Thermie Project

THERMIE

E.V.D. POST

Measurements performed in Turku, Finland
August 1999

VAN DEN BOSSCHE Peter
DELOOF Wim

CITELEC

This report has been written in the framework of the Thermie project "E.V.D.-Post" (Contract TR-140-97), supported under the European Commission DG XVII's Thermie programme.

CITELEC, Pleinlaan 2, B-1050 Brussel.

1. Introduction

In the framework of the Thermie E.V.D.Post project, CITELEC is responsible for evaluation of the electric vehicles deployed in the framework of this project, on a common basis, in order to have the opportunity to make a comparison of the different electric vehicle technologies that are used in this project.

In this framework, measurements are being performed on postal vehicles used for the project on different sites. After defining the used methodology during the first measurement campaign performed in Kajaani, Finland, in February 1998 (where special attention was given to the winter operations), a second Finnish measurement campaign was held in Turku in August 1999.

The underlying report gives an overview of the methodology used and of the results obtained.

2. Background: Electric vehicles in Turku

The city of Turku (known as Åbo in Swedish language) is the principal city of southwestern Finland.

In the framework of the EVD-Post project, 8 electric vehicles (type Elcat Cityvan) are being used in and around Turku by Finland Post on post delivery duties. Two further EVD-Post vehicles are deployed in Kajaani, and one in Rovaniemi.
The vehicles are used in several post offices located in the Finland Post Production Area of Southwest Finland:

- Seven in post offices in Turku city area (with two additional electric vehicles)
- Two in Raisio, a city to the north-west of Turku
- One in Kaarina, a south-eastern suburb of Turku
- One in Sauvo, a small commune 35 km south-east of Turku

The vehicles are thus used preliminary in the suburbs rather than in the city centre.

Furthermore, five EVD-vehicles (also Elcats) have been deployed by the City of Turku for its own services. One of these vehicles has been visited in the framework of the measurement campaign: this van, called "Ilmari"[1] is used to make technical visits by the city's environmental department. A further vehicle is used by the local energy utility (Turku Energia Oy), which has two further

1 This name refers to "Ilma", the Finnish word for "air"

Elcats in addition to the EVD vehicle. The utility will increase its EV fleet by one vehicle every year.

Figure 1: The "Ilmari" vehicle of the City of Turku

The measurements proper however concentrated on the postal vehicles.

3. The CITELEC measurement system[2]

The CITELEC data-acquisition measurement system is constituted as follows:
An intern serial datalogger, built in a portable 19"-rack, provides all the signal conditioning, multiplexing, discretisation and digitalisation. The rack is small and meets the needs that are demanded for such a device (electric and electromagnetic isolation, proof against external shocks, no obstacle for driver or passengers,...). In Figure 3 one can see the principal outline of the measurement system.
Voltages, currents and digital speed measurements are converted into load-independent output signals by internal transducers with linear characteristics. Outputs from the LEMs (Hall effect shunts) are converted into input voltages for the transducers by means of precision measuring resistances. The transducers provide filtering and galvanic isolation for the signals. Other parameters pass a buffer and a low-pass filter (Butterworth 5th order). The logger accepts input voltages up to 10 V. Data-acquisition is done by a serial

2 Cf. W. Deloof et al., *On-Road Measuring and Testing Procedures for Electric Vehicles*, EVS-14, Orlando, 1997

logger, consisting of a 16 channel data-acquisition card and a 64 Kbytes buffer microcontroller card. The system is powered by two external 12 V batteries providing both 24 V for the system proper and 12 V for the speed sensor.

Figure 2: the measurement system installed on board the Elcat

The logger is controlled by a Macintosh PowerBook via a serial connection, and is controlled by a specific application, EV-Powerlogger, written in LabVIEW™. On the front panel, the setting parameters include: scan rate (Hz), number of channels, path name,... While measuring, the data are stored in ASCII-files for easy data processing.

