Proceedings of the Hamburg International Conference of Logistics (HICL) – 24

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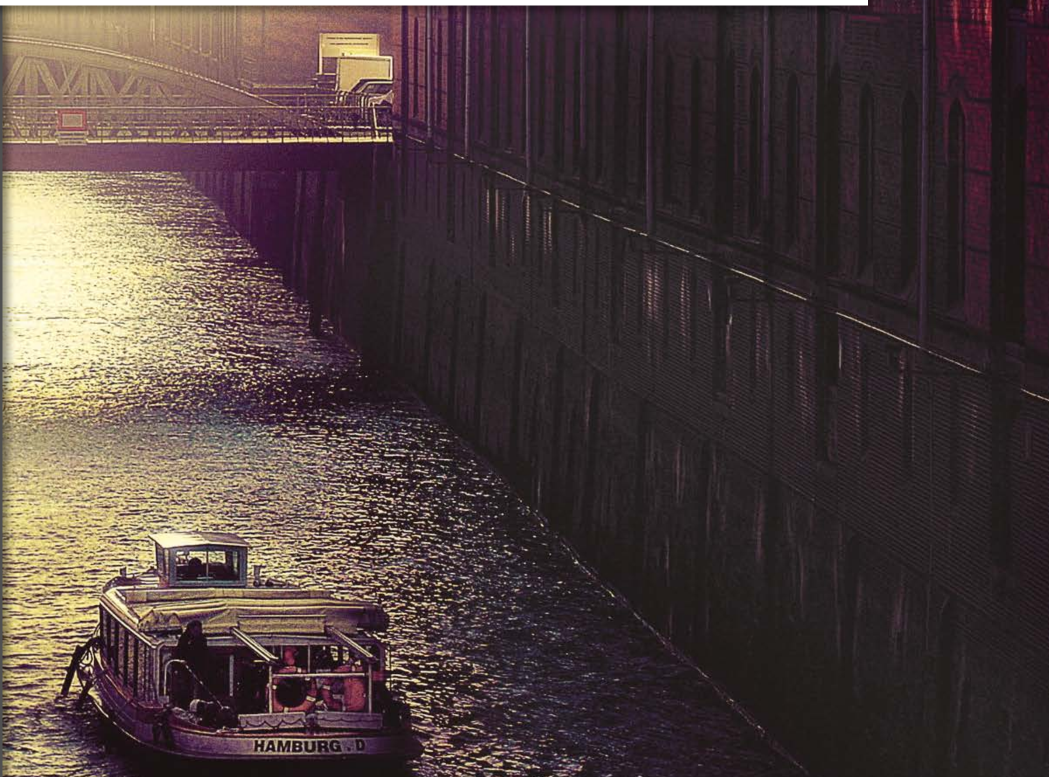

Published in: Digitalization in Maritime and Sustainable Logistics
Carlos Jahn, Wolfgang Kersten and Christian M. Ringle (Eds.)
ISBN 9783745043327, Oktober 2017, epubli

Utility Evaluation of Battery Electric Vehicles in Urban Distribution

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*Utilizing battery electric vehicles in daily distribution operations of logistics service providers and freight forwarders goes along with major uncertainties for companies. There is no mechanism how to evaluate the technical and economical use of battery electric vehicles in companies use cases and processes in status quo in contrast to vehicles with an internal engine. This paper adopts an evaluation mechanism from literature, which is bases on a value benefit analysis with compensation factors, and applies this evaluation model to three real life use cases of a renowned logistics service provider with worldwide activities and strong business in road-bound transportation of palletized goods for B2B and B2C customers. The results of the evaluation showed that a substitution of vehicles with internal combustion engines with battery electric vehicles is not an applicable approach. The evaluation shows, that using battery electric vehicles in distribution generates only 41% (*3.5 t *vehicles) respectively 34% (*7.5 t *trucks) of the benefit value as using conventional vehicles with internal combustion engine. The results of the evaluation confirm, that not parameters of range and the operating costs, but parameters of payload and the vehicle asset costs are determining the utility evaluation in distribution use cases. In fact planning of distribution operations need to be adapted to the specific performance parameters of battery electric vehicles. The presented evaluation model in this paper can identify the fields of action, in which a company needs to adapt existing distribution activities.*

