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Influence of a system “vehicle – driver – road – environment” on the energy efficiency of the vehicles with electric drive

Valerii Dembitskyi, Oleg Sitovskyi, Vasyl Pavliuk

Lutsk National Technical University, Lvivska str., 75, Lutsk, 43000, Ukraine; dvm2@meta.ua

Abstract: The purpose of this paper is to present the results of an investigation as to the interconnection between main exterior factors which can influence the power consumption during the vehicle movement in the conditions of real operation. According to the results of theoretic researches, there was determined an influence of every factor on the power consumption during vehicle movement in the modes typical for Lutsk city. There was established a contribution of the factors into the total power consumption on micro and macro levels. As a result of the study it was evaluated that an influence of a driver on a power consumption is situated within 50…80 %, an influence of an air resistance is up to 10 %, an influence of a longitudinal profile and a road resistance varies within 20…35 %. According to the results of experiments, there were determined the bus driving modes in urban conditions, and according to their results, there was built an average graph of bus movement in Lutsk city. There was made a mathematic modelling of electric vehicle movement, along with that there was taken into account the most probable range of change of the exterior factors, namely vehicle acceleration, road resistance, air resistance. It was proved that while speed is growing, the influence of road resistance and of air resistance is growing up and has a parabolic character, along with that the contribution of a driver is decreasing. The contribution of the study consists in that, There were proposed the coefficients of taking into consideration the influence of exterior factors on the power consumption by the vehicle and there was built a mathematic model for their determination. These coefficients of taking into consideration the influence of exterior factors on the power consumption give a possibility to evaluate the critical influences and to make an operative decision about the minimization of power consumption as for some specific vehicles, and for an enterprise. Further researches will focus on the plotting of telemetric means of informing, in a mode of real time, of the drivers of the vehicles, of the controllers of an enterprise about the exterior influences, that will give a possibility to make the appropriative decisions instantly. Besides, the given results can be used in order to determine the level of qualification of a driver, the state of road pavement, will give a possibility to find some more rational layout of bus stops, traffic lights, to optimize the routes of vehicles movement.

Keywords: exterior factors, power consumption, energy efficiency, influence factors, driving cycle.

1. Introduction

Nowadays the vehicles with electric drive are developed very intensively all over the world. Almost every manufacture deals with the electric cars production. The constructions of the vehicles with electric drive are improving, the motion reserve is growing up, and along with that during the real

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operation one can see some problems, the main of which are: a power consumption, and relatively a motion reserve are rather less than those declared by a manufacturer, a premature death of the storage batteries and energy storages. Mentioned problems are caused by the mutual influences of a system «vehicle – driver – road – environment». As a result of all that, there appears a task to examine a system «vehicle – driver – road – environment», to find the interconnections and to offer some measures to improve the energy efficiency of the vehicles with electric drive.

A number of factors influences the operation qualities of a vehicle, including power consumption: vehicle construction, exterior conditions (climate, state of road pavement), conditions of a vehicle movement (road traffic, operating mode of traffic lights, motion mode of traffic stream), driving style and driver's qualification. All these factors are inseparably interrelated, though the change of one won't always lead to the change of another one. The interconnections inside the system «vehicle – driver – road – environment» are shown at Fig 1.

At picture 1 the factors which can not be changed during the process of movement are painted yellow. The influences related with the driver, depend exclusively on his qualification and knowledge to use the economically efficient motion modes. Along with that, the vehicles manufacturers, during their designing, put in their construction some energy indices, including motion reserve and power consumption. One of the main indices which influence the power consumption and respectively the motion reserve, is the vehicles motion mode. Usually to calculate the traction and speed characteristics and power indices of a vehicle, the standardized driving cycle is taken. For the vehicles of category M1, the standards EN 1986-1:2000, EN 1986-2:2001, UN ECE № 101 are valid, meanwhile for buses such driving cycles are absent at all.

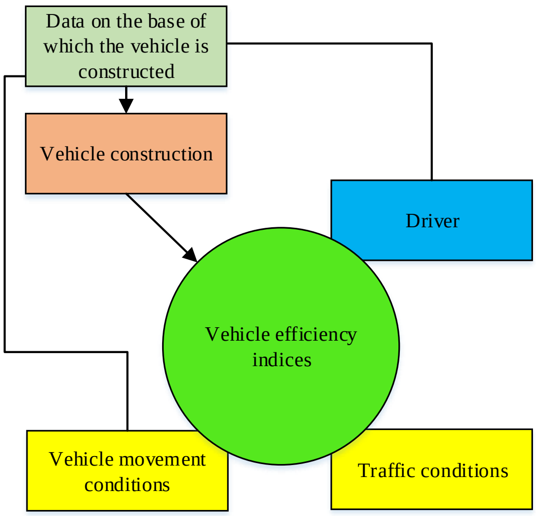


Figure 1. Interconnection of the factors of a system «vehicle – driver – road –environment»

But in real conditions of exploitation, the motion modes differ a lot from the standardized ones, and that leads to the disfiguration of the data concerning power consumption and energy efficiency of the vehicles, that's why it is necessary to make researches of the vehicles motion modes in real conditions and to offer the method of influence determination of given factors on the vehicle power consumption.