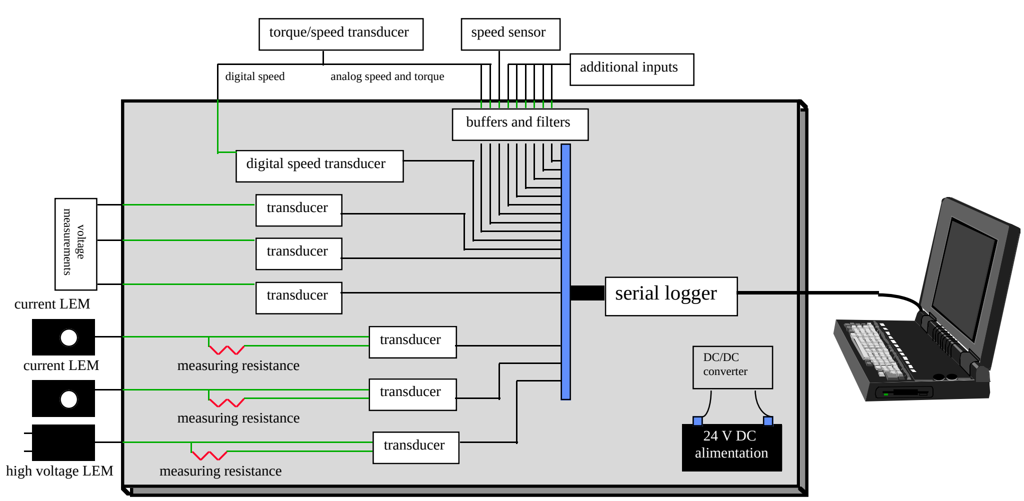

Figure 3: principal outline of the measurement system

The speed sensor is based on a correlation optical method with spatial-frequency filtering and produces an excellent result with very high accuracy. It is easy to mount on the vehicle through a magnetic plate or through suction caps. A 12 V lead-acid battery provides the supply voltage.
A last external device is the Macintosh PowerBook 190cs, which controls the serial logger and stores the measured data in ASCII-files. These files are further treated in a spreadsheet application (Excel)

Figure 4: The speed measurement system

4. Practical realisation of the tests

The tests took place in the week from 23 to 27 August 1999.
The first day, Monday 23 August, the measurement system was built into the vehicle, and a first short test performed in order to verify its operation.
The next three days, the vehicle was used in the normal postal service, two days in Raisio and one day in Kaarina.

5. The postal delivery service in Turku

Let us first consider the way postal distribution is organised in Finland. In city centres, the mail carriers usually go on foot, with an average tour length of 4,3 km. In the suburbs, bicycles are also used (average tour length 9,0 km).
Where cars are used for delivery, the average tour length is 43,5 km, including both urban and rural routes. One car route is thus equivalent to 3-5 bicycle routes.
In the residential suburbs, clusters of mailboxes are grouped on kerbside. The number of mailboxes together can be between 1 and 30.

Figure 5: Kerbside delivery in action (Raisio)

The postman drives by and serves the boxes from his vehicle window.
Only for some multiple dwellings, he has to leave his vehicle for delivery inside the building.

Delivery in Raisio

The electric vehicles used in Raisio are charged at the central post sorting office in the centre of the city. There, secure parking with charging facilities is available.

Figure 6: The electric vehicle charging facility in Raisio

The delivery round considered in these measurements started from the post office (run by postal agent) at Hakinmäki, some 2 km away. The vehicle starts its round there.
The first part of the round includes the delivery of parcels to another sub-office. These are mail order items, which are to be picked up by customers.
The round in Raisio covers some light industrial areas, but is mainly serving residential customers.

Delivery in Kaarina

The round in Kaarina starts from the central post sorting office in the village. Electric vehicles based there are charged outside of the office.
The round in Kaarina covers both industrial areas and residential quarters.

Figure 7: Delivery in industrial area in Kaarina

The following table gives an overview of the postal delivery round in Raisio and Kaarina

This table gives the main characteristics of mail delivery services in Turku.
These data enable to determine some typical characteristics of postal delivery traffic:

- The actual stop time exceeds 40 % of total mission time
- Feeder trajects (to be performed before actual mail delivery begins) account for 7,6 km in Raisio and 5,7 km in Kaarina. The long feeder traject in Raisio (which is necessary due to the fact that the Hakinmäki post office offers no charge facilities) is somewhat of a burden, since it may lead to early discharge of the battery before finishing the delivery round.
- The average distance between stops is 141 m. When considering industrial and residential areas separately, the difference between both environments is obvious.
- When considering the number of stops which made for actual mail delivery (roughly comparable to the number of mailbox locations served; these stops were logged manually), one comes to a number equal to 50-60% of total stops. The remainder of stops are dictated by traffic. The main distance between postal stops is 198 m for all areas; in a typical industrial area, 218 m was measured, while in a typical residential area only 114 m is the average distance between postal stops.
- The commercial (end-to-end) speed is very low, due to the frequent stops times

