EXPLOITATIONAL CHARACTERISTICS OF ELECTRIC VEHICLES

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Abstract: *Various electric vehicles are exploited in Latvia. The paper analyses experimental data for three different electric vehicles: a Fiat Fiorino Electrico, a conversed automobile Renault Clio and a Think City. The paper focuses on the following parameters of the electric vehicles: charging parameters, range per charge and cost per charge. Lower cost per 100 km distance covered – EUR 2.91for conversed Renault Clio.*

Keywords: ELECTRIC VEHICLES, EXPERIMENTAL ROUTE, BATTERY CHARGE, ELECTRIC MEASUREMENT, ELECTRICITY CONSUMTION.

1. Introduction

The world's non-renewable energy resources are limited. The consumption of the resources increases from year to year. According to various scenarios, the energy resources are sufficient for the next 40-50 years if their use is not reduced. A great deal of the world's energy resources is consumed by road transport. Consuming non-renewable oil products, road transport produces exhaust gases that contain a number of hazardous components. Exhaust gases are hazardous for humans and the surrounding environment. To reduce the effects on the environment and the consumption of oil resources, new technologies are developed, for example, biofuels for internal combustion engines and vehicles powered by electricity [1].

The idea of electric vehicles is not new. Electric vehicles appeared together with internal combustion automobiles more than a century ago. However, internal combustion vehicles developed faster and out competed electric vehicles having a number of advantages, such as silent, zero emission operation and easy start. Initially, the key advantage of internal combustion vehicles was their greater range per gasoline tank relative to the range of electric vehicles per charge.

During the entire evolution of automobiles for more than 120 years, electric automobiles were manufactured in small experimental series for the purposes of certain companies. However, a wider use of electric automobiles did not take place. Electric automobiles became more popular by the turn of the century. Sales of hybrid automobiles Toyota Prius began. Hybrid technologies for other serial automobiles developed, yet, the serial production of electric automobiles charged from the mains supply began later. The Mitsubishi IMi may be regarded as one of the first ones. This electric automobile was not equipped with an internal combustion engine but only with an electric motor. The key disadvantages of serial electric automobiles, compared with internal combustion automobiles, were the high cost and the small range per charge. For these reasons, enthusiasts suggested using electric automobiles particularly in cities. The main advantages and disadvantages of electric and internal combustion automobiles are summarised in Table 1.

Table 1: Main advantages and disadvantages of electric and internal combustion automobiles

Electric automobiles		**Internal combustion automobiles**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
1. Silent operation of the motor	1.Low range per charge	1. Relative low cost	1. Noisy operation of the engine
2. No exhausts are produced where exploited	2.Insufficiently developed infrastructures in a number of countries	2. High range per fuel tank	2. Exhaust gases (CO, CO_2, NO_x, C_nH_m, PM)
3. Exhausts are localised in electricity generation sites	3. High cost	3. Developed infrastructures in the entire world	3.Complicated structure of the engine, a lot of rotating and moving assemblies that have to be oiled and lubricated
4. High energy efficiency and a high efficiency factor	4. Users are accustomed to classical and traditional technologies	4. Heat generated by the engine can be used for heating up the cab	4. Low efficiency factor, below 40%
5. Simple structure, a few motor-related assemblies	5. Lifetime of the battery can be shorter than the period of use of the electric automobile	5.Technologies and designs have developed over the century	5. Special start up system is necessary
6. Low exploitation costs	6. Limited choices when purchasing an electric automobile	6. High energy density of liquid fuel, the weight and volume of fuel are small	6. Optimal use of power and torque curve characteristics is possible only within a small range of engine rotation frequency
7.Maintenance does not require changing motor oil and a filter	7. Batteries have to be disposed of and recycled	7. It takes a short time to fuel up an automobile at a gasoline station	7. High exploitation and fuel costs
8. Starting up the motor is not necessary	8. Special cab heat-up system is necessary, which consumes electricity or fuel	8. Usually there is no need to change costly assemblies during the lifetime of the automobile	8. Engine oil has to be periodically changed and the used oil has to be disposed of
9. Motor power and torque curves are adequate for the operation of an automobile	9. New and not always fully tested technologies	9. Maximum cost of damaged assemblies is less than 30% of the cost of the automobile	9. Use without a gearbox is not possible
10. Electricity generated from renewable sources may be used	10. Long battery charging time		10. Use in a city harms its residents

Enthusiasts of electric mobility tried to make electric automobiles by applying their own efforts. The cost of conversion is high, an electric motor, its control unit and batteries are the main items of expenditure. Yet, if converting an automobile into an electric one, it may be tailored to the requirements of any particular user. If the user needs an electric automobile for travelling only 30 km per day, the automobile can be equipped with batteries whose capacity is 3-5 times lower than for industrially manufactured electric automobiles. This is the way how to reduce the conversion cost.

