

Modeling of a power consumption by bus in the real operating conditions

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ABSTRACT

In spite of numerous researches concerning a power consumption by the vehicles, during everyday operation there are the significant deviations from the consumptions indicated by the factories-manufacturers. It is caused by a great number of different factors, the main part of which take the operating conditions. In order to determine the power consumption of a vehicle in real operating conditions, it is necessary to solve a difficult problem with many unknowns. While making the investigations, the authors have used a multi-criteria approach that takes into consideration the guided, unguided and conditionally guided factors that influence the vehicles power consumption. The in research work approach provides a modeling of a power consumption by the vehicles with a simultaneous changeability of factors in the determined limits. The researches were made on a base of T70110 trolleybus. There was made an investigation of influence of every factor on a power consumption, in addition to that there were made 7000 simulations, on the base of which, using a law of large numbers, there were found the corresponding changeability ranges. During the researches there were made 122 simulations of a power consumption, as a result of which there was determined an area of values of a power consumption.

The obtained theoretical results are very well correlated with the experimental data, and a deviation is equal to 3...6 % for normal operating conditions. A comparison of the received data of a power consumption with the researches results, obtained by another researchers, also shows a great convergence.

Introduction

A present stage of development of the vehicles constructions is characterized by a rapid improvement of the electrical traction vehicles, especially the electric buses and trolleybuses with an autonomous drive. The constructions of such vehicles are constantly improved and cheapened. In the complex researches [1] made by Oak Ridge National Laboratory (ORNL) and National Renewable Energy Laboratory (NREL) there were noticed the main achievements and blanks in the technologies concerning the vehicles electrification. The authors have stated a strong tendency to a decreasing of a cost of accumulator batteries up to 2030 (Fig. 1.1). Of course, it will positively influence the further development of the electric vehicles, but along with that there are still some problems that need a solution.

Literature review

One of the problems that is rather significant on a present phase of development of the electrical buses and trolleybuses with an autonomous drive, is their operating reserve on an electric traction. The value

of an operating reserve of electrical bus or trolleybus influences their cost and mass and, correspondingly, a passenger capacity, that means that in any case it will determine an energetic effectiveness of a vehicle. On the other hand, an increasing of an operating reserve raises the trolleybuses mobility, so it would positively reflect on the transport operation. The construction specialties of the trolleybuses bodies give a possibility to produce the vehicles in accordance with the concrete customer's requirements concerning an autonomous operating reserve on electrical traction. While taking this into consideration, it is necessary to serve the routes by the vehicles that have an optimal operating reserve, that is this operating reserve is enough for a movement by the determined routes and schedule, at the same time a non-used excess energy reserve is absent. This theory is confirmed by the researches [2], by the result of which there was presented an instrument of electrification of urban bus transport that is based on a virtual modeling of parks of ordinary and electrical buses during the recorded driving cycles, including a charge control. The instrument allows to arbitrarily install the disposition of the charging stations, the number and the parameters of charging devices for every station, the net restrictions, a capacity of accumulator of electric bus and other like factors. The similar researches

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were made and reported in the works [3], they are mainly based on a planning of infrastructure to ensure an operation of electric buses.

As the analysis of previous researches shows, the main problem that appears during a determination of necessary operating reserve by the electrical vehicles, is an indetermination of the operating conditions [4–6]. In the research work [7] there was made an analysis and comparison of the power consumption and the effectiveness of using the hybrid and electrical urban buses that are operated on different routes. Such researches are presented in the works [8–12].

In the research work [13] there are examined the factors that affect a power consumption by the electrical vehicles and there are given the interconnections inside the system «vehicle – driver – road – environment». In this research work the authors have examined an influence of external factors on a power consumption in Lutsk city taking into consideration a driving cycle. The factors that influence a power consumption by an electrical vehicle can be divided into three groups: guided, conditionally guided and unguided (Fig. 2.1). An influence of guided factors can be minimized by means of some measures. The conditionally guided factors are practically unchangeable during their operation, but their influence can be decreased by the infrastructure changes. An influence on the unguided factors is impossible, they can be only taken into consideration during the vehicles operation.

The guided factors are the factors that can be controlled, that is they are to be changed, and that allows to obtain such their values that the power consumption was minimal. A driving style and a traffic conditions are regarded as the guided factors. In a research work [14] the authors, on a base of the made experimental researches, have found that a difference of power consumption by different drivers, if all other factors are invariable, can be equal up to 10 times. Such researches, made for buses equipped with the internal combustion engines [15], prove a great difference of fuel consumption at different driving styles. Besides, one can notice the researches [16–18]. A bus traffic conditions usually greatly depend on a driving style, but a traffic schedule can also greatly influence a power consumption by bus. This hypothesis is proved by the researches results showed in [5,19–22]. Along with that, while planning a traffic schedule it is possible to take into consideration the economic traffic conditions. An analysis of the previous researches results proves a possibility of effective control of the mentioned factors and further minimization of their influence on a power consumption by buses with an electric traction.