- The average speed when running is about 19 km/h, corresponding to urban traffic
- The maximum speed of the vehicle rarely exceeds 50 km/h, except during feeder trajects
- Energy consumption is considerably more than the value of ordinary traffic (see also below)

		Raisio 24/8	Raisio 25/8	Kaarina 26/8	Average
Trip length	m	36411	36367	28528	33768
Postal delivery	m		28792	22828	
Feeder traject	m		7575	5700	
Total time spent	h:mm:ss	2:56:26	2:47:30	2:55:57	2:53:18
Stop time	h:mm:ss	1:07:08	0:56:41	1:25:26	1:09:45
%stop	%	38%	34%	49%	40%
Run time	h:mm:ss	1:49:18	1:50:49	1:30:31	1:43:33
%run	%	62%	66%	51%	60%
Number of stops		239	246	234	240
Stops per km		6,6	6,8	8,2	7,1
Average interval	m	152	148	122	141
industrial area				142	
residential area				67	
Number of postal stops			141	120	131
Postal stop rate	%		57%	51%	27%
Stops per km			4,9	5,3	5,1
Average interval			204	190	198
industrial area				218	
residential area				114	
Commercial speed	km/h	12,4	13,0	9,7	11,7
Maximum speed	km/h	50,0	50,2	63,4	63,4
Average speed	km/h	20,0	19,7	18,9	19,6
(when moving)					
Ah/km	Ah/km	3,08	3,03	3,83	3,27
%recup	%	12,8%	12,9%	12,8%	12,8%

Table I: Postal delivery rounds in Turku

These are the basic characteristics of postal traffic in one particular place. They will be compared with results from the other cities involved in the E.V.D.Post project, in order to allow characterisation of post delivery cycles in different cities. Comparison with similar vehicles operated in Kajaani is done in a later paragraph.