At present, the spectrum of electric automobiles offered in the market and being in use is wide, therefore, to make the right choice of electric automobiles that meet the consumer requirements, a comparative experimental research study on electric automobiles was performed, which was the key objective.

2. Researched exploitation parameters of electric vehicles and the research methodology

To compare and assess electric vehicles, a special experimental programme was developed, which involved a number of series of experiments and various kinds of experiments.

2.1. Methodology for determining the time to fully charge batteries and the amount of electricity consumed

The experiments were performed with an electric automobile under stationary conditions, doing slow charges from the 16 A mains supply. Before any experiment, it was made sure that the mains were grounded, as electric vehicles of some models cannot be charged if the mains are not connected to the ground wire. Slow-charge experiments are easier for comparison, as such a kind of charging may be usually used for any electric automobile. Fast charging options are various, and some models of electric automobile might not have them. The experiments were performed based on the following methodology:

- before performing a charging experiment, the odometer reading, km, was recorded. The charge indicator reading (the remaining battery charging rate, %) was also recorded. The experiment used as much discharged batteries as possible – when the discharge indicator was in the alarm zone;
- measurements were done in a closed room. The air temperature was +15 - +20^{0}C. The charging time was at least 8-10 h, from the one-phase 16 A mains;
- during the charging operation, the amount of electricity consumed was determined by means of an electric power meter;
- additionally, a data logger was connected during the charging operation to measure voltage and current;
- the experiment was repeated at least 5 times, and average charging parameters were used for the result.

2.2. Range per full charge for electric automobiles in the regimes of urban and non-urban driving

The experiments were conducted in Jelgava city on a certain circular route that was chosen and approbated before (Figure 1). The route included both central city streets with heavy traffic and detour streets, thus varying the intensity of traffic. The experiments were also conducted outside the city at a speed of 90 km/h, entering the flow of traffic. The experimental methodology was as follows:

- the electric automobile was fully charged. The experiments were done on asphalt roads with an average rolling resistance coefficient of 0.013 – 0.015. The experiments were performed when the road surface was dry; the air temperature was +10 - +20^{0}C. The wind speed was less than 3 m/s;
- the electric automobile was driven on the route, strictly observing the traffic rules, not exceeding the speed limit of 50 km/h in the city and of 90 km/h in the non-urban driving regime and smoothly entering the flow of traffic. The experiments were not interrupted and the automobile was not stopped, except in cases where the traffic conditions required it;
- the experiments in the non-urban regime were done on the road section between Jelgava city and Dobele town (Figure 2). The experiments were conducted back and forth on the mentioned road section, not entering the urban area of Jelgava and Dobele;
- the driving regime of the automobile (driving speed, time, distance) was registered by the data logger and, after the experiment, the distance covered was compared with the reading of the odometer. The experiment was repeated 3 times.

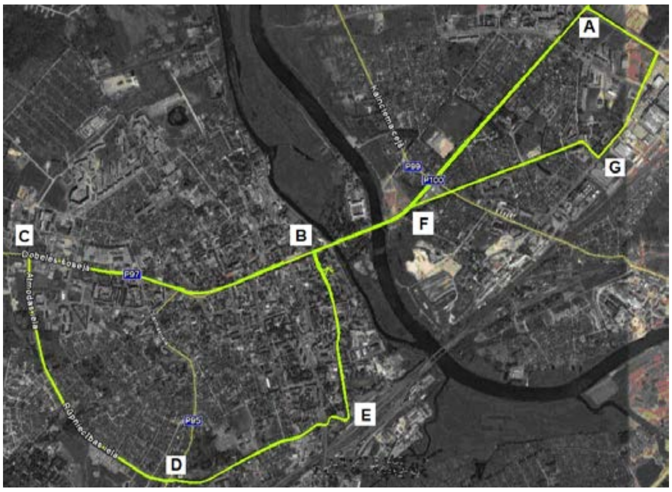

Fig.1. Experimental route in Jelgava city: *ABC- route down the main street of the city; CD- detour route, v=70 km/h; DE- detour route, v=50 km/h; EBF- city route with medium traffic; FGA- city route with light traffic*