Keywords: Evaluation; Distribution; Electric Vehicle; Logistics

1 Evaluation of the utilization of electric vehicles in day-to-day operations of a logistic service provider

Demand and requirements for the distribution of goods, in particular in urban areas, are changing with increasing speed. Ongoing globalization, shorter product life cycles, urbanization and new technologies are drivers of this development. In addition, the growing importance of e-commerce, increased customer demand for fast, flexible and high quality delivery, as well as an increasing environmental awareness in the society is fostering current challenges in distribution. Increasing regulation in cities targeting the reduction of noise, CO_2 and fine dust emissions are completing the set of new circumstances for distribution operations in logistics. These frame conditions are creating an increasingly complex and dynamic environment in the transport sector. Against this background electric vehicles are considered to be a key technology for climate friendly mobility. The wide use of electric vehicles in the transport sector is seen as an instrument for reducing greenhouse gas emissions emitted by traffic, which have a current share of 14% on the global greenhouse gas emissions (IPCC, 2014). Given the continuous increase in freight traffic in Germany, which is estimated to increase by 38 percent by 2030, the importance of a reduction of greenhouse gas emissions is essential to meet national and international climate protection targets (BMVI, 2014). Hence, the utilization of electric vehicles in distribution operations has a significant for logistics service providers and freight forwarders to overcome the mentioned challenges, in particular in urban areas. But, using electric vehicles currently implies various uncertainties for companies in both, economic and technical terms. Logistic service providers and freight forwarders face the challenge to evaluate in which use cases in distribution operations the utilization electric vehicles goes along with economic and technical advantages or at least similar performance as vehicles with internal combustion engines.

2 Methodology

In order to evaluate the technical and economical impact of the usage of battery electric vehicles in distribution operations a model, tailored to access individual use cases, was developed. The theoretical foundation was taken from literature and adopted to consider all aspects of various use cases of a renowned logistics service provider with worldwide activities and strong business in road-bound transportation of palletized goods for B2B and B2C customers. The evaluation model is based on a value analysis which is extended by compensation factors (Schöder, 2017, p. 40 ff). The evaluation model of Schöder is the up-to-date approach in literature regarding a standardized procedure for evaluating the utilization of battery electric vehicles in individual use cases in distribution. Other publications are evaluating the benefit value of electric vehicles in regard to customer demand (Kreyenberg et.al., 2013; Hoffmann et.al., 2012), the benefit value of electric vehicles in regard to ancillary services (Rehtanz, Rohling, 2010), or have a narrow focus on economical aspects (Hacker et.al., 2015) or ecological aspects (Held et.al, 2016). Schöder's model is the only approach combining both, a technical and economical evaluation in regard to logistics operations in distribution. However, this existing approach for evaluation is a general model, applicable to various use cases in distribution logistics (including CEP). The model developed in this paper takes the approach from Schöder and adjusted it to the special use case of distribution of palletized goods.

The underlying method of the model is a vale benefit analysis according to Zangemeister (Zangemeister, 1971). In addition, the standard value benefit analysis approach was extended by compensation factors according to Bárdossy (Bárdossy et. al., 1985). The model produces a utility value for electric vehicles on the first target level. Conventional diesel powered vehicles were used as the reference standard for determining the benefits of battery electric vehicle use. On the second target level the model takes performance parameters, economic parameters and ecologic parameters into account. On the third target level performance parameters were divided into performance requirements and payload requirements of the battery electric vehicle. On the same level the economic parameters are divided into fixed and variable costs, as well as the ecologic parameters, which are divided into emissions and customer demand for sustainable transportation. For the last named parameters, there was no further breakdown into parameters on the fourth target level. However, all other mentioned parameters on the third level were broken down to final evaluation parameters on the fourth target level. Performance requirements were fragmented into range parameter and charging time parameter. For the payload no further fragmentation was done, too. The fixed costs on the third target level were subdivided into vehicle asset costs (costs of purchase for the vehicle) and infrastructure asset costs (charging respectively fueling infrastructure). The variable costs were subdivided in the same way into use case dependent operating costs (dependent on required range per day, fuel or kWh consumption and fuel respectively kWh costs) and vehicle dependent