Graphical representation of postal delivery cycle

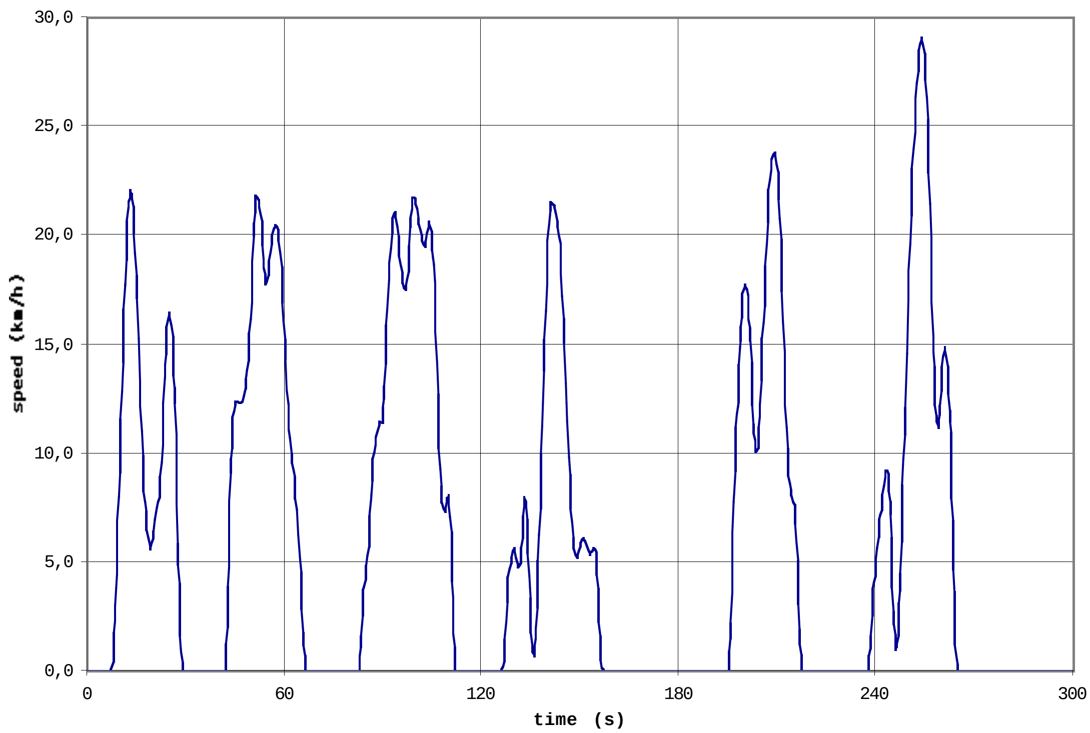

Figure 8: Typical delivery profile

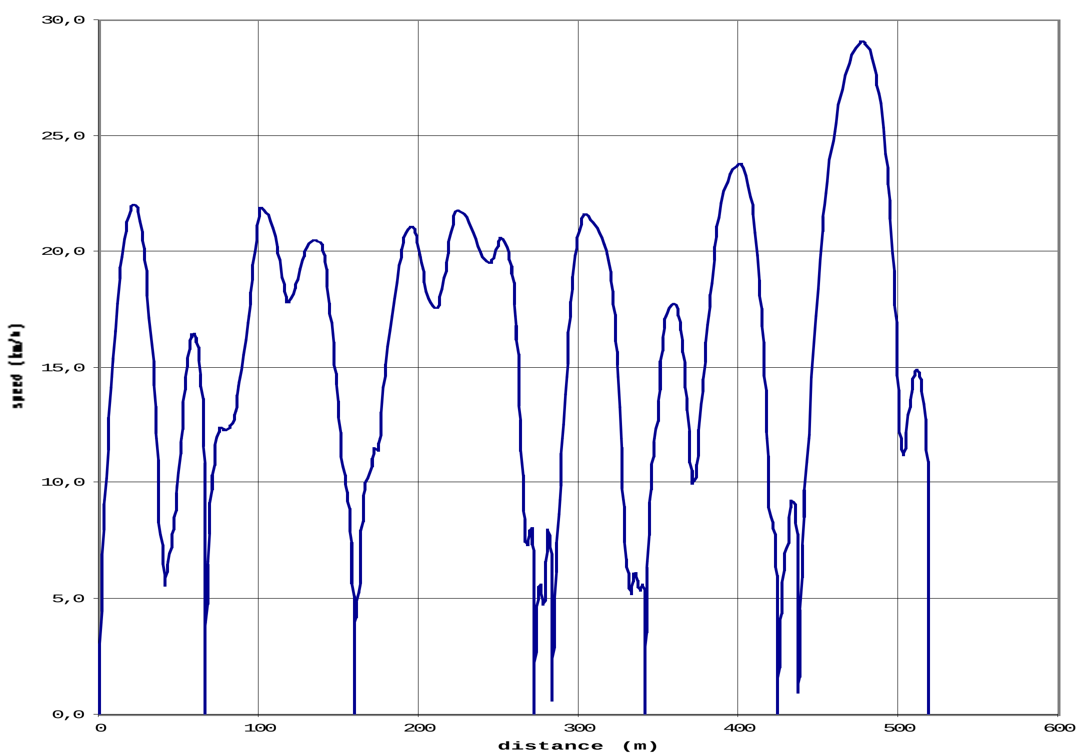

Figure 9: Speed/distance profile

Figure 8 shows a 5-minute extract of a typical delivery run (taken in Kaarina). One can clearly see the progress between the stops deserved, as well as the stop time between them.
The speed can also be plotted against the distance covered; this gives the results in Figure 9. This figure gives a better image of the geographical distribution of the stop points (i.e. mail boxes).

6. Comparison with Kajaani

The average daily exploitation values for Turku and Kajaani were compared (not taking into account the early morning newspaper distribution round which is not performed in Turku).