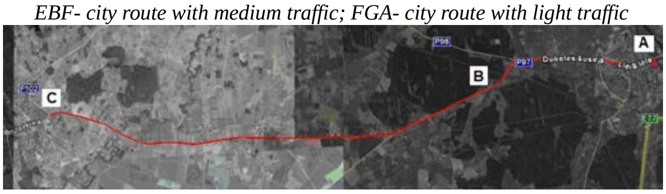

Fig. 2. *Experimental route for the non-urban regime on the road section between Jelgava and Dobele: AB- start and finish for the automobiles in the city driving regime in Jelgava; BC- experimental back-and-forth route.*

3. Equipment used in the experiments and the experimental objects

Three various electric automobiles were used in the experiments: a Fiat Fiorino Elettrico HC-S, a Think City and a converted automobile Renault Clio.

3.1. Experimental electric automobiles

A Fiat Fiorino Elettrico owned by the JSC Latvenergo was used in the experiments.

The Fiat Fiorino is conceived for build-up urban environments and small cities. It combines performance, agility and comfort with the load capacity. The car's main technical parameters:

- category – M1;
- motor – asynchronous, nominal power 30 kW, maximal power (peak) 60 kW;
- brakes – energy recovery;
- recharging socket – 230 VAC – 16 A – 3 kW;
- battery – lithium up to 22 kWh;
- transmission – direct drive;
- maximum speed – up to 100 km·h^{-1}
- distance of run with a single full charge (range ECE 101 cycle) 100 km;
- heating system with a fossil fuel [2, 3].

An electric automobile Think City belonging to the enterprise Rīgas Satiksme was used in the experiments. The electric automobile Think City is a two-seated car. Its key parameters:

- weight –1065 kg;
- maximum speed –120 km/h;
- maximum distance with a single charge – up to 180 km;

- climate control – electric heating of the cab, conditioner;
- brakes – energy recovery with ABS;
- transmission – fixed reduction permanently connected to drive wheels. Ratio 1: 10,15;
- 3-phase electric induction motor, Max power 34 kW 89.5 Nm [4].

The industrially manufactured electric automobiles used in the experiments are shown in Figure 3.

a) b)

Fig. 3. Experimental industrially manufactured electric automobiles a) Fiat Fiorino Elettrico HC-S b) THINK City

A converted automobile Renault Clio was also used in the experiments. The automobile was converted at Latvia University of Agriculture, Faculty of Engineering. The automobile's key parameters:

- category – M1;
- maximum motor power – 20 kW;
- battery voltage – 96 V, 100 Ah battery elements;
- weight – 1125 kg;
- transmission – standard 5-gear;
- maximum speed – 80 km/h;
- cab heating system – during the charging operation– 220 V cab heater; when driving – internal combustion heater running on E85, 2.5 kW 96 V electric heater.

The Renault Clio used in the experiments is shown in Figure 4.

Fig. 4. Electric vehicle Renault Clio

3.2. Equipment used in the experiments

Using the universal data collection and processing logger HOLUX GPSport 245, the electric car's running distance, speed and time were measured. The logger technical parameters [5]:

- weight – 72 g with battery;
- memory – RAM: 64KB;
- IO interface – Mini-USB charging;
- adaptor – input 100 – 240 VAC, 0.5 A max, DC output 5 V/1 A
- thought Mini-USB;
- function – save log data and 200,000 waypoints, show speed, time;
- environment temperature – operating temp. -10 ºC to 60 ºC.

For the registration of the consumed electric energy during charging, the digital energy measuring tool *ES-T9162* was used (P1 in Figure 5). The energy meter's technical parameters:

- voltage range- 190-276V;
- electric energy consumed during charging, 0- 9999.99 kWh;
- charging capacity, 5-4416 W;
- current range 0.02-16 A [6].