2. Literature review

Review and analysis of literature sources say about the actuality and importance of the research of a system «vehicle – driver – road – environment». Using of recuperative braking influences a lot the indices of energy efficiency of an electric car [1]. In their work the authors have made the preliminary researches of the interconnection between different electric vehicles and their power consumption in real motion conditions, a lot of attention is also paid to the efficiency of recuperative braking. The researches and modelling of roads net, traffic streams and choice of route by the drivers take a great interest [2].

In the research work [3] there were made the considerable researches about the evaluation of power consumption and CO2 emissions, and there was made an analysis of criteria of vehicles evaluation by the drivers taking into account their behaviour during the movement. A problem of making the real driving cycle for vehicles is examined in the research work [4], it is necessary to mention that in given research results there are also studied the movement parameters, taking into account real modes used by the drivers. The problems of efficiency of using the hybrid vehicles, from the point of view of fuel economy, in Bangkok city, are considered in the work [5]. In this work there was determined an influence of aggressive driving style on the fuel consumption by hybrid vehicles and there were offered the possibilities of fuel economy. Also the researchers from India [6] deal with the problem of creation a real driving cycle, taking into account the multi-parameters model. Practic methodology of making a typical driving cycle, which reflects the real conditions of movement, is worked out for testing the emissions and evaluation of a vehicle and is given in the work [7]. In order to determine a real driving cycle in the work [8] there was used Markov's theory and matrices of probabilities of passing of system states. Using Markov's theory and Monte-Karlo's method is layed in the base of modelling the real driving cycle, shown in the work [9]. Method of clasterization for making a driving cycle is used in the work [10]. Using of world geographic systems during the making of driving cycles is applied during the researches of movement conditions in Liubliany city [11]. The synergy of standardized and real driving cycles are applied in the work [12] that laid to an appearing of a new method of receiving of equivalent driving cycle of movement. A method of segmental division of driving cycles on the base of a bus station and a method of making a cycle of bus driving on a base of full journey is offered in a work [13].

A system of electrical energy control on a base of identification of a driving cycle, and depending on loading, is examined in the researches [14], the offered online strategy of control helps to improve the fuel economy of a vehicle.

In the researches [15] there is examined an influence of different styles of driving on a fuel consumption by an ordinary and hybrid vehicles. As a result of made researches, it was determined that fuel consumption can vary up to 34 %, depending on a scenario and style of driving.

A considerable influence on an efficiency of electric vehicle work is caused by an environment, thus, in a work [16] there is investigated an influence of environmental temperature on an efficiency of electric vehicles work in the USA. In a work [17] there was made a research of influence of extreme temperatures on accumulators charging and productivity of electric vehicles work.

The researchers from Brussels university [18] have made a great work about the investigation of influence of exterior factors. During the research, the authors took for a base five factors, each of them can have an influence on power consumption. Influence of exterior factors is examined on macro and micro levels. Using the main physic values, expressed in the equation of dynamic of the vehicle, there were built three models of prediction of EV energy consumption by the way of applying a statistic method of multiple linear regression to the data of real movement and power consumption for EV. Multi-level model for the evaluation of power consumption by an electric vehicle taking into account the influence on environmental temperature, individual inhomogeneity of drivers' behaviour is offered by the authors in [19]. The evaluation of fuel consumption by the electric cars according to the standardized driving cycle NEDC with the aim to study different movement modes at different ambient temperatures are shown in the work [20]. In the article [21] there were made the researches of influence of behaviour and personal driving style, transportation conditions and project of infrastructure in real world on the energy efficiency EVS. The researches were made with Nissan LEAF in the frames of typical driving cycle on a roads net of Beijing with the purpose to better understand the changes of energy efficiency among the drivers in different urban conditions. Instant model of vehicle movement [22], determined on the base of vehicle speed, acceleration level and gas pedal control, is used in suburban modes of movement, has shown rather exact results for total power consumption of a vehicle.