The conditionally guided factors. The conditionally guided factors do not allow a possibility to change their influence while operating, along with that their influence is fairly good taken into consideration while planning the route, the infrastructure or buying the vehicles. That is why a vehicle construction is added to these factors, that is determinant during the power consumption calculation [23–26], the infrastructure that is a presence of charging stations, of contact net [27], and also the

characteristics of a traffic route [28–30].

The design of an electric car, both for use in order to meet the delivery needs of the "last mile" in an urban area, and for suburban delivery in small villages in Italy (Sicily), is considered by the authors in the work [31]. The significance and influence of design factors on the efficiency of operation of vehicles is very well demonstrated in the article.

The ability to manage this group of factors has been demonstrated in studies [32]. In particular, the impact of traffic and traffic-related infrastructure on users and non-users of the system is shown in the paper.

The unguided factors. A traffic flow, that is the frequency of stops, the down time on the stops, the number of passengers will directly influence the traffic condition of an electric bus, its weight and, as a result, a power consumption [33–35]. An influence on a traffic flow on which there would depend a down time at the stops, is practically impossible. Taking into consideration that a driver should follow a traffic schedule, a presence of great number of passengers will lead to a longer down time, and in future the traffic conditions will be broken as a driver would have to compensate a schedule overrun by a more aggressive driving. A condition and a type of pavement, according to the made researches [36, 37], can also in a great way influence a power consumption by the vehicles. An analogical influence on an energy effectiveness of the electric buses is given also by the traffic conditions [34,38] and climatic conditions [37,39,40].

A great number of researches are dedicated to a research of mutual influence of different factors on a power consumption by the electric buses [41–45]. In a research work [46] the authors have made an investigation and have determined 19 factors that influence an effectiveness of movement of traffic flows that are divided into 4 categories. These researches give a possibility to make a fuller modeling of traffic conditions of the vehicles and their power consumption. An analysis of the above-mentioned researches demonstrates a great uncertainty of external affects, both guided and unguided factors, that makes an adequate modeling of power consumption by the electric buses, impossible. This fact leads to significant difficulties while predicting the real power consumption, and also to a minimization of negative affects on a power consumption by the vehicles.

In a research work [13] the authors have investigated an influence of external factors on a power consumption by the vehicles, but taking into consideration their great uncertainty, it is necessary to make a complex analysis of their influence.

The new research methods of the vehicles characteristics in the real operating conditions are given in the research works [47–53].

Two models of route selection (for freight and passenger transportation) were obtained by the authors in the paper [54]. The peculiarity of the studies carried out is precisely a demonstration of how the multinominal logit-model was adapted to simulate the choice of a route

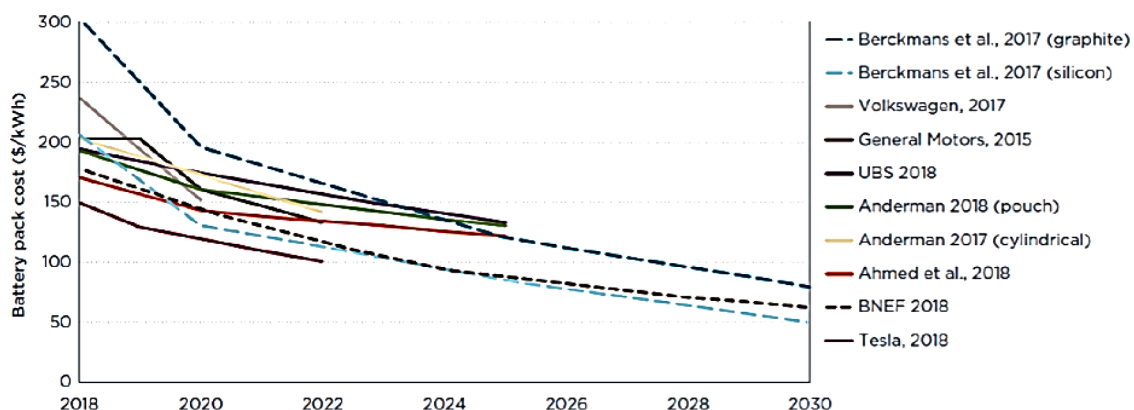


Fig. 1.1. Projection of battery pack costs compiled by the International Council on Clean Transportation. Source: Nic Lutsey and Michael Nicholas, "Update on electric vehicle costs in the United States through 2030," Working Paper 2019-06, International Council on Clean Transportation, April 2019 [1].