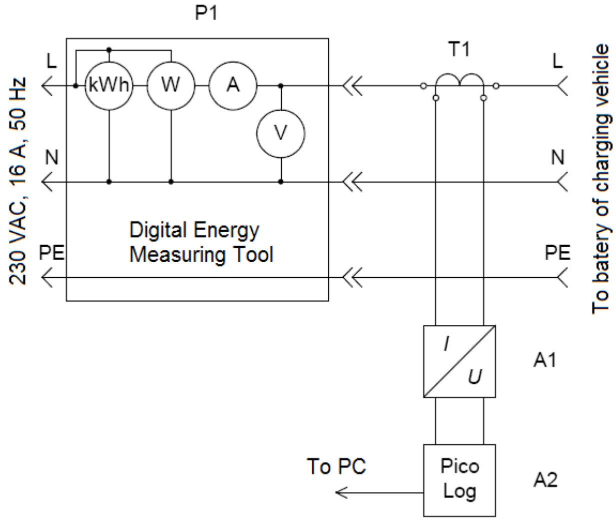

Fig. 5. Electric measurement diagram

The electricity characteristics were measured with 10 second intervals during the charging. A PicoLog ADC-24 data logger was used for gathering the experiment results. The data logger was equipped with a current converter A1 and a current transformer T1 (Figure 5). The actual power, current and voltage values were controlled by the digital energy measuring tool P1, which also was registering the total consumed electric energy [6].

3. Research results

When charging the batteries of the electric automobiles, changes in the current during charging were registered. All the electric automobiles were charged from the 230 VAC 16A mains. One of the examples of registered curves for the electric automobile Fiat Fiorino Electrico is presented in Figure 6. The average charging time for discharged batteries ranged from 7 to 8 h. An automatic balancing operation for the batteries was done during the final hour. A charging algorithm for all the electric automobiles was similar, as the battery management system (BMS) was employed in all the cases to charge the batteries. The converted electric automobile had a programmable BMS system that allowed choosing the charging regime, reducing the charging current to 5 A. In such a way, it was possible to charge an electric automobile from a small power socket. However, in this case, it took a longer time to charge a battery.

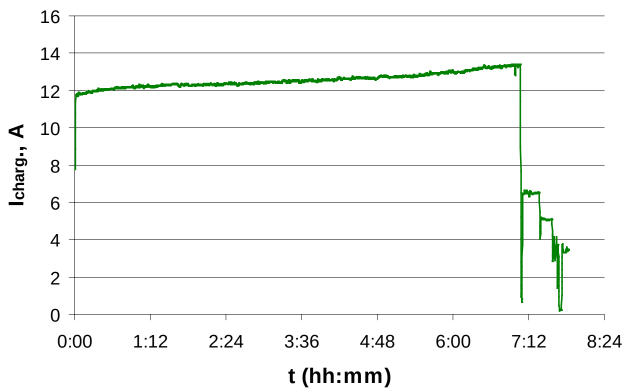

Fig. 6. Changes in the current during charging the lithium ion batteries of the electric automobile Fiat Fiorino

Users prefer electric automobiles not only owing to their environmental characteristics but also because of their low exploitation costs. According to the experimental data, the cost to drive 100 km for the researched electric automobiles ranged from EUR 2.91 to 3.77 (Figure 7), which was, on average, up to 2 times less than for internal combustion automobiles of a similar category.

The low cost per 100 km for the converted automobile may be explained by its small capacity batteries and the relatively small weight of its batteries, which were at least 2-2.5 times lighter than those of the other researched electric automobiles.

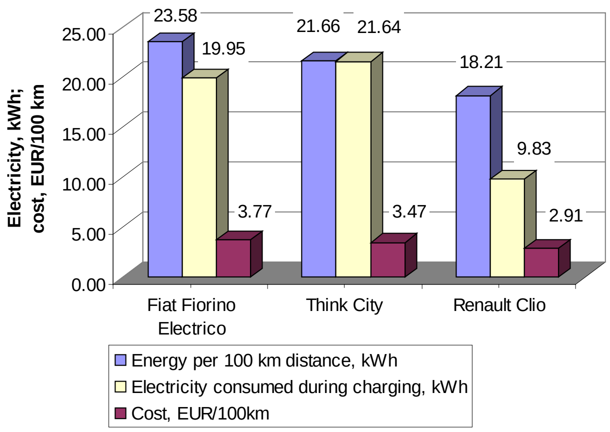

Fig. 7. *Electricity consumed to charge the electric automobiles, energy per 100 km distance covered and energy cost per 100 km*

The charging current exceeded 14 A in neither case. Such current is close to the nominal current intended for two-contact sockets. For this reason, an electric automobile has to be charged from the mains consisting of wires of adequate diameter. An obligatory requirement is the ground wire, as a few electric automobiles may not be charged if no ground wire is installed. The maximum charging power in all the cases ranged within 2.91- 3.15 kW.