The authors of the work [23], to estimate the energy consumed by an electric vehicle, have built a model of multi-variant linear regression (MLR), taking into consideration an influence on power consumption, the next four factors are analized: distance, speed, initial SOC and ambient temperature. Identification and quantitative estimation of relations between exterior factors such as topology of roads, traffic, driving style, environment and cinematic parameters of a vehicle and its power consumption are the aim of a work [24]. Article [25] represents a system for prediction of the necessary energy for chosen journeys of electric vehicles, which can be used for different assistants. Given system applies the statistic characteristics, obtained from the speed profiles, as though they take into account different factors of influence on individual driving style and overwhelming movement conditions. Model of statistic prediction uses these functions to predict the deviation from an average energy consumption by an electric vehicle. In the work [26] there was proposed a route conducting of engine of an electric vehicle, which also takes into consideration the driver's characteristics and road conditions using data bases. The coexistence of people and the world of machines depends not only on technical possibilities, costs of technology implementation, legal regulations, but also on social acceptance and people's ability to coexist with technologies [32].

The results of influence of an environment on a power consumption of a vehicle are given in [27]. Along with that, there was used a four-factors model which varies depending on the change of operation conditions of a vehicle. The estimation of sensitivity of necessary engine capacity of an electric vehicle and the degree of influence on environmental factors and a general battery power and energy consumption was made in the researches [28].

In such a way, according to the results of analysis of modern researches concerning the problem of determination of influence of exterior factors on a power consumption of a vehicle, there was found a great actuality of given problem. A huge problem is made of movement modes which differ a lot in different cities and countries from the standardized driving cycles, that makes researchers to make investigations of real movement modes of a vehicle in specific inhabited settlements. Besides, the research of power consumption requires an integrated approach to a system „vehicle – driver – road – environment" taking into account the specific operation conditions of the vehicles. Also it is necessary to remark, that it is reasonable to make a complex research of exterior factors, which would vary on all possible levels, as it is shown in [27, 28], that is to make a multi-criteria model, which will give a possibility, in future, to exactly evaluate the power consumption of the vehicles in real operation conditions and, as a result, to take measures to minimize its charges.

Great part of researches of electric vehicles is dedicated to the estimation of CO2 emissions and their ecological influence on the environment [3-5]. Taking into consideration the fact that the standardized driving cycles substantially influence the power consumption of the vehicles, the researches of the motion modes in real operation conditions and the development of real driving cycles are also important [6-9]. The environment affects a lot the efficiency of electric vehicle operation, namely the climatic conditions [10] and [11]. The researches were made by the scientists from different countries and show the necessity of taking the standardized driving cycle to the real motion conditions. A number of researches were made in this field [12-15].

