EVS27
Barcelona, Spain, November 17-20, 2013

Insight in actual operational costs of Electric Transport; A method to get increasing insight in actual costs of electric vehicles in Rotterdam "on the road".

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Abstract

Cost-effectiveness is extremely important for the success of electric road transport.

At the Rotterdam University of Applied Science a cost model was developed that uses a Functional Unit (FU) to create the possibility to objectively compare operational costs (TCO) of Electric Vehicles (EV) with Internal Combustions Engine Vehicles (ICEV). Four studies on different EVs were conducted in practice over a period of several years to get insight in the actual costs "on the road". The cost model includes the important costs of Operation; like maintenance and energy. Because these cost aspects influence the Total Cost of Operation of EV radically.
With the cost model the operational costs of electric road transport can be calculated, estimated and thus compared with the total costs of function fulfilling of both EV and ICEV. Additionally it becomes possible to optimize the costs of road transport in Rotterdam with Electric Vehicles EV.

Keywords: Costs, Functional Unit, Total Costs of Operation, EV, ICEV

1 Introduction

The success of electric road transport is based on the number of electric vehicles (EV) sold. The purchase and B2B-sale of EV mainly depends on the costs of ownership. The operational costs of electric transport can be calculated, estimated and compared with the costs of Internal Combustion Engine Vehicles (ICEV). It should also be possible to optimise the operational costs of EV transport. This can be concluded from the results of the eMobility-Lab research of the Rotterdam University of Applied Sciences, which focuses on research in practice. Cost-effectiveness is extraordinary important for success of electric road transport.
The preliminary research-questions of the eMobility-Lab aim at getting insight in:

What are the actual costs of electric vehicles "on the road" in Rotterdam? and
Is it possible to optimize the operational costs of EV road transport in Rotterdam?

2 Method

2.1 Model

To get answers on the above mentioned research-questions a cost model was applied. This cost model is especially designed for EV but flexible regarding the application, as it calculates with a practice based, applicable Functional Unit (FU). For instance the following 4 practical Functional Units were used in the research:
1st Collecting of 30 tons business waste per week in the inner-city of Rotterdam for a period of 10

years; in Rotterdam inter alia fullfilled with the Ecotruck.

Figure1: Ecotruck 7500

2nd The transport of an average number of passengers on the Rotterdam RET-bus route 46 during 8 hours per day for a time period of 10 years; in Rotterdam inter alia fullfilled with the e-Busz.

Figure2: e-Busz

3rd The B2B transport of 2 persons and 50 kg luggage in the inner-city of Rotterdam with a daily-range of maximal 90 km for a period of 8 years; in Rotterdam inter alia fullfilled with the Spijk-e.

Figure3: Spijk-e

4th The transport of 2 persons and 50 kg luggage in a roadster in the Rotterdam region with a average speed of 20 km/hour and a maximum speed of 100 km/h and with a daily-range of maximal 100 km for a period of 7 years; in Rotterdam inter alia to be fullfilled with the GTZero.

Figure4: HR GTZero

2.2 Functional Unit FU

In B2B the application of an applicable Functional Unit FU is essential, as business is generally focused on optimal satisfaction of needs. Those needs can be clearly described through the rate of “fulfillment of functions”. A fair comparison of different offers requires that a FU is formulated for a start.
This way of working makes it possible to compare the operational costs of B2B transport by means of Electric Vehicles EV to those by means of an Internal Combustion Engine Vehicles ICEV without ulterior motives.

2.3 Implementation

The studies into the cost-effectiveness of EV were performed by students and teachers in close cooperation with (representatives of) manufacturers, governments and users of EV. The results gathered can be applied in other crowded inner cities.

2.4 Other Models

Other cost models are mostly not based on a Functional Unit FU. The application of a usable FU makes it possible to compare costs of different function fulfillment in an objective and fair way.