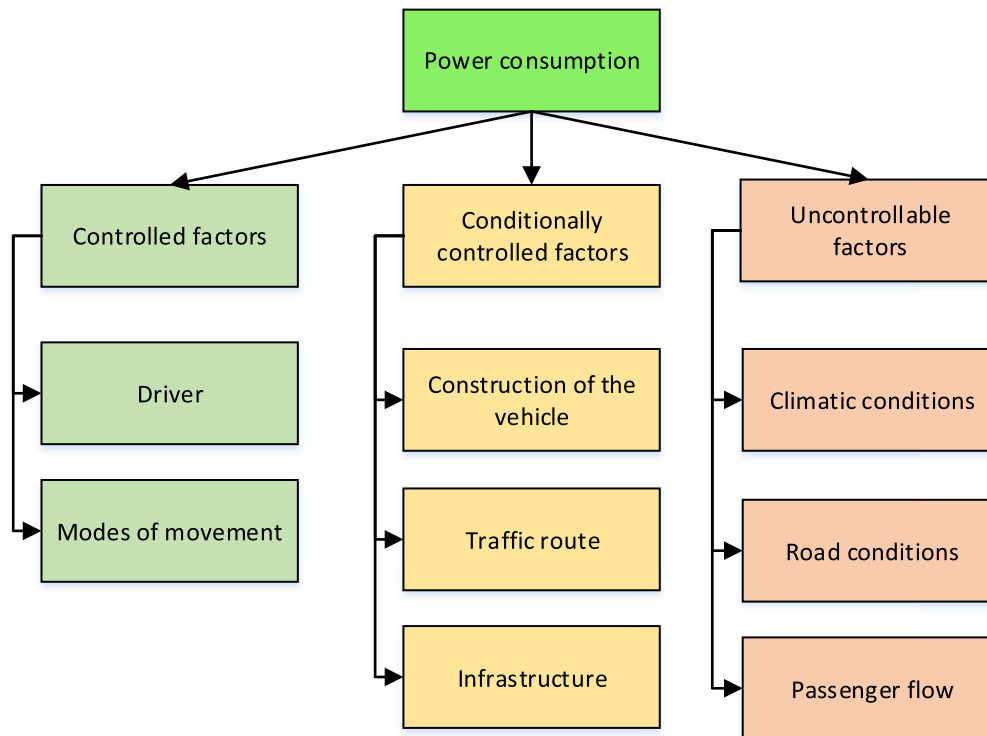


Fig. 2.1. Factors that influence a power consumption by the vehicles.

for a large problem for both passenger and freight transport.

Due to the increase in the number of deliveries from seller to customer, a phenomenon called "last mile" delivery has recently emerged. It is actively researched from a scientific point of view [55,56]. The authors, as one of the options for optimizing delivery processes, consider the use of electric vehicles. In addition, the issue of reducing the cost of delivery of goods is the solution of a multifactor problem with a large set of controlled, uncontrolled and conditionally controlled factors. The results of the studies, given in [54–57], demonstrate trends in the adaptation of vehicles to real (specific) operating conditions.

Having reviewed the literature on the modeling of energy consumption by electric vehicles, the authors concluded that the creation of a multi-criteria model of electric energy consumption would make it possible to assess the efficiency of the use of vehicles with certain characteristics in specific operating conditions.

An analysis of the modern scientific researches indicates a great interest among scientists in solving a problem of the vehicles power consumption in different operating conditions. This question is rather significant while developing the new motor vehicles, using the vehicles in some special conditions, during their comparative evaluation.

In such a way the object of given research work is a modeling of an influence of external factors on a power consumption by the vehicles equipped by the electric engines.

Modeling energy consumption

Equation of motion of the car

It is advisable to make a calculation of fuel consumption using the clauses of a theory of the vehicles traffic [34,40,58,59]. In a research work [60] there was made a modeling and an evaluation of power consumption by an electric vehicle, and along with that there was made a modeling of all the necessary vehicle components. As for the purpose of given researches there is important just an influence of external factors, so the further calculations will be made without taking into consideration the particularities of a bus construction, except a loading,

because this indicator greatly depends on a passenger traffic. As though almost all the external factors that influence a power consumption by a vehicle, are the random quantities that are characterized by an uncertainty in some range, so it is advisable to use a Law of large numbers to vary these factors [61,62].

Determining of the forces that influence a motor vehicle during its movement was made by the well-known power balance equations [52, 53,58,63–65].

Parameters change limits

To make further researches, it is necessary to determine an area of the parameters change, to find the changeable and unchangeable parameters. For this purpose all the parameters that are included into the equation of a vehicle movement are divided into two groups: constructional that are determined only by a vehicle construction and do not change while moving, and operating that change during vehicle movement (Table 3.1). Besides, the operating parameters are divided into subgroups, according to a scheme given on Fig. 2.1.

By the accepted values of the indices, using the power balance equations [52,53,58] one can calculate a force necessary for a vehicle movement.

Electricity consumption

It is reasonable to calculate a power that would be consumed for a vehicle movement, by a dependence [74–77]:

$$E = \frac{A}{\eta_{\Sigma}} \quad (3.3)$$

Taking into consideration (3.3), it is reasonable to calculate a general power consumption as a sum of momentary power consumptions, per every second of a driving cycle [13]:

Table 3.1
Accepted admissible ranges of the parameters change that are included into an equation of a vehicle movement.