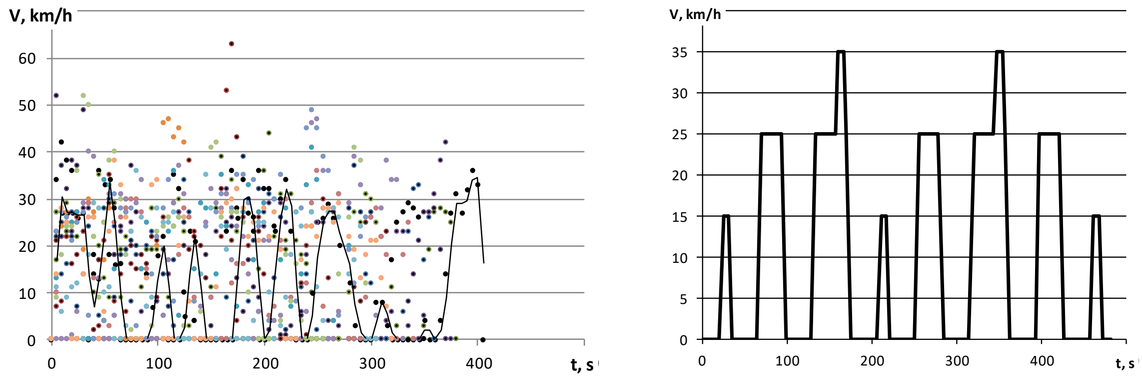
3. Research methods

To solve the given problem, there were received some data concerning the motion mode of the vehicles in Lutsk city by mean of an experiment. Taking into consideration a complication of receiving the real bus movement modes, in order to receive the experimental data, there were used the data of systems of monitoring of public transport movement MAC, which is introduced and operates in Lutsk. Periodicity of data renovation was equal to 5 second [5,8,10,18]. After that, using the methods of statistic results processing and the methods of mathematic modelling, there was made a calculation of the vehicles motion modes. According to the experimental data concerning the buses motion modes, the driving cycle for Lutsk city was determined. On the base of received driving cycle, using the statements of vehicle theory, there was made an investigation of influence of exterior factors on a power consumption. During the mathematic modelling the exterior factors varied in the most probable ranges, thus the acceleration and deceleration changed within 0…2 m/s2, wind speed – 0…8 m/s, road slope – 0…8°, vehicle speed – 0…20 m/s. To determine the mathematic dependences of change of influence coefficients, there was used an approximation of received data. To determine the necessary capacities that are spent to overcome the forces of resistance of the car, a mathematical model of the balance of power was used, similarly as in [28]. To determine the mathematical dependencies of the change in the coefficients of influence, approximation of the obtained data was used, as in [29]. This combination of applied research methods makes it possible to construct a three-factor model of variation of the factors of influence of external factors. This model can easily be adapted to any specific operating conditions or any vehicles.

4. Research results

The researches of flow of traffic modes were made on the city bus routes of Lutsk city, using multimedia automated complex МАК. Complex МАК, using the system of GPS-monitoring, allows to follow the characteristics of the city buses traffic on-line. The choice of city public transport which goes along the determined routes, is caused by a number of reasons, the main of which are: availability of strict route and traffic schedule, rise of communities' interest to the usage of electric buses as public transport, substantial affect of the traffic modes on the indices of energy efficiency and power consumption for this mean of transport.

According to the results of made experiments there was built a curve of urban driving cycle for Lutsk city (Fig. 2) [16, 17]. The given results were averaged using the linear filtration by a group of points which are situated on the same time period, in such a way there was received an average graphic model of a driving cycle for city buses.



(**a**) (**b**)

Figure 2. City driving cycle of a bus: (**a**) experimental data; (**b**) averaged curve

The made researches will contribute to the next developing of a question of creation of a standardized driving cycle for electric buses.

In general case the power consumption by a vehicle with electric drive is a ratio of a performed work A, J and general efficiency η_Σ:

$$E = \frac{A}{\eta_\Sigma} \quad (1)$$

General power consumption E_Σ is determined by the instant power consumption, for every second of driving cycle E_Σ:

$$E_\Sigma = \sum_{i=1}^{t} E_{mi} = \sum_{i=1}^{t} \frac{A_{mi}}{\eta_\Sigma} \quad (2)$$

On the other hand, work A, which was performed during the movement of a vehicle, is calculated by the dependence:

$$A = \int_0^t \left(P_k \cdot V\right) dt = \int_0^t \left((P_j + P_f + P_w \pm P_h) \cdot V\right) dt \quad (3)$$

where P_k, Н – tractive force on the wheels; P_j, Н – force of inertia of a vehicle; P_f, Н – rolling resistance force; P_w, Н – air resistance force; P_h, Н – elevation resistance force; V, м/с – speed of a vehicle; t, с – time.

In given quotation the forces P_j, P_f, P_w, P_h characterize an influence of exterior factors on the power consumption of a vehicle. Especially the force of inertia of a vehicle P_j depends on the acceleration, which in its turn depends on the driving style, road circumstances and road infrastructure, also characterizes the process of braking of a vehicle. The rolling resistance force P_f characterizes the state of road pavement. The air resistance force P_w – weather conditions. The elevation resistance force P_h - longitudinal road profile. The speed is determined by the road circumstances, the state of road pavement, the driver, the availability and the branching of road infrastructure. So, using the force balance of a vehicle, one can determine an influence of exterior factors on the power consumption of a vehicle.

For theoretic researches there was chosen an electric bus Bogdan A70100, manufactured by Daughter enterprise «Automobile assembling factory № 1» of public joint-stock company «Automobile Company «Bogdan Motors», whose characteristics are given in Table 1.

Table 1. Characteristics of electric bus A 70100

Title of an index	Units of measurement	Value
Bus model	-	A 70100
Full mass	kg	18000
Overall height	mm	3500
Overall width	mm	2550
Transmission ration of main gear	-	9,2
Radius of wheel rolling	m	0,49
Engine power	kW	235
Maximum speed	km/h	70

On the Fig. 3-5 there is shown an influence of different factors on the power consumption of a bus. During the calculating there were taken the next ranges of indices change: acceleration – 0.1…2.00 m/s²; wind speed – 0…8 m/s; slope – 0…6°. The choice of given ranges was made taking into consideration the real conditions of buses operation in cities. Calculating was made up to the speed 20 m/s.