2.5 Aspects in the Rotterdam Cost Model

The Rotterdam Cost Model takes several aspects into consideration, for instance the purchase costs (including the batteries), maintenance costs and energy costs. Also -self-evidently- insurance

costs, road-tax, depreciation costs and opportunity costs are considered. Conclusively the newly developed cost model includes all important costs of Operation (like maintenance and energy) that are crucial for EV. For that matter this method offers more usable insight into the total cost of operation than for instance the regular Total Costs of Ownership TCO.
The referred flexible cost model is shaped in EXCEL. This model is partially based on figures that may vary over time. Prices and/or cost, like for instance purchase prices of an Internal Combustion Engine Vehicle are not fixed nor rigid in negotiation. The Rotterdam-model gives the users the possibility to adjust the costs in the separate cells easily; and than recalculate the Total Costs of Operation TCO. Additionally it offers the possibility to try out the effect of assumptions and check the results.
Even if alterations to meet present data are not made, the model intends to give manufacturers and purchasers of such vehicles some insight in the magnitude of the operational costs related to the FU's to start with. This will add some objective information to contract negotiations.

3 Data

The data concerning the costs that were collected from practice, from public sources and from internet sites of manufacturers were not in all cases sufficient to fill the cost model adequately. Therefore, semi-structured interviews with informants were held. The informants were selected for their expertise and were asked to come up with some educated guesses and assumptions to complete the model. The argumentation supporting those guesses and assumptions were collected as well.

4 Continuation

4.1 Expectations about Maintenance

Lower maintenance costs seem to be an advantage to the Electric vehicles EV. This is because there is no need to perform the relatively costly periodical engine maintenance such as oil, soot and air filter replacement, revision of transmission, cylinders etcetera. Practical data about vehicles with the new electric propulsion is scarce.

However, information about comparable electric motors such as elevator motors shows that the maintenance costs are minimal. This concerns brushless permanent magnet motors that require no periodic maintenance or revision. Practice will need to prove this assumption for EV, which will take a longer period of time.

4.2 Environment

Except the Total Costs of Operation the environmental impact of electric vehicles on the Rotterdam roads might possitively influence the eventual succes of it. Use of electrical vehicles instead of ICEV changes the environmental impact considerably. These changes are not yet incorporated in the model, but the CO2 emissions were calculated and incorporated and can be found under the heading RESULTS-5.

5 Results

5.1 Results-1:

5.1.1 Total Costs of Operation TCO

Firstly, the students of the Rotterdam University of Applied Sciences, the Netherlands investigated the described 1st function fulfilling with the Ecotruck 7500. The energy consumption of this Ecotruck is measured in the Rotterdam practice. Including the cost of employees the results of this business case proved to be positive (see Table1).

1st Estimated costs of electric transport in Rotterdam based on the FU:
Collecting of 30 tons business waste per week in the inner-city of Rotterdam for a time period of 10 years.

Table1: TCO Ecotruck 7500

Ecotruck 7500 EV		Conventional garbage truck ICEV
Total Costs per Functional Unit	Price Difference	Total Costs per Functional Unit
€ 1.383.329,10	**€ - 108.006,90**	**€ 1.491.336,00**

The figures in the table have an illustrative purpose and should not be used outside this specific context.

5.1.2 Some interpretation of the results:

This favorable upshot was at that time totally unforeseen. Conventional garbage trucks are actually fully developed and are deployed for decades; the Ecotruck 7500 was new.

However the figures found made it possible to rethink the situation based on the function fulfillment; being the collecting of business waste in a inner-city. Among others is was possible to imbed a more effective design, cheaper employees with renewed logistics. The Ecotruck was the first application of an EV in the Netherlands where it became clear that there was a positive business case.

5.2 Results-2:

5.2.1 Total Costs of Operation TCO

Based on the positive business case with the Ecotruck 7500, a second investigation was undertaken by students of the same university: the function fulfillment with the e-Busz. The energy consumption of these innovative electric city buses in Rotterdam was monitored over a more than 15,000 km travel distance. The research was performed in close cooperation with the Rotterdam public transport company (RET), nevertheless there were some serious troubles with the monitoring due to unruly variables. Notwithstanding those irregularities, this business case showed an interesting difference in Total Costs of Operation in function fulfillment in FU between EV and ICEV (see Table2).