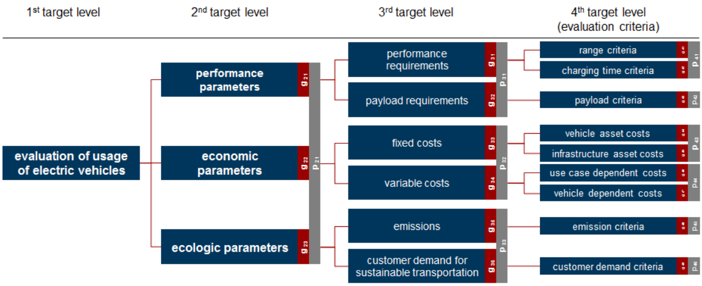

Figure 1: Target system of the value analysis model

operating costs (tax, insurance). Figure 1 visualizes the structural set up of the target system of the adjusted value analysis according to the literature.

The aggregation of values of each section is processed by using weighting factors (g) and compensation factors (p) on each target level. The weighting factors on the second target level are determined by the user of the model, as well as the weighting factors g_{31} and g_{32} on the third target level. The reason for that is that the weighting of these parameters in the target system depends on individual conditions of the use case and the company applying the model. All other weighting factors of the model are set as basic setting and are the same in every use case. All weighting factors in summation of one functional group of parameters have to be 1 (see formula 1; Schöder, 2017, p. 16, 44-47).

$$1 = \sum_{j=1}^{n} g_j \tag{1}$$

$g =$ weighting factor
$j =$ indicators
$n =$ total number of all considered criteria j

The settings of all weighting factors of the model are shown in table 1. All set values were validated with decision makers and managers from a renowned German

Table 1: Weighting factors

weighting factor	value	explanation
g_{21}	-	individual user input to the model
g_{22}	-	individual user input to the model
g_{23}	-	individual user input to the model
g_{31}	-	individual user input to the model
g_{32}	-	individual user input to the model
g_{33}	0,5	basic setting of the model
g_{34}	0,5	basic setting of the model
g_{35}	0,5	basic setting of the model
g_{35}	0,5	basic setting of the model
g_{41}	0,8	basic setting of the model
g_{42}	0,2	basic setting of the model
g_{43}	1	basic setting of the model
g_{44}	0,7	basic setting of the model
g_{45}	0,3	basic setting of the model
g_{46}	0,9	basic setting of the model
g_{47}	0,1	basic setting of the model
g_{48}	1	basic setting of the model
g_{49}	1	basic setting of the model

logistics service provider. The weighting factors of the second (and partially of the third) target level cannot be presented within this paper, due to the confidentiality of these information. Nevertheless, they were elevated and used for conducting the evaluation.

The purpose of the usage of compensation factors in the model is to countervail the major weakness of the value analysis. That disadvantage of a pure value analysis model is that – despite the use of weighting factors – the value of a parameter can be compromised in the course of aggregation of values between the target levels of the target system (Bárdossy et. al., 1985, p. 375 ff). An advantageous value of one factor can compensate a less advantageous value of a second factor, due to the given formula for aggregation in value analysis according to Zangemeister (Zangemeister, 1971; Schöder, 2017, p. 18).

$$N_{i \;\; 1} = \sum_{j=1}^{n} g_{ij} e_{ij} \tag{2}$$

$N =$ value of benefit

$e =$ value of evaluation

$g =$ weighting factor

$i =$ considered target level

$j =$ indicators

$n =$ total number of all considered criteria j

Thus, the compensation factor was introduced. One compensation factor applies for the entire functional group of parameters on a certain target level. A compensation factor with the value 1 has no effect and will result in the same outcome as formula 2. Every value of a compensation factor > 1 will defang the degree of compensation between the aggregated factors. A compensation factor > 6 will have the same mathematical outcome as a compensation factor of infinite value, meaning that in the aggregation of 1+x parameters the lowest value of evaluation of one factor will fully determine the value of benefit (Schöder, 2017, p. 60-65). Therefore the new formula for aggregation of value analysis with compensation factor can be described as seen in formula 3.