Parameter name	Designation	Measuring unit	Range of a change
1. Constructional			
Vehicle mass		kg	Does not change for a specific vehicle. For the researches, there were determined the ranges of change from 10 000 kg – for a curb weight of a 10 m electric bus up to 30 000 kg for a full mass of 18 m electric bus
Coefficient of consideration of the vehicle gyrating masses		–	Does not change for a specific vehicle. Approximately can be calculated by a dependence [66,67]: $\delta_r = \frac{1}{1.04 + 0.04 \cdot u_i^2}$ where u_i - a transmission ratio of i -gear. Taking into consideration that most trolleybuses and electric buses have no gearbox, it is accepted that $u_i = 1.00$
Wheel track of a vehicle	B	m	Does not change for a specific vehicle, the values are taken according to its technical characteristics.
Maximum height of a vehicle	H	m	Does not change for a specific vehicle, the values are taken according to its technical characteristics.
Coefficient of a vehicle streamlining	k_w	–	Does not change for a specific vehicle, the values are taken according to its technical characteristics. It is calculated by a formula [68] $k_w = 0.5 \cdot C_x - \rho_a$ where C_x - a coefficient of aerodynamic force that depends only on the vehicle surfaces configuration. It is taken as 0.76...0.86, according to [69] $= 1.229 \text{ g/cm}^3$ - air density
2. Operating			
Acceleration of a vehicle during its speed-up		m/s^2	According to [13] the accelerations of a vehicle during its speed-up are equal to: $\begin{cases} j = 0 \dots 1.0 \text{ m/s}^2 & V = 0 \dots 5 \text{ m/s} \\ j = 0 \dots 0.7 \text{ m/s}^2 & V = 5 \dots 10 \text{ m/s}, (3.1) \\ j = 0 \dots 0.5 \text{ m/s}^2 & V > 10 \text{ m/s} \end{cases}$
Retardation of a vehicle while braking		m/s^2	According to [70] a retardation of a vehicle while braking is accepted within: $\begin{cases} j = -1.05 \dots 0 \text{ m/s}^2 & V = 0 \dots 5 \text{ m/s} \\ j = -0.85 \dots 0 \text{ m/s}^2 & V = 5 \dots 10 \text{ m/s}, (3.2) \\ j = -0.50 \dots 0 \text{ m/s}^2 & V > 10 \text{ m/s} \end{cases}$
Running speed of a vehicle	V	m/s	It is determined by a driving cycle or the real traffic conditions. A corresponding reasoning of the taken values would be given below.
Wind speed	V_a	m/s	It depends on a season of the year and a region of operation, it is taken within 0...7 m/s, according to [71]
Angle between a wind direction and a longitudinal axis of a vehicle	b	–	0...360°
Coefficient of a rolling resistance		–	It depends on a state and a type of pavement, meteorological conditions, it changes within 0,01...0,02 [72]. Besides a coefficient of a rolling resistance depends on a vehicle speed and can be calculated by a dependence $f = 0.005 + (1/p)(0.01 + 0.0095(V/100)^2)$ where p - an air pressure in tires, bar; V - a vehicle speed.
Angle of a longitudinal rise (slope) of a road.		°	Depends on a specific road, taking into consideration the urban operating conditions it is taken 0...10%, according to [73]

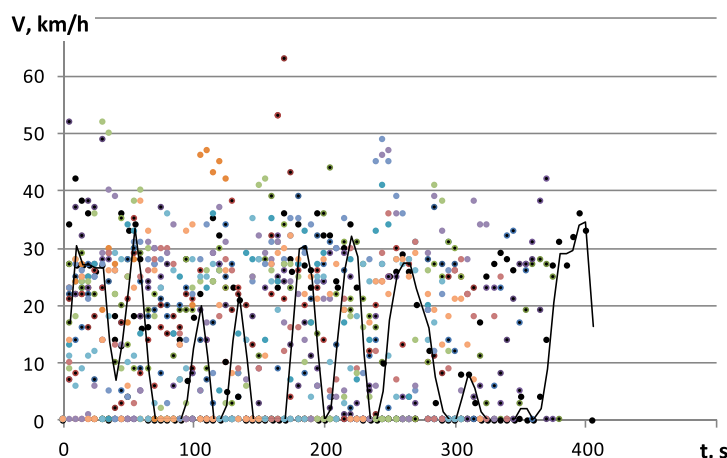


Fig 3.1. Fragment of a bus schedule in Lutsk city [13].

$$E_{\Sigma} = \sum_{i=1}^t E_{mi} = \sum_{i=1}^t \frac{A_{mi}}{\eta_{\Sigma}} \quad (3.4)$$

Then a power consumption of a vehicle during its movement will be equal to:

$$E_{\Sigma} = \frac{1}{\eta_{\Sigma}} \int_0^t (P_k \cdot V) dt = \frac{1}{\eta_{\Sigma}} \int_0^t ((P_j + P_f + P_w \pm P_h - P_{\tau}) \cdot V) dt \quad (3.5)$$

While analyzing a dependence (a previous formula), it is necessary to determine a driving cycle by which there would be made the next calculations.