2nd Estimated costs of public transport in Rotterdam based on the FU:

The transport of an average number of passengers on the Rotterdam RET-bus route 46 during 8 hours per day for a time period of 10 years.

Table2: TCO City Bus

Electric City Bus (e-busz)		Conventional City Bus ICEV
Total Costs per Functional Unit	Price Difference	Total Costs per Functional Unit
€ 785.275,63	**€ - 95.369,50**	**€ 880.645,13**

The figures in the table have an illustrative purpose and should not be used outside this specific context.

5.2.2 Some interpretation of results:

Also this upshot was surprising. The explanation for this difference might be found in the direct drive of the e-Busz that works with build in energy saving wheel hub motors. The main difference between such a system and a conventional traction system is the absence of a driveline. In a conventional system the power from the diesel engine is transferred from the engine through the driveshaft, gearbox and differential to the wheels, which is a lot more complicated and more expensive to maintain than the wheel hub motors. Furthermore the latter also efficiently uses regenerative braking energy (> 20%).

5.3 Results-3:

5.3.1 Total Costs of Operation TCO

Following the e-Busze experiment, subsequent student of the same university focussed on the function fullfilment of the Spijk-e. Because this vehicle is only recently available figures form practice in Rotterdam are not available yet, nevertheless some estimated guesses are made on the energy consumption in practice (see Table3).

3rd Estimated costs of electric transport in Rotterdam based on the FU:

The B2B transport of 2 persons and 50 kg luggage in the inner-city of Rotterdam with a daily-range of maximal 90 km for a period of 8 years.

Table3: TCO Spijk-e

Spijk-e EV		**Conventional car** ICEV
Total Costs per Functional Unit	Price Difference	Total Costs per Functional Unit
€ 37.309,45	**€ - 6.527.61**	**€ 43.837,06**

The figures in the table have an illustrative purpose and should not be used outside this specific context.

5.3.2 Some interpretation of results:

The Spijk-e is fully new on this market/Functional Unit FU. The batteries can be leased; which lowers the purchase cost; and thereby the amount of (additional) costs of redemption and financing.

5.4 Results-4:

5.4.1 Total Costs of Operation TCO

On the basis of the above mentioned studies and results students of the Rotterdam University of Applied Sciences drafted the TCO of the HR GTZero (see Table4). This roadster was conceived, designed, engineered, calculated and build by a multi-disciplinair studentteam of the Rotterdam University (HR). As the on site emission is Zero the car is named HR GTZero.

4th Estimated costs of electric transport in Rotterdam based on the FU:

The transport of 2 persons and 50 kg luggage in a cabrio trolly tour in the Rotterdamregion with a average speed of 20 km/hour and a maximum speed of 100 km/h and with a daily-range of maximal 100 km for a time period of 7 years.

Table4: TCO HR GTZero

HR GTZero EV		**Conventional Cabrio** ICEV
Total Costs per Functional Unit	Price Difference	Total Costs per Functional Unit
€ 32.020,27	**+€ 1.072,19**	**€ 30.948,08**

The figures in the table have an illustrative purpose and should not be used outside this specific context.

5.4.2 Some interpretation of results:

The GTZero was recently developed and was put on licence to drive the roads in June 2013. Students used their provisional figures in the Rotterdam TCO-model. By doing so a clear insight was obtained in the uncertainties in the cost structure of the selected function fulfillment. Further evaluation remains necessary. It is to be expected that the TCO of the special designed full electric GTZero are higher than the TCO of a

Table5: Impression of detailed TCO calculation

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Versie 1.00
6-6-2013

Het TCO-kostenmodel is gebaseerd op de volgende functionele eenheid (FU):
"Het zelfbouwen zonder uitbesteed werk en het vervoeren van maximaal twee inzittenden in een tourwagen(cabrio)en maximaal 50 kg bagage in Rotterdam gedurende 7 jaren met een gemiddelde snelheid van 20 km/h en een maximaal snelheid van 100 km/h en een afgelegde afstand -zonder bijladen- van 100 km/dag."
Scenario= Zelfbouw zonder uitbesteed werk
(Non optionele uitvoering)