		Turku	Kajaani
Trip length	m	33768	23556
Total time spent	h:mm:ss	2:53:18	3:39:15
Stop time	h:mm:ss	1:09:45	1:59:22
%stop	%	40%	54%
Run time	h:mm:ss	1:43:33	1:39:53
%run	%	60%	46%
Number of stops		240	311
Stops per km		7,1	13,2
Average interval	m	141	76
Commercial speed	km/h	11,7	6,4
Maximum speed	km/h	63,4	60,8
Average speed	km/h	19,6	14,1
(when moving)			
Ah/km	Ah/km	3,27	4,82
%recup	%	12,8%	5,0%

Table II: Comparison Turku - Kajaani

The main differences between the two sites can be summarised in the following points:

- The average stop time is significantly lower in Turku. This is due to the fact that the delivery round in Kajaani contained more apartment buildings, where the postman had to leave the vehicle for mail distribution inside the building. This takes more time, of course, than kerbside delivery.
- The number of stops per km is also significantly lower in Turku. This can be contributed to two factors:

- On one hand, the feeder trajects (from the post office to the actual start of the round) were longer
- On the other hand, the rounds in Turku covered more industrial areas, where the average distance between delivery points is higher than in residential areas

- The higher number of stops and the longer stop time lead to a significantly lower commercial speed in Kajaani.
- Energy consumption in Kajaani is more than 50% higher. This is due to the higher number of stops, and can also be attributed to the low temperature during the winter tests.

7. Road use of the vehicle

The figures for postal delivery use can be compared with road driving trips (which include the postal feeder trips which are part of the ordinary postal traject)

The energy consumption measured during this trip amounted to 2,19 Ah/km (with 8,3% regeneration). These values are lower than those in Kajaani (2,74 Ah/km with only 4,6% regeneration); this effect can mainly be allocated to the influence of the temperature, since driving on snow roads forces one to decelerate more carefully, not exploiting regenerative braking to its full extent.

		Post driver	CITELEC driver	All road trajects
Trip length	m	16073	25912	41986
Total time spent	h:mm:ss	0:30:59	1:01:17	1:32:16
Stop time	h:mm:ss	0:04:42	0:10:27	0:15:09
%stop	%	15%	17%	16%
Run time	h:mm:ss	0:26:17	0:50:50	1:17:07
%run	%	85%	83%	84%
Number of stops		18	32	50
Stops per km		1,1	1,2	1,2
Average interval	m	893	810	840
Commercial speed	km/h	31,1	25,4	27,3
Maximum speed	km/h	69,2	72,5	72,5
Average speed	km/h	36,7	30,6	32,7
(when moving)				
Ah/km	Ah/km	2,35	2,07	2,18
%recup	%	6,9%	9,8%	8,6%

Table III: Road use

The difference between the values obtained by the regular Post drivers and the CITELEC driver can be explained by the more “dynamic” driving style (with a higher average speed) of the former and their greater acquaintance with the local traffic.
The average standstill time of 16% is due to traffic constraints.

8. General description of the vehicle

The ELCAT is an electric van derived from the Subaru Cityvan.

Motor and battery

The vehicle is powered by a 13,1 kW DC motor acting on the rear axle through a five-speed manual. The motor is fed through a Mosfet chopper with possibility of energy regeneration during braking.

The traction battery consists of 12 monoblocs of 6 V, 180 Ah to obtain a nominal voltage of 72 V.
The vehicle is fitted with an on-board charger; the plug is located in front of the vehicle.

The auxiliaries are powered through a DC/DC converter 72/12 V; a buffer battery is present.

Access and loading

Access to the vehicle is identical to the thermal version.

Batteries are located in the middle of the vehicle, taking a part of the loading space. The battery cover can also be used for storage upon it.

For postal use, the vehicle comes with in right-hand drive version, enabling kerbside delivery without leaving the vehicle. The window is fitted with Finland Post’s proprietary easy opening system.
The passenger seat is removed and replaced by a receptacle for a standard plastic letter container. Additional containers can be stored in the back.

Driving behaviour - Acceleration

The traction circuit of the vehicle consists of a series DC motor, fed by a chopper and coupled to a five-speed manual gearbox.

Due to the high starting torque of the electric motor, the vehicle can be started and stopped with the clutch engaged; this is very interesting for city driving with frequent stops.

The starting torque is very high in first gear (and in reverse); in most cases, second gear can be used for starting. First gear is only necessary for starting on steep slopes.