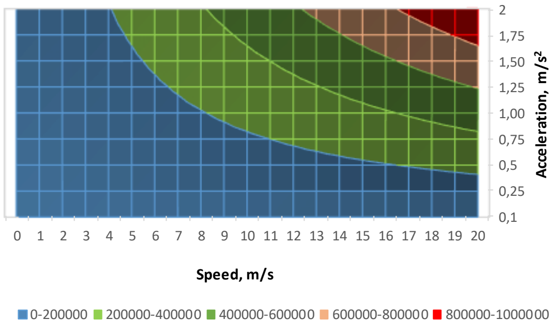


Figure 3. Dependence of power on acceleration at the speed change

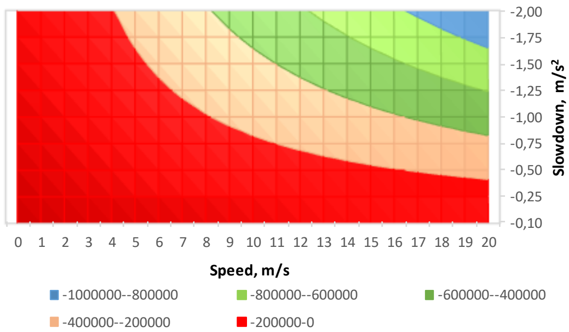


Figure 4. Dependence of power on deceleration at the speed change

In order to simplify the calculation of force of rolling resistance and force of elevation resistance, it is reasonable to consider together, $P_h + P_f = P_\psi$, because both these forces depend on the angle of road slope α .

Fig. 4 shows the dependence of influence of deceleration change on the bus power consumption. In this case it is taken into consideration that a vehicle is equipped with a system of recuperative braking, that is why due to the returned energy, its total consumption will decrease.

Fig. 5 shows a graph of influence of cross-wind speed on the bus power consumption. In a case of fair wind – total power consumption will decrease.

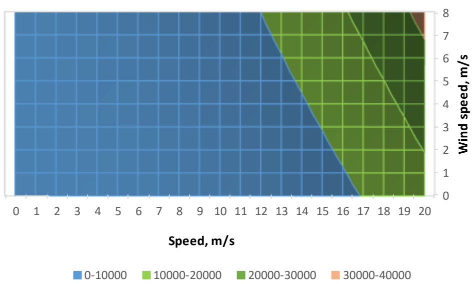


Figure 5. Power necessary to overcome an air resistance at speed change

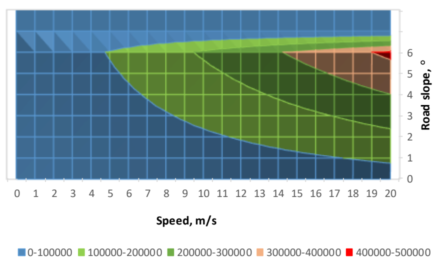


Figure 6. Power necessary to overcome an road resistance at speed change

In order to determine an influence of factors on the vehicle power consumption, all the factors, respectively to the quotation of power balance, are put to the power necessary for bus movement, than a quotation will look like:

$$\frac{N_j}{N_k}+\frac{N_\psi}{N_k}+\frac{N_w}{N_k}=\frac{E_j}{E_k}+\frac{E_\psi}{E_k}+\frac{E_w}{E_k}=1, \tag{4}$$

where N_k, E_k – respectively power and energy spent for vehicle movement, kW; N_j, E_j – respectively power and energy spent for vehicle acceleration, kW; N_w, E_w – respectively power and energy spent for overcoming an air resistance, kW; N_ψ, E_ψ – respectively power and energy spent for overcoming a road resistance, kW.

It was achieved from a dependence (4):

$$k_1+k_2+k_3=1, \tag{5}$$

where $k_1=\frac{N_j}{N_k}=\frac{E_j}{E_k}$ – coefficient, which takes into account an influence of acceleration on power consumption (describes an influence of a driver); $k_2=\frac{N_\psi}{N_k}=\frac{E_\psi}{E_k}$ – coefficient, which takes into account an influence of road on power consumption; $k_3=\frac{N_w}{N_k}=\frac{E_w}{E_k}$ – coefficient, which takes into account an influence of air resistance on power consumption (describes an influence of exterior factors).