Determination of the driving cycle

In a research work [78] there was made an analysis of the modern approaches concerning the application of driving cycles during the modeling of operating indices of the vehicles, including the power consumptions. An absence of a standardized driving cycle for the vehicles of M₃ category leads to a development of the driving cycles for specific operating conditions and specific cities. The results of the made experimental researches concerning the buses traffic conditions that run by the established urban routes, are showed on a Fig. 3.1.

As it is shown on Fig. 3.2, the elementary parts of a driving cycle «speed-up - braking» are preceded on a graph, with maximum speed 30 km/h. That is why for further researches there was accepted an elementary part of driving cycle, shown on a Fig. 3.2.

Maximum running speed is equal to 35 km/h (9.7 m/s), running time is 23 s. It is worse saying that in this case only the completely electrical vehicles are investigated that is why it is accepted that during the stops they do not consume power that is used for running, and that explains an absence of such parts in an elementary driving cycle shown on a figure.

Technical characteristics of the vehicle

A calculation of power consumption was made for a trolleybus T701, its technical characteristics are given in Table 3.2.

On a first phase there was made a modeling by separate components, that influence a power consumption: a vehicle inertial force (P_j), a movement resistance force (P_f), an air resistance force (P_w), an elevation resistance force (P_h), a braking force of a vehicle (P_τ), in order to determine a contribution of every of them. During a modeling the parameters changed in the frames whose grounds are shown in Table 3.2.

Forces acting on the vehicle

By the results of made researches there were built the corresponding graphs shown on the Figs. 3.3–3.6. The given graphs were built on the

Table 3.2

Technical characteristics of a trolleybus of a model Bogdan T701.

Index name	Trolleybus modification
	T 70,110
Overall length by the body elements, mm	11,960
Overall width, mm	2550
Overall height, mm	3800
Wheel base, mm	5860
Track of front/rear axis, mm	2160/1890
Passenger capacity, persons	105
Empty mass, kg	11,800
Technically admissible maximum mass, kg	18,940
Front axis	VOITH TURBO IFS 75–225
Rear axis (driving)	ZF AV-132/80
Gear ratio of a main gear	9.82
Wheel tires	275/ 70R 22.5
Tires pressure, kgs/cm ²	8.0
Traction engine	EJL–139AY2
Impulse converter (IGBT)	Cegelec CDC 050P
Static converter 600/27 V, 3 pH 400 V	Cegelec SMTK 7.0Z
Block of brake resistors	R9PO4B125, 300 kW
Engine of a compressor actuator	Siemens 1LA7113–4AA10-Z
Engine of a hydraulic pump actuator	Siemens 1LA7106–4AA16
Accumulator battery	6CT–190, 12B, 190 A*h (2 pcs)
Radio interference reduction unit	EMC 2KN-350
Front axis suspension	Independent, pneumatic with two-lever directors, two elastic elements, two telescopic hydraulic shock absorbers and a body position regulator
Rear axis suspension	Dependent, pneumatic with a bar director, four elastic elements, four telescopic hydraulic shock absorbers and two body position regulators
Steering control	Steering device – integral with a hydraulic booster. Steering column – regulated by an angle of slope and by height
Running brake system	Pneumatic, double-circuit with ABS system, braking devices of all wheels – disk, with automatic control of clearance between the brake pads and a disk
Parking brake system	One of the contours of a running brake system
Emergency brake system	Mechanical drive of the wheels braking devices of the driving axis from the spring energetic accumulators of rear axis with pneumatic control
Auxiliary brake system	Electrodynamic braking as a function of tractive electric engine

base of received values of corresponding forces, taking into account a law of large numbers – a number of points is 7000.

On Fig. 3.3 there was shown a range of change of an elevation resistance force during a vehicle movement. A symmetry of obtained

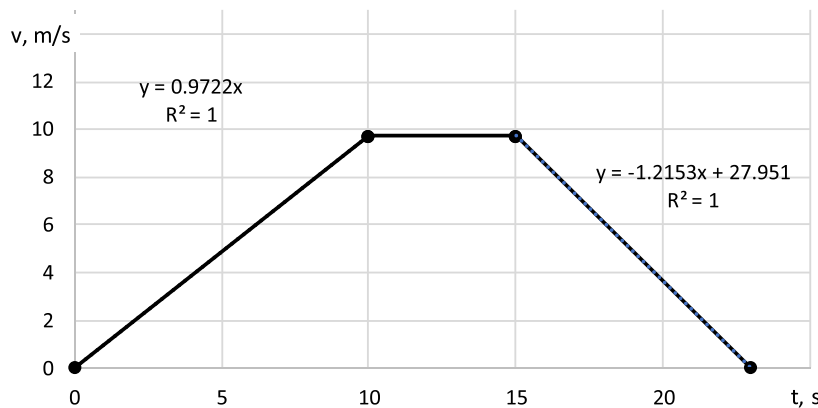


Fig. 3.2. Part of driving cycle where there was calculated a power consumption by the vehicles.