Electric braking

The new model of Elcat comes with electric regenerative braking. An extra contactor is used to invert the field of the motor, thus enabling braking.

Appreciation

The Elcat is an electric vehicle designed for use in urban traffic; the vehicle performs this job in a very satisfactory way.
Driving the vehicle is simple and straightforward; prospective drivers however must be acquainted to the characteristic behaviour of the electric traction motor to get the best results; more particularly they should observe the gear changing sequence typical for electric traction (where, unlike a thermal engine, lower consumptions are obtained with higher motor speeds). This is facilitated through the presence of a motor speedometer; the measure of the motor current however is quite simplistic, with two leds changing over at 175 A.
New versions of the Elcat come with an integrated instrument offering measures of battery current and Ampère-hours used. This will offer more interesting information to the driver.
Once a driver has been acquainted with the vehicle's behaviour, the characteristics of the vehicle are generally appreciated.
Range and speed are sufficient for urban or suburban use; in postal distribution traffic however, it would be preferable to have a slightly extended range.

9. Energy consumption

Energy consumption at mains level

The operation costs of the vehicle are function of the energy consumption at the mains when charging the vehicle's batteries.
The average weight of the vehicle during the tests can be estimated at 1350 kg (including postal load and the extra person for the measurement system).

		km	kWh	Wh/km	Wh/Tkm
24-Aug	Raisio	35,8	17	475	352
25-Aug	Raisio	42,7	17	398	295
26-Aug	Kaarina	52,5	21	400	296
Total		131	55	420	311

Table IV: Energy consumption

These values are to be compared with the measurements done by Finland Post on a routine basis, illustrated in Table V. (Values in Wh/km) The average energy consumption for all vehicles in the Post/Turku region for the period May-August 1999 was 410 Wh/km.

	Raisio	Kaarina
May-99	472	
Jun-99	432	
Jul-99	395	
Aug-99	463	
Sep-99		481

Table V: Energy consumptions by Finland Post

How to evaluate this result?

One may recall the tests done by CITELEC on the first generation Elcat vehicle, which gave a result of 204 Wh/Tkm on average. In this case however, normal road traffic had been considered, and not the postal delivery work, the energy consumption of which is considerably higher.

One could take into account the well-known empirical formulas to assess electric vehicle energy consumption (C is the consumption in Wh/Tkm; W the weight in tons):

- "Average" value corresponding to today's usual technology:

$$C = 150 + \frac{100}{W}$$

- "Minimal" value, corresponding to state-of-the art technology and an economic driving style:

$$C = 80 + \frac{80}{W}$$

- "Maximal" value, corresponding with a less efficient technology:

$$C = 220 + \frac{120}{W}$$

For a 1350-kg vehicle, this gives respectively 224, 139 and 309 Wh/Tkm.
The average value of 311 Wh/Tkm, is in line with the "maximal value". In this case, this has nothing to do with efficiency of the technology, but with the operation mode of the vehicle.
It is clear that the above formulas are referring to ordinary use of the vehicle.

The value obtained in Kajaani (387 Wh/km) is significantly higher, which is due to the higher energy consumption in winter driving and to the additional consumption of the battery heating system (estimated at up to 4 kWh per 24 hours).

Instantaneous consumption

The instantaneous consumption is measured at the battery terminals during the vehicle operation, and is expressed in Ah/km.
It gives a more clear idea about the influence of traffic conditions and driving style.

As stated above, an instantaneous energy consumption of on average 3,28 Ah/km has been recorded in postal delivery duty. This is to be compared with the value of 2,36 Ah/km measured on the Elcat in Brussels, and to the 4,78 Ah/km recorded in Kajaani.

Range

Even if a full range test has not been performed, forecasts about the range of the vehicle can be taken from the instantaneous energy consumption.
Given the average consumption, and given the available capacity of the battery, one can forecast the available range of the vehicle.
The battery has a nominal capacity of 180 Ah; when considering, a depth of discharge of 80% (144 Ah), which is the normal recommended practice, one becomes a theoretical range of 44 km with the 3,28 Ah/km consumption in postal duty, significantly lower than the range that may be expected in ordinary operation.
The practical operation of the vehicle goes indeed to the limit of this range; the distribution rounds in both Raisio and Kaarina fully exhaust the battery.