Kilometer per dag	100
Aantal rijdagen per jaar	90
Kilometrage per jaar	9000
Looptijd in jaren	7

Burton versies, zonder optionele accesoires	HR GTZero	Burton Petrol	Burton Electric
Investeringskosten (inclusief uitbestedingskosten)	€ 27.560,79	€ 15.764,51	€ 31.403,72
incl. BTW			
Ontwikkelingskosten	€ -	€ -	€ -
Uitbestedingskosten maximaal	€ 2.792,35	€ 1.668,35	€ 1.793,35
Maandelijkse kosten			
Afschrijving	€ 269,05	€ 153,89	€ 306,56
Aflossing	€ 65,62	€ 37,53	€ 74,77
Verzekering	€ 5,00	€ 15,00	€ 5,00
Onderhoud	€ 4,73	€ 9,08	€ 4,73
Elektriciteit	€ 73,72	€ -	€ 71,31
Wegenbelosting	€ -	€ 7,00	€ -
Brandstof	-	€ 169,95	€ -
Overige kosten	€ 10,42	€ 2,92	€ 10,42
Restwaarde			
Voertuig	€ 4.960,94	€ 2.837,61	€ 5.652,67
Batterij	€ 806,61	-	€ 806,61
Total Cost of Ownership			
	€ 32.020,27	€ 30.948,08	€ 35.498,12
Kosten per maand	€ 381,19	€ 368,43	€ 422,60
Kosten per jaar	€ 2.668,36	€ 2.579,01	€ 2.958,18
Kosten per kilometer	€ 0,5083	€ 0,4912	€ 0,5635

Petrol cabrio. Table5 gives an impression of a detailed overview of a TCO-summary of this HR GTZero made by students that serves as a basis for this assumption. But the flexible cost model gives the possibilities to easily apply other assumptions and moreover to observe how such actions influence the final results.

5.5 Results-5:

5.5.1 Comparing CO2-emissions from Well-to-Wheel (city buses)

A standard diesel bus uses 40 L diesel/100km. The CO2-emissions from diesel are Well-to-Tank 13,6 g CO2-eq/MJ [3] and Tank-to-Wheel 73,25 g CO2-eq/MJ [4]. In the study with the RET, the Green Certificate from the Hydro Power stations in Norway were used which refers to 5 g CO2 eq/kWh for the Well and 5,5 g CO2eq/kWh for Well-to-Tank [1]. The EU-25 mix is considered to have an emission of 380 g CO2eq/kWh [2] for the Well and 400 g CO2eq/kWh for Well-to-Tank.

The overall avoided CO2-eq. during the test period (distance 16828 km) of the e-Buszes in the innercity of Rotterdam is 16,9 ton. When the range extender is left out and the EU-25 Power Station mix is used an the avoided CO2-eq. will be 63 kg /100 km.

[1] G.J. van de Vreede en M.I. Groot, Ketenemissie hernieuwbare elektriciteit, CE, Delft, April 2010

[2] Bettina Kampman et al., Green Power for Electric Cars, CE Report, Delft, January 2010

[3] Well-To-Tank Report Version 2c, European Council for Automotive R&D, March 2007

[4] Tank-To_Wheel Report Version 3, European Council for Automotive R&D, October 2008

5.6 Continuation:

The intention of the study is to remain improving and filling the model during a few years with data from the Rotterdam practice. The aim is to provide for an increasing insight in the actual performances and costs ‘on the road’. This way of working makes it even possible to come up with a preliminary comparison between different types of B2B transport. So, this research was based on four FU’s but more will follow.