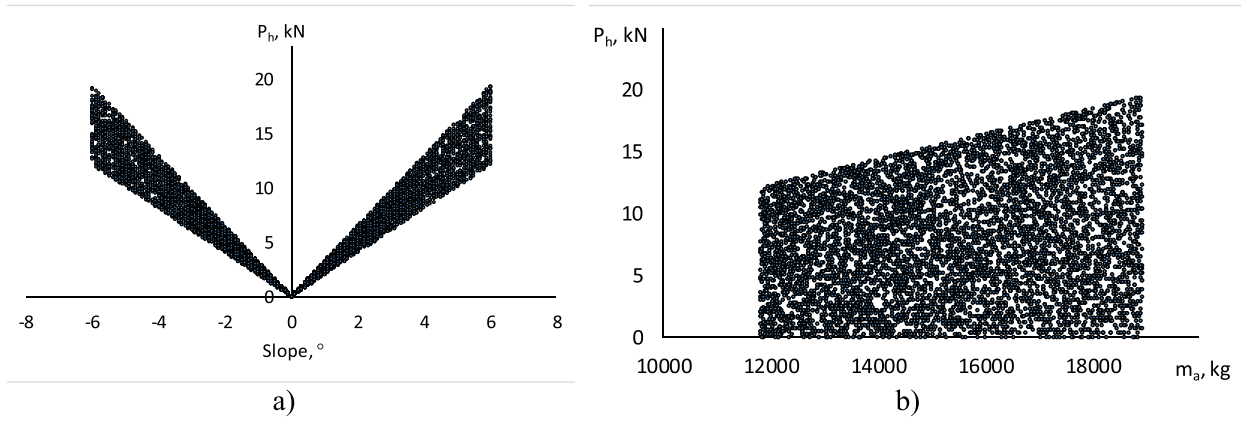


Fig. 3.3. Range of change of an elevation resistance force during a vehicle movement: a) value of slope; b) value of mass.