Research of a contribution of every factor to the power consumption is rather difficult process, because it is necessary to make an investigation of a car multiple-factor dynamic model where all the factors change in time by chance. That is

$$E=\{E_j;E_w;E_\psi\}, \tag{7}$$

where $E_j=\{E_{j1},E_{j2},E_{j3},...E_{jn}\}$ – set of energy change, spent for vehicle acceleration; $E_w=\{E_{w1},E_{w2},E_{w3},...E_{wn}\}$ – set of energy change, spent for air resistance overcoming;

$E_{\Sigma fh}=\{E_{\psi 1},E_{\psi 2},E_{\psi 3},...E_{\psi n}\}$ – set of energy change, spent for road resistance overcoming.

If one goes to the influence coefficients, the dependence will look like:

$$E=\{k_1;k_2;k_3\}, \tag{8}$$

Along with that, the change of influence coefficients takes place continuously, dynamically in time and as it is shown at Fig. 3 – 6, depends on speed, that is why it is reasonable to make modelling of mutual influence of a system «vehicle – driver – road – environment» taking into account speed of a vehicle. A mathematic model of interconnection of influence coefficients can be shown in matric view:

$$E_c = \begin{matrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ \dots & \dots & \dots \\ k_{(n-1)1} & k_{(n-1)2} & k_{(n-1)3} \\ k_{n1} & k_{n2} & k_{n3} \end{matrix}, \tag{9}$$

where E_c – energy spent for movement during some time or cycle; n – range of speed change during some time or cycle.

In a dependence (9) an amount of all rows of matrix is equal to 1.

As it is almost impossible to make experimental researches with variation of all factors on all levels, there was made a mathematic modeling and determination of coefficients k_1, k_2, k_3. The coefficients were determined respectively to the dependences (4) and (5). The modeling was made by a method of accidental numbers, generating a change of vehicle acceleration, of wind speed, of road slope. The characteristics of road pavement corresponded to a dry bituminous concrete covering.

As it is known, if a number of experiments $m \to \infty$ accidental values take the characteristics of constant. That is why there were determined 5000 of values of influence coefficients for speeds 1, 5, 10, 15 and 20 m/s. According to received values there was built a dependence of influence coefficients from vehicle speed (Fig. 7), in addition to that a matrix of influence coefficients looks like:

$$E_c = \begin{matrix} 0,642 & 0,0028 & 0,3552 \\ 0,648 & 0,0058 & 0,3462 \\ 0,637 & 0,0110 & 0,3520 \\ 0,638 & 0,0170 & 0,3450 \\ 0,629 & 0,0259 & 0,3451 \end{matrix}, \tag{10}$$

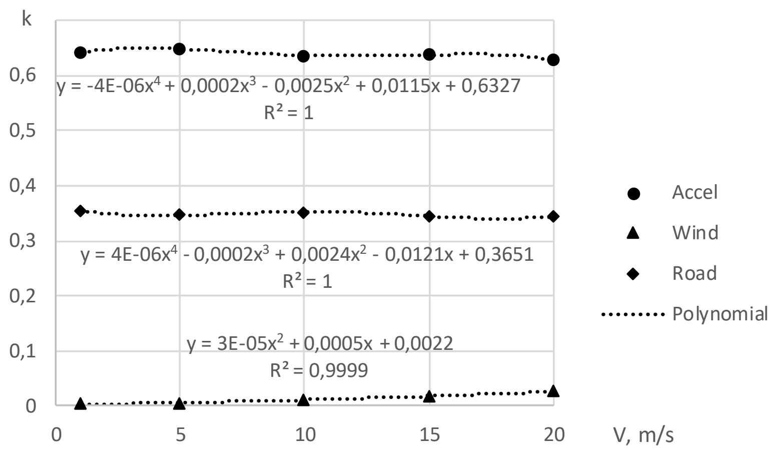


Figure 7. Change of influence coefficients from vehicle speed

Along with that, a dependence (10) does not allow to estimate an influence of factors which lead to diminution of power consumption. That is why it is offered to calculate a contribution of factors according to some values of power consumption. It is offered to take a power consumption of a vehicle in normal conditions as a base. In addition to that, taking into consideration the requirements of UN ECE during road tests, it is recommended to take the next values: an acceleration is equal to 0,75 m/s^2, a wind speed is equal to 0, a road slope is equal to 0, a value of power consumption E received during the calculation, will become a standard value. Than a calculation of influence of exterior factors on an actual power consumption E_c of a vehicle will reduce to a calculation of system of quotations:

$$\begin{cases} k_{11} \cdot E_c + k_{12} \cdot E_c + k_{13} \cdot E_c = E \\ k_{21} \cdot E_c + k_{22} \cdot E_c + k_{23} \cdot E_c = E \\ \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \\ k_{(n-1)1} \cdot E_c + k_{(n-1)2} \cdot E_c + k_{(n-1)3} \cdot E_c = E \\ k_{n1} \cdot E_c + k_{n2} \cdot E_c + k_{n3} \cdot E_c = E \\ k_{i1} = 4 \cdot 10^{-6} V^4 + 2 \cdot 10^{-4} V^3 + 25 \cdot 10^{-4} V^2 + 1{,}15 \cdot 10^{-2} V + 63{,}27 \cdot 10^{-2} \\ k_{i2} = 4 \cdot 10^{-6} V^4 + 2 \cdot 10^{-4} V^3 + 24 \cdot 10^{-4} V^2 + 1{,}21 \cdot 10^{-2} V + 36{,}51 \cdot 10^{-2} \\ k_{i3} = 3 \cdot 10^{-5} V^2 + 5 \cdot 10^{-4} V + 22 \cdot 10^{-4} \end{cases}, \quad (11)$$

Given system of quotations (11) does not completely reflect the real traffic modes. According to the statements of automobile theory, the values of speeding-up during an acceleration of a vehicle stand for:

$$\begin{cases} j = 0 \dots 1{,}0 \ npu \ V = 0 \dots 5 \ m/s \\ j = 0 \dots 0{,}7 \ npu \ V = 5 \dots 10 \ m/s \\ j = 0 \dots 0{,}5 \ npu \ V > 10 \ m/s \end{cases}, \quad (12)$$

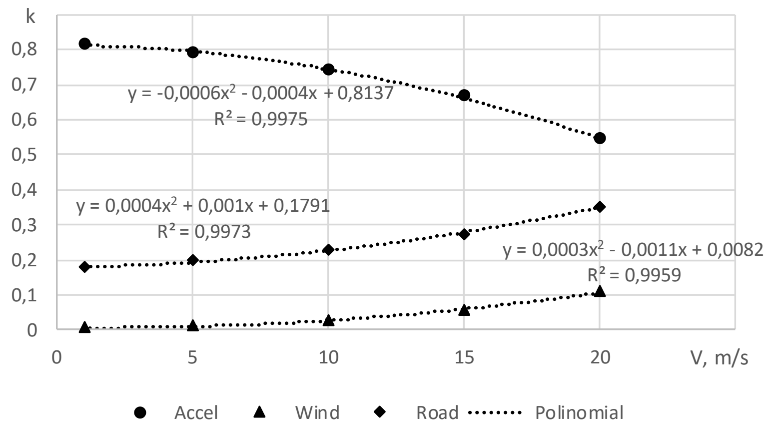


Figure 8. Change of influence coefficients from the speed of a vehicle with inserted restrictions

Than, taking into account the data of a graph shown at picture 8 and restrictions (12), a system of quotations (11) will look like:

$$\begin{cases} k_{11} \cdot E_c + k_{12} \cdot E_c + k_{13} \cdot E_c = E \\ k_{21} \cdot E_c + k_{22} \cdot E_c + k_{23} \cdot E_c = E \\ \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \\ k_{(n-1)1} \cdot E_c + k_{(n-1)2} \cdot E_c + k_{(n-1)3} \cdot E_c = E \\ k_{n1} \cdot E_c + k_{n2} \cdot E_c + k_{n3} \cdot E_c = E \\ k_{i1} = -6 \cdot 10^{-4} V^2 - 4 \cdot 10^{-4} V + 81{,}37 \cdot 10^{-2}, \\ k_{i2} = 3 \cdot 10^{-4} V^2 + 11 \cdot 10^{-4} V + 82 \cdot 10^{-4} \\ k_{i3} = 4 \cdot 10^{-4} V^2 + 10^{-3} V + 17{,}91 \cdot 10^{-2} \\ j = 0 \dots 1{,}0 \ m/s^2 \ npu \ V = 0 \dots 5 \ m/s \\ j = 0 \dots 0{,}7 \ m/s^2 \ npu \ V = 5 \dots 10 \ m/s \\ j = 0 \dots 0{,}5 \ m/s^2 \ npu \ V > 10 \ m/s \end{cases} \quad (13)$$

In order to solve a problem of determination of external influence levels on a power consumption of a vehicle on some road or a part of road, it is necessary to determine coefficients k_1, k_2, k_3 in a system of quotations (14):

$$\begin{cases} k_1 = -6\cdot 10^{-4}V^2 - 4\cdot 10^{-4}V + 81{,}37\cdot 10^{-2} \\ k_2 = 3\cdot 10^{-4}V^2 + 11\cdot 10^{-4}V + 82\cdot 10^{-4} \\ k_3 = 4\cdot 10^{-4}V^2 + 10^{-3}V + 17{,}91\cdot 10^{-2} \end{cases}, \quad (14)$$

