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Assessing the cost-optimal mileage of medium-duty electric vehicles with a numeric simulation approach

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ABSTRACT

Electric freight vehicles have the potential to mitigate local urban road freight transport emissions, but their numbers are still insignificant. Logistics companies often consider electric vehicles as too costly compared to vehicles powered by combustion engines. Research within the body of the current literature suggests that increasing the driven mileage can enhance the competitiveness of electric freight vehicles. In this paper we develop a numeric simulation approach to analyze the cost-optimal balance between a high utilization of medium-duty electric vehicles – which often have low operational costs – and the common requirement that their batteries will need expensive replacements. Our work relies on empirical findings of the real-world energy consumption from a large German field test with medium-duty electric vehicles. Our results suggest that increasing the range to the technical maximum by intermediate (quick) charging and multi-shift usage is not the most cost-efficient strategy in every case. A low daily mileage is more cost-efficient at high energy prices or consumptions, relative to diesel prices or consumptions, or if the battery is not safeguarded by a long warranty. In practical applications our model may help companies to choose the most suitable electric vehicle for the application purpose or the optimal trip length from a given set of options. For policymakers, our analysis provides insights on the relevant parameters that may either reduce the cost gap at lower daily mileages, or increase the utilization of medium-duty electric vehicles, in order to abate the negative impact of urban road freight transport on the environment.

1. Introduction

Electric freight vehicles have been proposed as a measure to reduce the air pollutant emissions from transport and achieve carbon dioxide-free city logistics by 2030, as envisioned by the European Commission (2011). However, the numbers of electric vehicles operated by logistics companies remain marginal, despite the recent bans on combustion vehicles in some Asian and European cities due to overstepped air pollutant threshold limit values, and despite growing corporate environmental responsibility (CER) activities in the transport sector.

One of the main barriers for the companies are the higher costs of an electric vehicle (EV), compared to a conventional vehicle with an internal combustion engine (ICEV) (Amburg and Pitkanen, 2012; Kley et al., 2011; Taefi et al., 2015). Due to the expensive battery, the purchase price of an EV is about twice as high as a conventional vehicle, while operational costs are usually less expensive. For this reason, total cost of ownership (TCO) calculations suggest that a key variable to determine the competitiveness of

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electric freight vehicles is their utilization (Feng and Figliozzi, 2013; Lebeau et al., 2015b; Lee et al., 2013).

A possible option to achieve a high mileage is to recharge the electric freight vehicles during or between shifts to extend their daily reach. On the downside, recharging the EV leads to more frequent battery replacements. Hence, the time and number of battery replacements have to be considered in TCO calculations, as they can impair the competitiveness of the electric freight vehicle (Feng and Figliozzi, 2013; Lebeau et al., 2015b; Lee et al., 2013).

However, the existing literature does not provide a conclusion on the optimal balance between EV utilization and the necessary battery replacements. A more detailed understanding of the energy model of the EV regarding TCO and electric vehicle routing problems (EVRP) is required (Afroditi et al., 2014; Conti et al., 2015; Cauwer et al., 2015; Lebeau et al., 2015a). While first energy models exist in EVRP, they have not been applied in TCO calculations and the scientific evidence on the realistic energy consumption of medium-duty EV types is scarce.

The aim of the present work is to fill in the described gaps and deliver a generic vehicle-centered cost analysis to answer the questions:

- Which average daily mileage is the most cost-efficient for a certain EV model compared to a similar diesel model?
- What are the main parameters that influence the cost efficiency?

Our work may provide the basis for enhancing utilized energy models of existing TCO and EVRP calculations. Furthermore, our model may help practitioners in deciding on a suitable freight EV model or finding the most competitive operational profile for their existing freight EV types. Finally, our results indicate which parameters are most relevant for policymakers to possibly subsidize the purchase or the operation of electric freight vehicles.

The remainder of this manuscript is structured as follows: Section 2 presents the related literature and details the research gaps and available knowledge in the related scientific disciplines. Section 3 describes the TCO calculation and sets up an energy model. The utilized real-world energy consumption and results of the TCO calculation are detailed in Section 4 and they are supplemented by applying a linear regression. The results are discussed in Section 5. Finally, Section 6 draws conclusions of the work.

2. Background

Energy (or fuel) consumption is a sensitive parameter in TCO calculations (Feng and Figliozzi, 2013; Lee et al., 2013), but field data on the realistic energy consumption of electric freight vehicles are still scarce, as detailed in Section 2.1. Due to the missing data, the energy consumption is incorporated differently throughout TCO studies. Parameter values are either taken from manufacturer's data sheets (Section 2.2), or they are calculated by applying real-world travel speed profiles or drive cycles (Section 2.3). In order to detect the most cost-efficient mileage of an EV, the TCO at various driven mileages up to the possible maximum have to be determined and compared to those of an ICEV. In existing TCO calculations, usually a fixed daily mileage within the range of an EV is assumed and subsequently varied in a local sensitivity or elasticity analysis. For the medium-duty EV, to the best of our knowledge the process of battery recharging has received no attention in TCO calculations and only some attention in EVRP calculations. Thus, the fringe effects that occur at very high mileages are not yet fully implemented in the energy models of the calculations (Section 2.4).

2.1. Deviation between data sheet and real-world energy consumption of EV models

Field tests suggest that the realistic energy consumption of electric freight vehicles can deviate from the values reported by the vehicles' manufacturers, as utilized in the TCO calculations above, but scientific evidence is scarce. A real-world test in the US with a total of 530 medium-duty electric vehicles of two types delivers an average energy consumption of 0.52 kW h/km (Navistar eStar) and 1.15 kW h/km (Smith Electric Newton) (Prohaska et al., 2015). However, the authors indicate in the supplementary material that these figures cover multiple vehicle configurations, in multiple environments, topologies, and load profiles and hence are an average that cannot be used to predict the efficiency of any particular vehicle.

A better comparability between the values given by the manufacturer and realistic energy consumption can be drawn if a specific vehicle is tested according to a standard test procedure. In Europe and China, the energy consumption of any passenger car (EV or conventional) is measured by a dynamometer test defined in UN ECE-R101 based on the New European Drive Cycle (NEDC). Commercial freight vehicles (EV or ICEV) are tested on the road according to German standard DIN 70030-2.

European studies that compare the real-world energy consumption of passenger vehicles to the value measured by the NEDC find the following deviations: The study of Cauwer et al. (2015) in Belgium finds that the real-world energy consumption of a small electric delivery van, the Renault Kangoo ZE, deviates by 48% from the energy consumption according to the NEDC. This result is similar to the outcome of a field test evaluating 200 electric passenger cars over a two-year period in Denmark (Fetene et al., 2016), where the EV consumed on average 46.6% more energy than indicated by the manufacturer's data sheets. As a consequence, our study will correct the energy consumption of the EV by 45%, in the case where the data sheet values are based on NEDC measurements.

The first models have been developed to describe the energy consumption of electric passenger cars and an overview of the past studies is provided for example by Zhang and Yao (2015). Electric freight vehicles differ from electric passenger cars since the amount of loaded cargo is an additional factor influencing the energy consumption. Hence, additional empirical evidence on the realistic consumption of the medium-duty EV is required and reported on in this study.