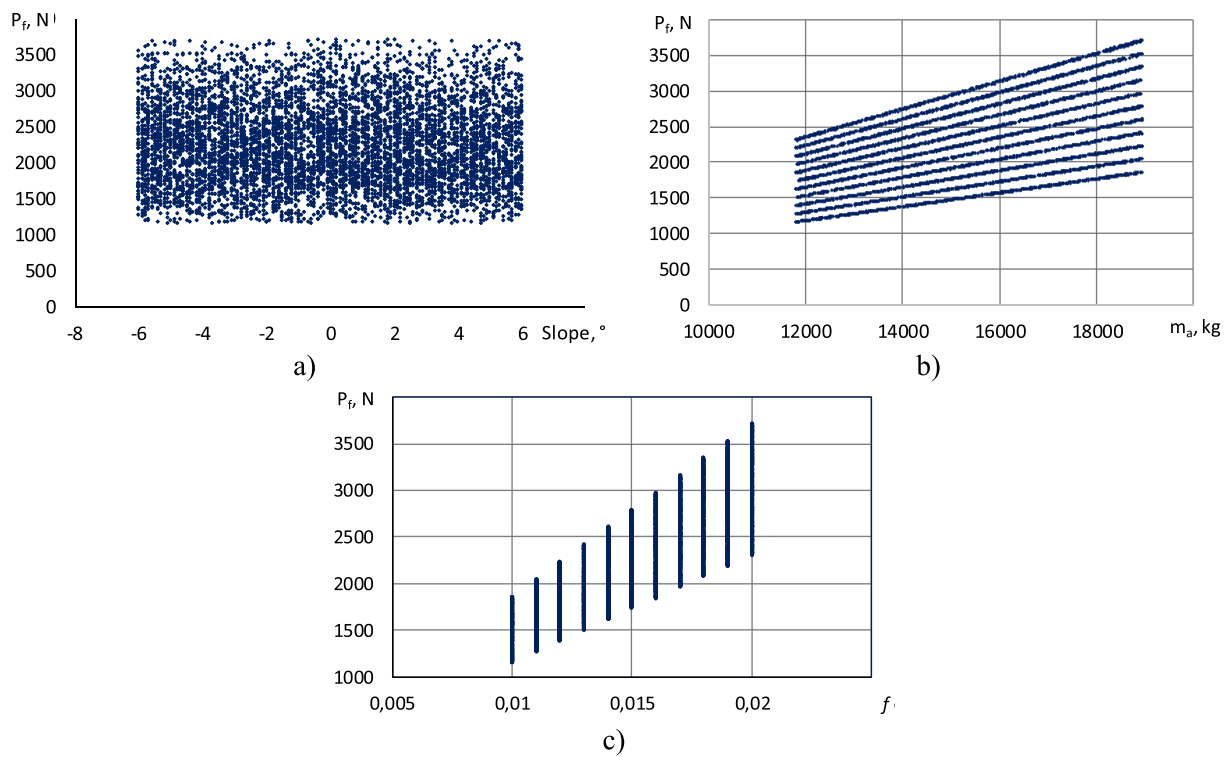


Fig 3.4. Range of change of a rolling resistance force during a vehicle movement: (a) value of slope; (b) value of mass; (c) value of a rolling resistance coefficient.

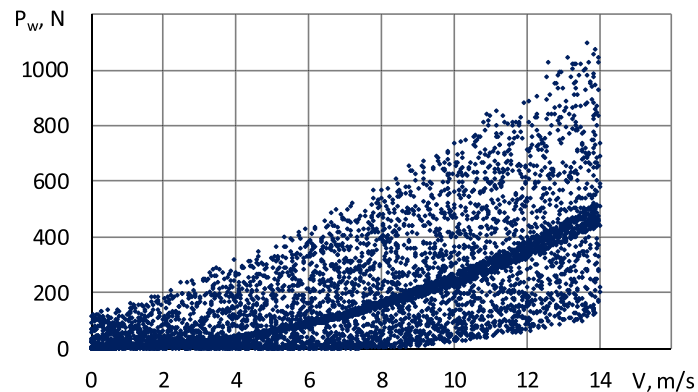


Fig. 3.5. Range of change of an air resistance force during a vehicle movement.

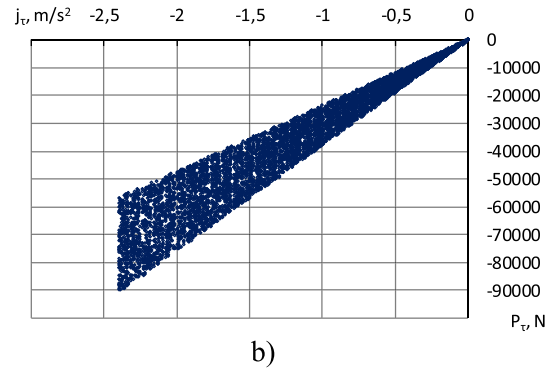
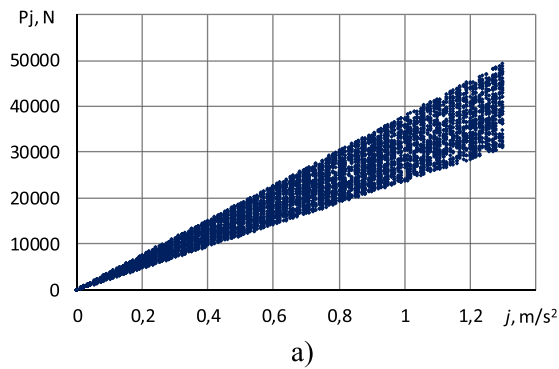


Fig. 3.6. Range of change of: (a) a force of inertia and (b) a braking force during a vehicle traffic.

graph indicates the identity of the elevation resistance force, the key meaning has a mathematical character. In this case a positive meaning of slope indicates a vehicle movement up, and a negative – down. Also a traffic condition of a very vehicle is important, as though an influence of given force can both help to economize an electricity and lead to a decreasing of its consumption. Besides during a modeling of influence of an elevation resistance force, a meaning of a bus mass was accidentally changing from a curb weight to a full weight, imitating a change of passenger number, that is why given model takes into consideration a change of two factors: a road slope and vehicle mass that change incidentally independently of each other. A range of change of given force is shown below in Table 3.3.

On Fig. 3.4 there are given graphs of change of a rolling resistance force during a change of three parameters: a vehicle mass, a rolling resistance coefficient and a road slope.

Range of change of a rolling resistance force is equal to 1100...3800 N.

To make a model of influence of an air resistance force there were used three changeable factors: a vehicle speed, a wind speed and its direction, along with that the main purpose was to take into consideration an influence of a head wind and a fair wind. The graphs are given on Fig. 3.5.

A range of change of an resistance force is rather significant, as though wind speed and direction have got a great influence, also there is a big data scattering at high vehicle speed. But there is noticed a strict accumulation of points from a speed 4 m/s, where a scattering is equal approximately 50 N.

A dynamics of change of a force of inertia and of a braking force is shown on Fig. 3.6 (a, b).

As it is noticeable from the given graphs (Fig. 3.3–3.6) a character of influence and a scattering of the forces of inertia and braking forces are almost equal, by their value the braking forces are approximately 1.5...

Table 3.3

Range of change of an elevation resistance force depending on a value of slope.