$$I_{i \;\; 1} = 1 \quad \sqrt[p]{\sum_{j=1}^{n} g_{ij} (1 \quad e_{ij})^p} \tag{3}$$

$I =$ value of indication (similar to value of benefit)

$e =$ value of evaluation

$g =$ weighting factor

$i =$ considered target level

$j =$ indicator

$n =$ total number of all considered criteria

$p =$ compensation factor of a functional group

Table 2: Compensation factors

compensation factor	value
p21	5
p31	5
p32	2
p33	1
p41	1,2
p42	1
p43	2
p44	1
p45	1
p46	1

The settings of all compensation factors of the model are shown in table 2. All set values were validated with decision makers and managers from a renowned German logistics service provider.

The value of evaluation, meaning the value of the evaluation criteria on target level four, is created by using target functions. Target functions can transform values with dimension (such as km, h, Euro etc.) into values without a dimension. A basic assumption of this model is that all target functions have a linear developing graph. All in course of the development of this model used target functions were linearly interval functions. Furthermore, the developed target functions were referencing to diesel technology vehicles. In addition the values of evaluation of diesel technology vehicles were fixed to a degree of performance of 70%. By doing so, evaluation results of electric vehicles can be above or under 70%. The theoretical concept of a target function is shown in figure 2 (Schöder, 2017, p. 17).

The detailed data for the individual target functions, which were developed for the evaluation of the utilization of electric vehicles in use cases of a renowned German logistics service provider were shown in table 3.

The value of the parameters range, charging time, payload and vehicle asset costs was researched by literature review and were presented in table 5 (Orten, 2017; Nissan, 2017, Forium, 2017; Mobile, 2017). Further input factors of the model, such as the requirements for the use cases and the assessment of the customer demand for sustainable transportation, were surveyed with representatives of

Table 3: Information of the individual target functions

target function	degree of performance (y-axis)	interval points value of the evaluation criterion (x-axis)
range	0	use-case minimum requirement * 0,9
	50	use-case minimum requirement
	100	use-case maximum requirement
charging time	0	duration diesel vehicle * 3,1
	50	duration diesel vehicle * 3
	100	duration diesel vehicle
payload	0	payload diesel vehicle * 0,5
	50	payload diesel vehicle * 0,75
	100	payload diesel vehicle
vehicle asset costs	0	asset costs diesel vehicle * 2
	75	asset costs diesel vehicle
	100	asset costs diesel vehicle * 0,5
infrastructure asset costs	0	infrastructure asset costs diesel vehicle * 3
	100	infrastructure asset costs diesel vehicle
use case dependent costs	0	use case dependent costs diesel vehicle * 2
	75	use case dependent costs diesel vehicle
	100	use case dependent costs diesel vehicle * 0,5
vehicle dependent costs	0	vehicle dependent costs diesel vehicle * 2
	75	vehicle dependent costs diesel vehicle
	100	vehicle dependent costs diesel vehicle * 0,5
emissions	0	Euro 4 norm
	75	Euro 5 norm
	100	Euro 6 norm
customer demand for sustainable transportation	0	1 on a Likert scale from 1 to 7
	100	7 on a Likert scale from 1 to 7

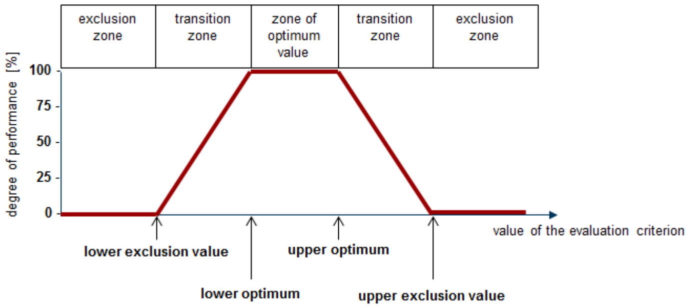

Figure 2: Theoretical concept of a target function

reowend German logistics service provider. Formulas for how to generate model input values for the parameters infrastructure costs, use case dependent costs, vehicle dependent costs and emissions were taken from literature (Schöder, 2017, p. 47-60).