6 Conclusion and Discussion

6.1 Conclusion:

On the basis of the above mentioned Functional Units, the Total Costs of Operation of 3 types of B2B Electric Vehicles EV were compared with the Internal Combustion Engine Vehicles ICEV in an objective way based on the extend of function fulfillment. The design of the study comprises of the subsequent addition of different types of vehicles and a range of FU’s. With this method insight grew by each step which results in an increased insight in “on the road” actual costs of Electric Vehicles EV. It is important to see that Electric Vehicles EV contributes to a clean and silent city. When batteries are charged with green power the local as well as the total CO2-emissions are zero. This way energy is saved from well-to-wheel compared to ICEV. Three years of practice study offers an interesting view on the balance between energy costs on fuel and electricity. If in time many B2B-vehicles will become electric, this would contribute to the ambitious climate targets of the Rotterdam Climate Initiative. This initiative aims at cutting the CO2 emissions of 1990 by half in 2025. Furthermore, electrification of transport in the inner-city suits the regional policies ‘Dat lucht op’ (May 2008) in this way. Besides the CO2 emissions, this policy statement aims also at NOx-emissions, soot reductions. Additionally traffic noise will be audibly reduced by the introduction of electric transport. EV are both from the inside and the outside almost silent.

6.2 Discussion:

In relation to the preliminary research-questions; as they are called:
What are the actual costs of electric vehicles “on the road” in Rotterdam? and Is it possible to optimize the operational costs of EV road transport in Rotterdam ?

In close cooperation between innovative students, representatives of users of EV and manufacturers new insights were gained in redefinition of entrenched concepts.

Vehicles on the road in Rotterdam:
Categories of inner-city transport:

The research and analysis of the results of function fulfillment with Electric Vehicles EV in the practice in the inner-city of Rotterdam indicated that redefinition is desirable. Electric Transport actually differs fundamentally form transport with the aid of ICEV. For that reason a.o. three types of function fulfillment/vehicles have to be defined:

1. B2B-vehicles that drive relatively long distances on workdays.
2. B2B-vehicles that drive relatively short distances on workdays.
3. B2B-vehicles that drive under conditional circumstances on workdays.

6.2.1 Categories of inner-city transport:

1. B2B-vehicles that drive relatively long distances on workdays.

ad 1. In inner-cities the average speed is 20 km/hour. So, on workdays of 18 hours (as for taxis under conventional conservative logistics) a distance of 360 km has to be bridged. Hybrid vehicles are the most designated solution for this function fulfillment. These hybrid also allows *inter*city rides.

2. B2B-vehicles that drive relatively short distances on workdays.

ad 2. In inner-cities the average speed is 20 km/hour. For mechanics and home care employees an optimum logistic planning is necessary to minimize the time they lost in driving between clients. So, on workdays, only 2 hours driving is allowed.
EV are optimal to fulfill this function during 2 hours/day.

3. B2B-vehicles that drive under conditional circumstances on workdays.

ad 3. In inner-cities the average speed is 20 km/hour. For electric public transport buses the driving range on the line is around 80 km or > 4,5 hours. For electric taxis the driving range is to about 100 km or > 5,5 hours. This complies in both cases with a half days service. The electric buses will be deployed twice a day: during the traffic peaks/rush hours in the morning and afternoon/evening. In-between to services the battery pack is charged. The battery pack of the electric taxis needs to be substituted or the vehicle connected with a quick charger. Logistics has to be optimized for these purposes to create optimal conditional circumstances.

6.2.2 New Considerations:
Studying the operational costs of Electric Transport to get Increasing insight “on the road” in actual costs of electric vehicles in Rotterdam led to interesting considerations. As there are: Electric Vehicles until now often are based on the principles of old-fashioned ICEV. For instance electric buses like the prototype e-Busz are still provided with a range extender and an AC/DC convertor. These devices have to be avoided.
A redefinition of categories of function fulfillment and employability seems necessary.

6.2.3. Cost reduction possible:
Devices or system components that are left out will lower the costs of operation. The costs of a non-mounted device are extremely minimized. Because left-out system components require no

- ➔ Purchase costs,
- ➔ Mounting costs,
- ➔ Transport of weight,
- ➔ Space,
- ➔ Energy costs,
- ➔ Maintenance costs,
- ➔ Probability of failure.