The actual capacity which has been extracted from the battery however does not reach 144 Ah, as shown in
Table VI, which gives the covered distance from the beginning of the round to its end, as well as the net consumption in Ah (regenerative braking being subtracted). The data for Kaarina are not included here, since they include the non-standard run from PT depot to Kaarina, as well as an intermediate charge, and are thus not representative for the ordinary operation).
The available capacity is only about 112 Ah, representing only 62% of the full rated capacity.

	km	Ah net
24-Aug	36,4	112,2
25-Aug	36,6	110,5

Table VI: Ah consumption

This reduction in capacity can be due to the following reasons:

- Deterioration of the battery with age. In the case of the EVD-Post vehicles, the batteries were about one year in service at the moment of the test. Flooded lead-acid batteries with tubular plates, which are properly maintained, should still be in good condition after one year hoever.
- Decreased capacity due to more intensive discharge. This is the likely reason. In fact, the capacity of 180 Ah is rated at a 5-hour discharge, i.e. with an average current of 36 A. In the practical use of the vehicle however, the average discharge current is much higher.

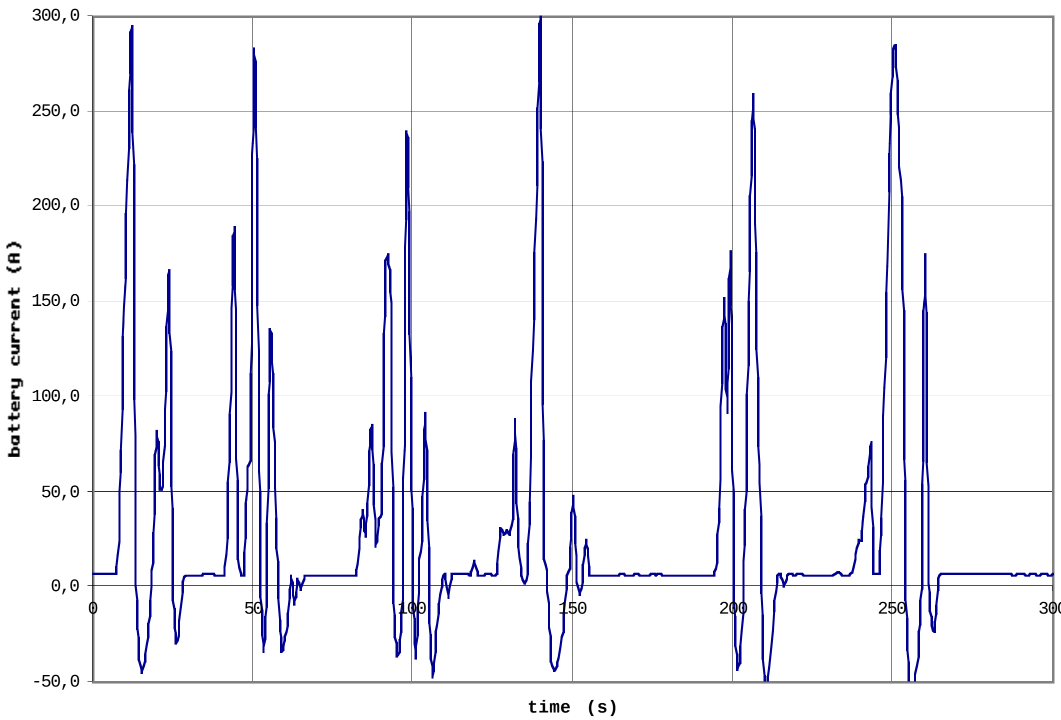

Figure 10: Current profile

Figure 10 shows the current profile for the delivery cycle illustrated above. The average discharge current when the battery is discharging [3] is 106 A in this case. This is about 3 times the rated current; the actual capacity of the battery in this case is much less, and the outcome stated (112 Ah) is an acceptable value.

Influence of driving style

It is interesting to make a comparison between driving styles.

---

3 The average discharge current while the battery is discharging is measured during the time when the battery discharges a current of at least 10 A, thus excluding the time when the vehicle is coasting, braking or standing still.