3 Findings

Using the presented target system, formula for aggregation, weighting factors, compensation factors and target functions, the evaluation for the use cases of a …

- 3.5 t transporter in CEP local distribution
- 7.5 t truck in general goods rural distribution
- 7.5 t truck in general goods urban distribution

… was conducted.

The requirements of the evaluated use cases, which the surveyed logistics service provider sets, are shown in table 4. In addition, table 5 gives an overview over the used basic input parameters, needed for the used formulas. Moreover, table 6 informs about all additional information needed for the evaluation.

Table 4: Requirements of the use cases

requirement	value
range requirement CEP local distribution	150 km to 250 km
range requirement 7.5 t urban distribution	150 km to 200 km
range requirement 7.5 t rural distribution	300 km to 350 km
payload requirement CEP local distribution	1.8 t
payload requirement 7.5 t urban distribution	2.5 t
payload requirement 7.5 t rural distribution	2.5 t
charging time requirement CEP local distribution	10 min to 360 min
charging time requirement 7.5 t urban distribution	5 min to 360 min
charging time requirement 7.5 t rural distribution	5 min to 360 min

Table 5: Basic input parameters

parameter	3.5 t diesel vehicle	3.5 t battery electric vehicle	7.5 t diesel vehicle	7.5 t battery electric vehicle
vehicle asset costs	35 000 €	29 878 €	48 000 €	170 000 €
service life	36 month	36 month	36 month	36 month
value after service life	60%	30%	60%	30%
insurance costs	1500 €/a	1500 €/a	1800 €/a	1800 €/a
maintenance costs	5040 €/a	2400 €/a	5040 €/a	2400 €/a
range	1085 km/ 80 l	160 km/ full cycle	1500 km/ tank	100 km/ full cycle
charging time	2 min	330 min	5 min	360 min
consumption	7.3 l/ 100 km	16.5 kWh/ 100 km	15 l/ 100 km	72 kWh/ 100 km
vehicle tax	300 €/a	300 €/a	487 €/a	487 €/a
payload	1.2 t	695 kg	3 t	2.4 t

Table 6: Additional information for the evaluation

parameter	value
operation days per anno	250 days
average useful life	36 month
diesel price	1.12 €/l
electricity price	20 € Cent/kWh
price per charging point	1500 €
Euro 4 emissions	0.45 kg CO2e/km
Euro 5 emissions	0.3 kg CO2e/km
Euro 6 emissions	0.2 kg CO2e/km
tax-free years for battery electric vehicles	5 a

The results of the evaluation model have shown, that the functional ability of using battery electric 3.5 t vehicles in CEP local distribution is 29 value point (compared to 70 value points of a comparable diesel vehicle of the same class and in the same use case). Primary reasons for this result can be found in the evaluation of performance parameters, which had a value of benefit on the second target level of 21 value points. In particular payload and charging time requirements are not fulfilled and are producing a quite low value of benefit on the fourth target level of the model. In contrast, the evaluation of the economic parameters on the second target level was 60 value points, which is close to the 70 value points of a comparable diesel vehicle. Drivers of this evaluation score are the comparable vehicle asset costs of battery electric vehicles and diesel vehicles within the 3.5 t vehicle category. Furthermore, have major advantages regarding the use case dependent and vehicle dependent costs, due to the significant lower price of kWh compared to liters of diesel and subventions of vehicle taxes by the governmental administration in Germany. Regarding the ecological parameters and their value benefit in the model, the lack of customer demand for sustainable transportation is the major driver for the result of 70 value points on the second target level. Hence, the model could not state an ecological benefit value above the evaluation of comparable diesel vehicles. In result for the evaluation of this use case, due to the set, and company individual, weighting factors along the target levels and the set compensation factors, a usage of battery electric vehicles in CEP local distribution is not beneficial for companies.