Is it possible to optimize the operational costs of EV transport in Rotterdam?

6.2.4 Three opportunities for cost reduction:

1. The e-Busz needs DC for its propulsion. Nevertheless EV are generally charged with AC electricity from the grid. As the B2B vehicles like the buses are charged in specially equipped stations, it would be possible to convert the AC to

DC in the station and charge the vehicle with DC in stead. This will reduce the Total Cost of Operations considerably as you would be able to remove the converter from the vehicle. Furthermore the distance range of the vehicle would increase significantly the device uses energy.

2. For B2B-vehicles that drive relatively short distances on workdays, used by mechanics and home care employees, a maximum of 2 hours/day is sufficient. This correspondents to a maximum range of 40 km/day and a corresponding capacity of the battery pack; that until now is calculated for a daily range of > 82 km. Conclusion: for a cost effective function fulfillment the battery capacity could be halved.

3. Traffic noise will be audibly reduced by the introduction of electric transport. The e-Buses are both from the inside as the outside almost silent. When garbage truck and other trucks that supply super markets become electric, this means it becomes possible to work to later hours and start working in the early morning. This will make it possible to miss out on the peak hours for traffic jams.

An increase in Electric Transport does demand for a change in the logics of logistics.

My heart cry is: Rethink fulfillment of functions!

In General:
The Rotterdam practice oriented eMobility-Lab research is educationally strong.
There is a first insight and facts based discussion about the real bottlenecks, improvements, costs and price developments of urban electric mobility.

Because:
The insight "on the road" in the actual costs of electric transport is increasing. It is still possible to optimize the costs of B2B EV- transport in Rotterdam.

References:

www.ebusz.nl
www.eMobilitylab.nl
www.e-traction.eu
www.spijkstaal.com

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The **Ecotruck 7500** is an electric driven chassis/cabin with a high loading capacity of abt. 4000 kg and a very special cabin which is extremely suitable for the many getting in and exiting of the driver and driver's mates. The transport in urban areas is mostly at low speed, short distances and many stops. The Ecotruck is now regularly supplied for waste collecting. For this it has been equipped with a 7 m3 refuse compactor with lift for the waste containers and a press-unit which can compact with factor 3 - 3,5. So in total this vehicle is able to pick up 25 m3 or 2 tons of waste.
Maximum range of action abt. 100 km.
Maximum speed abt. 40 km/h.
Main dimensions abt. 6.500 mm length, 2050 mm width and 2.750 mm height (ex. refuse compactor).
Max. GVW 7490 kg; so in many countries the driver needs no special truck driving licence.


The electric **e-Busz** that is used by the Rotterdam public transport company (RET) is a prototype, which is fitted with build in energy saving wheel hub motors. It concerns a former diesel bus (type Citea of VDL), which was refitted by a specialist e-Traction in Apeldoorn to become an electric bus. The battery pack on the roof is recharged over night in by a charger in the bus remittance. While driving the battery is also recharged by using the brake energy (regenerative braking).

Length	12 m
Passengers max	95
Basic weight	13.220 kg
Maximum weight	18.600 kg
Batteries	105,6 kWh (60*1,76 kWh)

TheWheel SM500/2.6 → 320 kW peak (10sec) and 166 kW nominal.

- The **Spijk-e** –as showed below- is available in 3 versions
- with a range of respectively 82 km, 98 km and 152 km per time charge.
- Besides they can be charged about 3.000 times.
- The maximum speed of the Spijk-e is 72 km/hour.

The **HR GTZero** is designed and a prototype is build by the Rotterdam University HR.
This electric sport cabrio has two seats, a range of 130 km, a maximum speed of 100 km/hour and a enegyconsumption of 118Wh/km. Exterieur dimensions are 3830 x 1480 x 1600 mm.(l x w x h) Acelleration 0...100 km/h in 15 seconds.