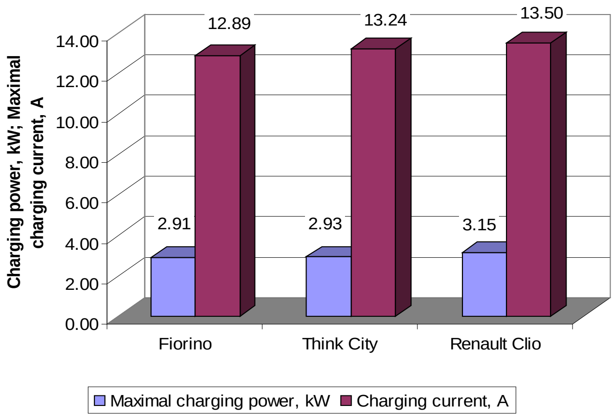

Fig. 8. *Maximum charging characteristics for the electric automobiles*

The range experiments were performed in Jelgava city and in non-urban traffic in accordance with the methodology described in Chapter 2. Route data from the data logger are presented in Figures 9 and 10. Driving on the city route involved a number of instances of braking, stopping and acceleration.

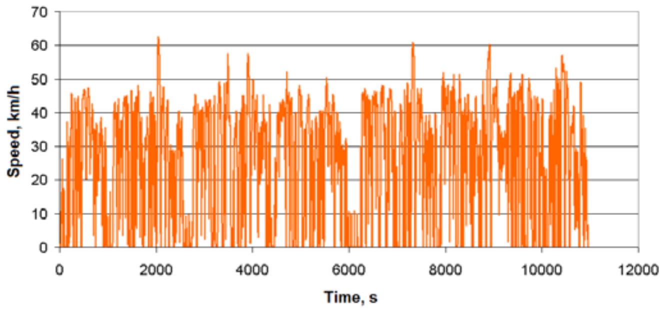

Fig. 9. Example of the driving speed graph for an electric automobile in the urban driving regime

Using the graphs obtained, it is possible to make an analysis of a micro-route; yet, more precise data were obtained at the next research stages by means of a scientific radar STALKER.

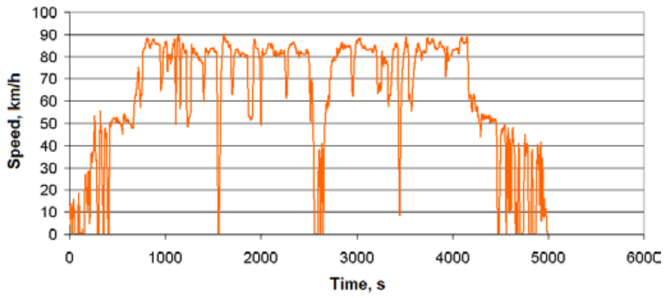

Fig. 10. *Driving speed graph for an electric automobile in the non-urban driving regime*

Figure 11 presents data on the movement of the electric automobiles in the urban driving regime. In all the experiments, the average speed was approximately 30 km/h. The longest distance covered was achieved by the electric automobile Think City, 101.5 km. According to the charge data, the electric automobile Fiat Fiorino had batteries of slightly smaller capacity. The longest distance covered by the Think City may be also explained by its smaller weight. The converted automobile covered the shortest distance, 56.8 km, as its batteries' capacity was only 100 Ah, while the nominal voltage was 96 V.

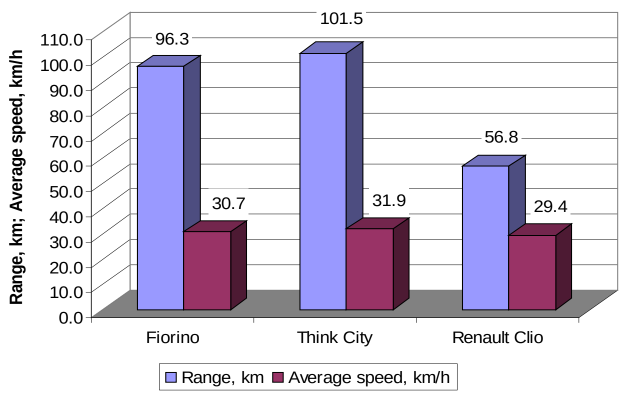

Fig. 11. *Distances covered by the electric automobiles in the urban driving regime*

In the non-urban driving regime, the electric automobile Think City achieved a 16.9% shorter distance than the Fiat Fiorino. Besides, unlike the other electric automobiles, this vehicle covered a longer distance in non-urban traffic than in the city. It might indicate the poor performance of the regeneration system of this electric automobile when driving in a city or the too small power limit when accelerating.