The evaluation of the use case of 7.5 t trucks in general goods urban distribution results in 24 value points (compared to 70 value points of a comparable diesel vehicle of the same class and in the same use case) for battery electric vehicles. Reasons for this evaluation result can be found in the evaluation of the performance and economic parameters. The evaluation result of performance parameters on the second target level was 21 value points, due to the fact that range and charging time requirements of the use case are not fulfilled (0 value points on the fourth target level each). Only payload requirements were partially matched with 53 value points on the fourth target level (compared to 70 value points of the diesel vehicle). Regarding the economic evaluation results the model clearly showed, that – due to the 3.5 times increased vehicle asset costs of an electric 7.5 t vehicle – only 28 value points could have been scored. The high gap between the purchasing costs of an electric vehicle and an diesel vehicle (0 value points on the third target level) negated the advantageous evaluation of operating costs of battery electric 7.5 t vehicles on the third target level (83 value points compared to 70 value points of comparable diesel vehicles). The ecological evaluation result of a battery electric 7.5 t vehicle is 70 value points, which was identical to the 70 value points of diesel vehicles. On the fourth target level the emission parameter of the battery electric 7.5 t truck were evaluated with 89 value points, due to the reduced emissions and a trend to longer ranges per tour of this use case. Nevertheless, customer demand is negating this high value over the aggregation over the target levels to the mentioned 70 value points.

The evaluation of the use case of 7.5 t trucks in general goods rural distribution results also in 24 value points (compared to 70 value points of a comparable diesel vehicle of the same class and in the same use case) for battery electric vehicles. Both evaluation results of the urban and rural use case differed only in the required range of the vehicle. With 300 km to 350 km the range requirement in rural distribution with this vehicle category is slightly higher than in the urban use case. But since the evaluation of the range parameter on the fourth target level in urban distribution was already zero value points, the result in the rural distribution case is also zero value points. The evaluation of all other parameters is nearly identical and due to the aggregation formula – using weighting and compensation factors – the result of the evaluation of both use cases shows no difference.

Since 12 t battery electric trucks are not available on the market at the moment, an evaluation of 12 t electric trucks would be pure theoretical with too many uncertainties (especially regarding the vehicle asset costs and parameters like range and payload). For this reason the evaluation was not conducted, but will be – once these battery electric vehicles are available on the market.

4 Conclusions

The results of all evaluated uses cases makes it evident, that a substitution of currently used diesel vehicles in distribution operations by battery electric vehicles goes along with no benefits in technical and economical terms. Quite the opposite is the case; a substitution of diesel vehicles goes along with significant disadvantages for the company, regarding performance and cost structure of their distribution activities in all evaluated use cases. Hence, further technological improvements of the current battery electric technology of electric vehicles are needed, especially in the direction of improves range, shorter charging time and higher possible payloads. The conclusion from literature, that payload requirements are more important to fulfill as range requirements and that vehicle asset costs have a more significant impact on the evaluation results as vehicle and use case dependent operating costs have been confirmed by these research results (Schöder, 2017). Nowadays the gap between vehicle asset costs of battery electric vehicles and comparable diesel vehicles of the same vehicle category is decreasing, resulting in a trend towards balanced cost structures of both vehicle technologies and even advantages for battery electric vehicles. Furthermore, changes in design of current logistics processes in operative distribution and distribution planning open the possibility to increase the value score and the utilization evaluation of battery electric vehicles in distribution. The evaluation was processed in status quo of operative process chains. The possibilities, to implement changes within operative distribution processes have a strong potential to increase the utilization of electric vehicles. Adjustments of that kind should focus on reducing the required payload and decrease the required range per tour, for instance by redesigning distribution areas and tours. In addition longer and more regular time slots at the logistics provider's facilities can help to overcome current challenges regarding long charging times of battery electric vehicles. In order to keep the number of deployed trucks on the same level, redesigning distribution processes by implementing multi-shift operations (two driver shifts per vehicle) could be an option. And last, but most important, increasing the customer demand for sustainable transportation – best if the customer is even willing to pay for it – is critical in order to utilize battery electric vehicles in distribution on a larger scale. Therefore, further research should focus on empirical evaluations on customers demand and expected changes in regulation by the authorities. This further research should focus to the question: How to turn the customer (B2B and B2C) into a pull-factor for sustainable transportation? Applying battery electric vehicles in distribution only makes sense, if the customer demands that kind of transportation or if basic circumstances of regulation by the authorities were making the use of battery electric technology mandatory for logistics service providers and freight forwarders.

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