In such a way, there were established two ways of determination of influence of exterior factors on a power consumption of a vehicle on micro and macro levels. It is offered to establish an influence of exterior factors on micro level, that is on every simple part of cycle of vehicle movement, using the dependence (13). Using the dependence (14) it is offered to determine an influence of exterior factors by the results of passing some part of a road, that is on macro level. In this case it is reasonable to take into consideration an average technical speed of a vehicle while calculating. It is worth to mention that the research of influence of exterior factors on micro level, that is a growing of number of detailing points, essentially increases the exactness of calculation, but along with that it rather complicates the process of calculation and needs a usage of probabilistic methods, that will be made for certain in future researches.

5. Discussion of the results

According to the results of analysis of taken researches, there was determined an influence of exterior factors, namely a driving style, an air resistance and a road profile on a power consumption of a bus equipped with electric drive. It was shown that an influence of bus driver decreases along with bus speed increasing, and an influence of road pavement and air resistance grows up.

By a defined city bus driving cycle shown at picture 1a, there was determined a total power consumption at ideal conditions (Fig. 9), and at a condition of increasing of bus acceleration for 30 % (Fig. 10), that is an imitation of aggressive traffic conditions.

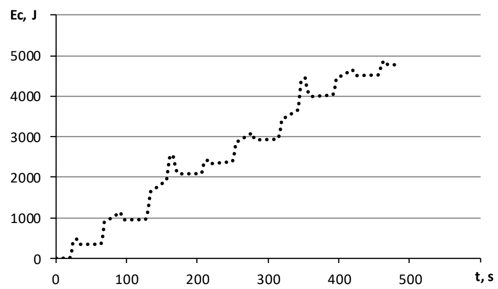


Figure 9. Power consumption during the bus movement by a driving cycle at normal conditions

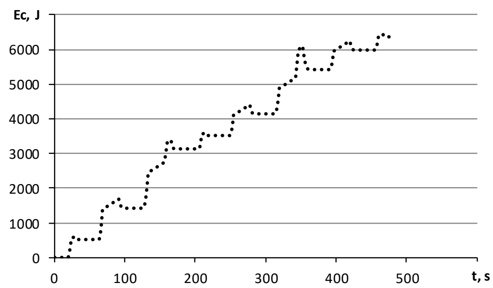


Figure 10. Power consumption during the bus movement by a driving cycle at increase of acceleration for 30 %

Power consumption, with taking into account an operation of energy recuperation system, in first case stands for 4761.5 kJ, in second case – 6376.9 kJ. The results of calculating the coefficients of influence are given in table 2.

Table 2. Results of calculating the coefficients of influence k_1, k_2, k_3

	k_1	k_2	k_3	Quantity of spent energy, kJ	Average technical speed of movement, m/s
Normal conditions	0.787367	0.019997	0.192636	4761.5	4.7
Aggressive type of movement (at acceleration increasing for 30 %)	0.779975	0.023325	0.19670	6376.9	5.5

As it is evident from Table 2, at the aggressive movement mode, the coefficients of driver's influence is a little decreasing, and influence of environment and of road resistance are respectively growing up, what is caused by higher speeds. Along with that power consumption increased for 34%. Such disconformity is caused by a factor that the calculation of influence coefficients was made for driving cycle shown at Fig. 2(**b**), and in order to get more exact evaluation of influence of exterior factors, it is worth to make their calculation for elementary parts of driving cycle.

6. Conclusions

The aim of present researches was to explore an influence of exterior factors on the power consumptions of the vehicles which go along set city routes. Used method foresaw the data collection about real traffic modes of buses in Lutsk city, a treatment of their results and a determination of driving cycle, an exploring of contribution of exterior factors in power consumption.

Received results of theoretic researches give a possibility to divide an influence of main factors on power consumption of a vehicle and to determine their contribution on macro level. It was found that an influence of a driver on power consumption is within 50…80 %, an influence of air resistance is up to 10 %, an influence of longitudinal profile and road resistance changes within 20…35%.

Received results can be used rather widely: a determination of driver qualification level, of state of road pavement, will give a possibility to find more reasonable placement of bus stops, cross-lights etc.

Offered researches results can not be directly used for other traffic conditions, regions, using another vehicles without additional researches. Along with that the present object research assures the previous results aimed at the decreasing of influence of exterior factors on power consumption of the vehicles.

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