric trucks

Fig. 2: Distribution of pickup duration and consumption of electric trucks

4. Results

After tracking the SOC of the trucks, it can be seen that the SOC of some trucks still drops below 0 % which indicates that not all trucks can complete their route (Fig. 3a). Therefore, it is not possible to charge all vehicles at the depot even with high charging power as shown in Figure 3b. For this reason, this number of vehicles is not considered for planning the infrastructure at the depot. Furthermore, it shows that even with a relatively low charging power of 200 kW or 400 kW a high percentage of vehicles can be sufficiently charged. Charging powers of over 600 kW do not provide better performance of the fleet. As some trucks are below a SOC 0 %, the calculation of the number of charging stations is executed once with all trucks (279 trucks) and once only with the trucks that make their route (248 trucks at 400 kW charging power). The number of trucks depends on the charging power and can be seen in Figure 3b. 248 trucks require a maximum of 181 normal chargers and 61 fast chargers or a minimum of 67 fast chargers, see Table 2. By installing additional charging points, the entire truck fleet (all 279 trucks) in Berlin can cover its planned route. The number of additional charging stations is related to the charging power of the depot charger and is displayed in Table 3. The results show that the supply of food retailing stores using electric vehicles is possible in urban areas. Over 90 % of conventional trucks can be replaced by electrified trucks when recharging during the day at the depots is applied. We show that 67 fast charging points with 400 kW charging power would be needed in the depots. The analysis shows that with a good occupancy rate, about four trucks can use a single charging point overnight. Even with a higher charging power of over 600 kW, the number of charging stations cannot be further reduced because it is limited by the charging stations that are needed simultaneously during the day. The difference of 6 chargers is the result of several depots that do not need fast charging during the day (because the tours starting from these depots are rather short) but still need chargers for over night charging. Charging stations with a power of over 400kW would therefore be over-dimensioned. Chung [4] comes to a similar conclusion in his analysis. Since the case study of the food retailing in Berlin contains some really long routes, state of the art BEV-technology cannot complete these tours, even with intermediate charging at the depot. This explains the permanent deviation in Figure 3b. By setting up a further 31 HPOCs in public places, all electrified trucks could manage their route. 400 kW charging power is also sufficient for these stations if a 30-minute charging stop is planned. However, this would mean that the trucks that have an extra charging stop would end their tours up to 30 minutes later. Other than the charging during loading times, these extra 30 minutes would be unproductive time.



(a) SOC of all trucks over the day with 400 kW charging power

(b) Percentage of vehicles that can be charged with specific charging power

Fig. 3: SOC analysis of all trucks with depot charging only

Table 2: Resulting number of chargers for the different charging strategies

	Trucks	Normal charger	Fast charger	HPOC
Maximum (used by only one vehicle overnight)	248	187	61	-
Minimum (400 kW charger used by multiple vehicles overnight)	248	-	67	-
Maximum with additional charger (used by only one vehicle overnight)	279	214	65	31
Minimum with additional charger (400 kW charger used by multiple vehicles overnight)	279	-	71	31

Table 3: Additional HPOCs depending on the charging power

Charging power depot charger [kW]	200	400	600	800
Number of HPOCs	36	31	27	27

5. Conclusion and Outlook

We presented a methodology to determine possible charging strategies for urban freight transport. Therefore, we provided current literature on charging and transport simulation. We analyzed the MATSim case study on the food retailing industry and found that with 31 HPOCs all tours can be operated. In the depots, 214 normal combined with 65 fast charging points are sufficient to charge the trucks. If the vehicles share the charging points overnight, this number is reduced to 71 fast charging points with 400 kW. With higher charging power, the share of fully charged vehicles hardly increases. Due to the large variance in route lengths, the results of the case study can be representative for the entire delivery traffic. Berlin can be seen as the ”worst case” of an urban region due to its large extension compared to other European cities. Our results show that the electrification of the food trade is technically feasible and that the charging can be performed with a high number of normal chargers combined with a few fast chargers. Additionally, our results show that only a few additional fast chargers are sufficient to serve the energy demand of the fleet, without any normal chargers. Fast charging in the depot is sufficient for most routes of urban freight traffic. However, it is necessary to consider the economic side, which was not taken into account in this analysis. This could be investigated in detail with a Total Cost of Ownership analysis. For even better performance, the next step is to consider the ranges of the truck types in the MATSim model using the range constraint presented in [5] in combination with the here presented method to determine adequate charging strategies. It is expected that the number of trucks and thus also the number of charging stations will increase slightly, since the 9 % of trucks that would currently not be able to complete their route, will be distributed among several trucks.This way however, the unproductive recharging time at HPOCs could be avoided. Further research should investigate the limits of electrification, e.g. by running scenarios with BEVs with a higher battery capacity, even if this results in less payload due the higher weight of the batteries. This could be extended by running the electrification scenarios with electric trucks with different battery capacities for each vehicle type. The presented method is transferable to various transport sectors. MATSim scenarios including for example personal commercial transport could be analyzed as well.

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