When comparing the data for the driver in Raisio with the driver in Kaarina, one becomes the instantaneous consumption in Ah/km, as well as the average driving current[4] as shown in the table below.
One sees clearly that:

- For postal delivery duty, the driver in Raisio has a significantly lower consumption in Ah/km, as well as a lower average current level. This driver is thus driving more economically than the Kaarina driver.
- For road feeder services, the differences are less obvious. It is interesting to note that average driving current is higher in this case, but the consumption is lower. This can be explained because the road feeder rips have long trajects at constant speed and constant current, and because for the postal delivery, frequent stop cycles make the average current decrease due to regenerative braking.

Place	Use type	Ah/km	Avg.driving current
Raisio	Postal delivery	3,15	57
Raisio	Road feeder	2,20	79
Kaarina	Postal delivery	3,83	66
Kaarina	Road feeder	2,40	87

Table VII: Driving behaviour

Increasing the useful range

The introduction of charging at the vehicle's starting point (eliminating unnecessary feeder trajects) and the introduction of opportunity charging between delivery rounds) is to be recommended.
Another option would be to fit the battery with a battery management system, which, due to individual monitoring of battery modules, optimises its use and increases the useful capacity that the battery can deliver.

---

4 The average discharge current when driving is measured the time when the vehicle is moving. It takes into account coasting and braking; this value will thus be lower than the former one.

10. The traction battery

The ELCAT comes with a battery pack consisting of 12 tubular plate vented lead-acid batteries of 6 V each. The batteries in the tested vehicle were manufactured by FIAMM. These give a system voltage of 72 V and a total capacity of 180 Ah (5h). Each battery weighs 31 kg, giving a total weight of 372 kg. This corresponds to a (theoretical) energy density of 34,8 Wh/kg.

The battery pack is located centrally in the vehicle. Access can be gained by removing the cover; this makes all batteries readily available for watering, control,…
The batteries need watering approximately every 1000 km.
The batteries are fixed to the vehicle floor by means of safety belts. These belts are also used to remove the whole battery pack with a workshop crane or fork truck. This allows an easy changing of the battery pack.

The battery heating system, which proved its usefulness in the winter tests performed in Kajaani, did not need to come into operation during this summer test.

11. The battery charger

Connection of the charger

The Elcat is fitted with an on-board, high frequency charger located in the electronic control box on top of the motor. Connection of the charger is done through a spiralled cable located in a swing-out box in the front bumper. This cable is fitted with a Schuko side-earthed plug.
For a demanding application like electric vehicle battery charging however, this type of plug, and more in particular the corresponding current outlet, may not be fully suitable and are prone to early failures, as shown by the 15year long experience of Brussels University. The use of more robust, industrial-type, connectors (IEC 309 specs) is recommended.
The charger has an I-U characteristic (cf. Measurements in Kajaani).

12. Safety aspects

Electrical safety

The traction battery in the tested vehicle is isolated from the vehicle frame, and the DC/DC converter is isolated. This is an essential safety precaution.
The chances of coming into contact with live parts are limited. Live parts are accessible of course inside the battery tray and the electronics box, but these can only be opened with the aid of tools and are in principle only allowed to trained service personnel.

Functional safety

The functional safety characteristics are satisfactory: the structure of the vehicle permits safe operation of the control system. A single consideration however:

- The vehicle can not be started when charging; this protection is based on the presence of 220 V AC. When the charging cord is inserted in a dead socket, which has been switched off for example, the vehicle can still be driven away, with possible damages as a result.

13. Conclusions

The measurement campaign performed for the E.V.D. Post project in Turku has been performed using the methodology developed during the first campaign in Kajaani. The comparison of the two sites has highlighted both the operational and the climatic differences between the two sites.
Furthermore, opportunities for improving the practical range of the vehicles have been identified.
The use of electric vehicles for postal distribution continues to show itself as an ideal opportunity to improve the energetical and environmental characteristics of postal services. The commitment of Finland Post towards the electric vehicle is providing a major showcase for other operators. This report brings forward the information about the postal experiences, in the framework of E.V.D. Post project.

14. Acknowledgements

The authors wish to thank the people of Finland Post and of the City of Turku, in particular Mr. Matti Meri, Mr. Vesa Peltola and Mrs. Satu Lindgren for making this measurement campaign possible.

Table of Contents

Table of Figures

Table of Tables