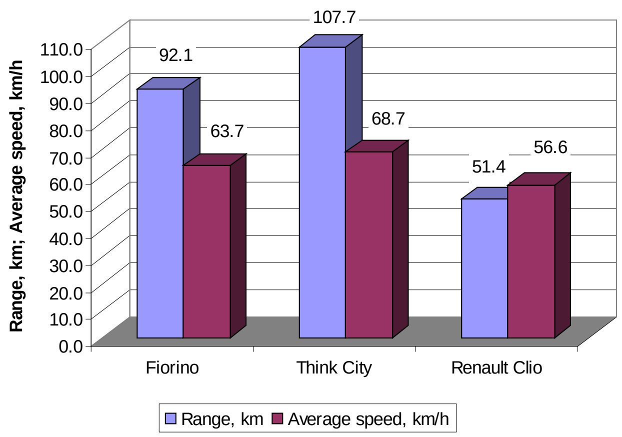

Fig. 12. *Distances covered by the electric automobiles in the non-urban driving regime*

In the result of effective performance of the regenerative braking system, in city traffic, the distance covered is usually slightly longer than in non-urban traffic, as the air resistance force is smaller at lower speeds and, when standing at an intersection, the motor is not running, unlike it is with traditional automobiles without a start-stop system.

Conclusions

1. A methodology for determining battery charging parameters and distances covered for electric vehicles at various driving regimes was developed and approbated.
2. An experimental route for determining distances covered by electric vehicles in Jelgava city and in non-urban traffic was developed and approbated.
3. Charging current curves for all the researched automobiles were similar. It took 7-8 hours to charge the batteries of the researched electric automobiles in slow charging from the 230 VAC 16A mains supply.
4. At the end of charging, automatic battery balancing was observed, which lasted for 0.7- 1 h.
5. The charging current exceeded 14 A in neither case; yet, such current is close to the nominal current intended for particular sockets. For this reason, an electric automobile has to be charged from the mains consisting of wires of adequate cross sectional area. An obligatory requirement is the ground wire, as a few electric automobiles may not be charged if the ground wire is damaged.
6. Industrially manufactured electric automobiles are equipped with 18-22 kWh capacity batteries and an electric motor for a voltage of 300 V. Such electric automobiles are designed for the average range of 100 km.
7. Electric motors for a voltage of less than 200 V are usually used for converted electric automobiles. At such a voltage, the electrical current rises up to 600 A. Batteries are chosen according to the specifics of their use.
8. In all the cases, the maximum charging power ranged within 2.91- 3.15 kW, which was observed during the beginning of charging.
9. The average speeds of the electric automobiles in the urban driving regime did not significantly differ and were within a range of 29.4-31.9 km/h. The longest distance in the city was covered by the electric automobile Think City, 101.5 km. The shortest distance, 56.8 km, was covered by the electric automobile Renault Clio, the batteries of which had the smallest weight and capacity.
10. Reducing the weight and capacity of batteries results in lower conversion costs and lower cost per 100 km distance covered – EUR 2.91.
11. In non-urban traffic too, the electric automobile Think City achieved the longest distance, 107.7 km. The average speed of the electric automobile Renault Clio was lower than that of the other experimental electric automobiles, as its maximum driving speed was only 80 km/h.

References

1. Berjoza D., Jurgena I. Economic effect of electric vehicles In: Proceedings of 10th International Scientific Conference "Engineering for rural development": proceedings, May 26 - 27, 2011. Jelgava, LUA. - Vol.10, pp. 179 -184.

2. Berjoza D., Dukulis I., Ceple D. Investigation of electric car acceleration characteristics performing on-road tests In: Proceedings of 11th International Scientific Conference "Engineering for rural development", Jelgava, Latvia, May 24 - 25, 2012. Jelgava, LUA. – Vol.11, pp. 318 -323.

3. Fiorino (Combi) (2009) Micro-Vett SpA veicoli elettrici [online] [01.03.2015]. Available at: http://www.micro-vett.

4. THINK City user manual. [online] [03.03.2015.]. Avalable at: www.thinkev.com

5. HOLUX GPSport 245 (2012). Specifications [online] [16.04.2015]. Available at: http://www.dvr-tc.holux.com/

6. Galins A., Putnieks U. Electric vehicle charging characteristics. In: Proceedings of 11th International Scientific Conference "Engineering for rural development". Jelgava, Latvia, May 24 - 25, 2012. - Jelgava, LUA. – pp. 355 -359.