Slope value, °	Value of an elevation resistance force, N	
	maximum	minimum
-6	19,394.3	10,286.8
-5	16,183.8	8416.6
-4	12,872.2	6287.1
-3	9659.1	4282.0
-2	6424.6	2271.8
-1	3213.7	204.0
0	2900.5	0.0
1	6010.5	2047.6
2	9372.2	4062.8
3	12,575.6	6095.3
4	15,693.4	8096.1
5	18,925.1	10,316.4
6	19,342.0	12,149.2

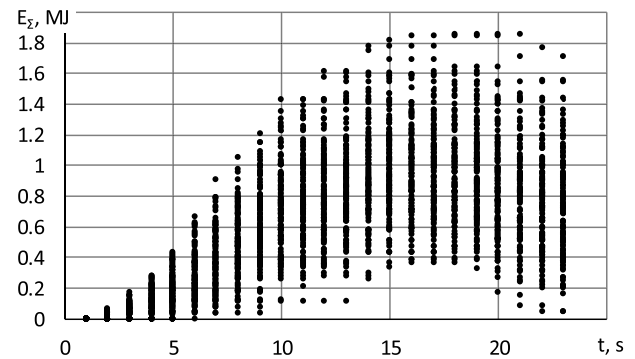


Fig 3.7. Modeling of the accumulated power consumptions by a trolleybus T 70,110, during an influence of external factors.

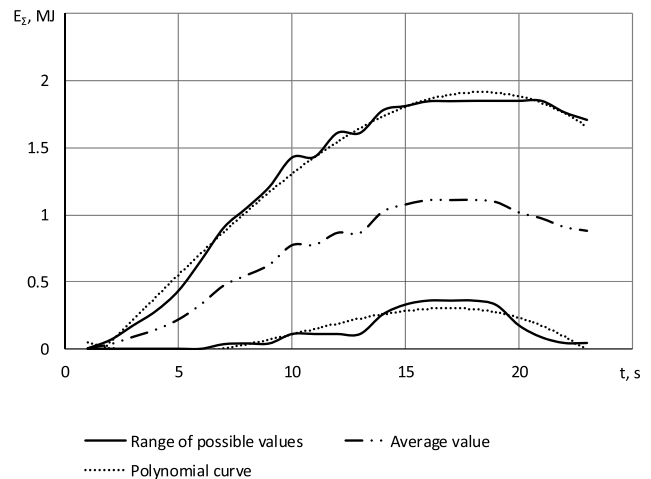


Fig. 3.8. Range of change of the accumulated power consumptions by a trolleybus T 70,110, during an influence of external factors.

2.0 times more than the forces of inertia. While modeling an effect of forces, a vehicle mass and a value of acceleration (deceleration) changed randomly, within the values indicated in Tables 3.1 and 3.2.

Energy consumption during vehicle movement

By the initial data indicated in Tables 3.1, 3.2, 3.3 there was made a modeling of power consumption to overcome a driving cycle shown on Fig. 3.2. The modeling results are given on Figs. 3.7, 3.8, 3.9.

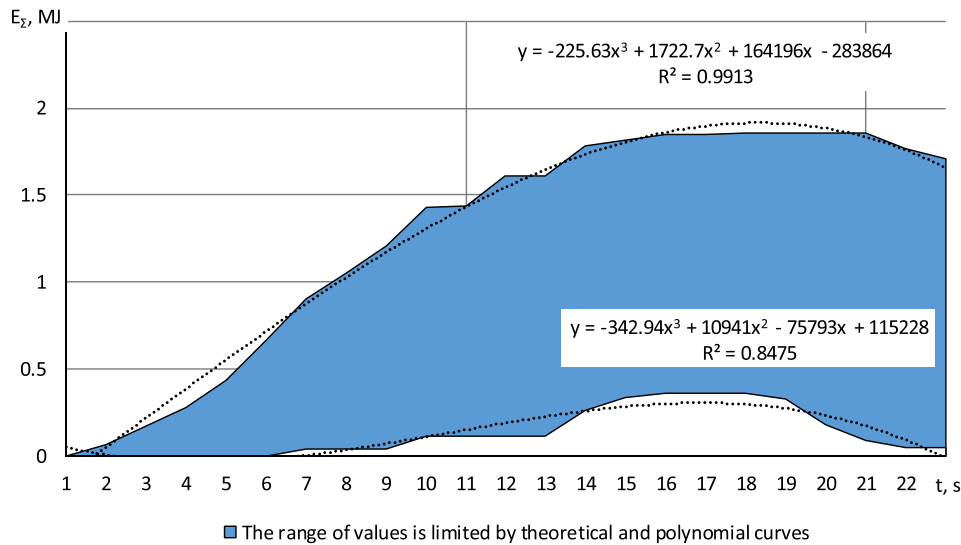


Fig. 3.9. Range of values of the accumulated power consumptions during a traffic by a chosen driving cycle.

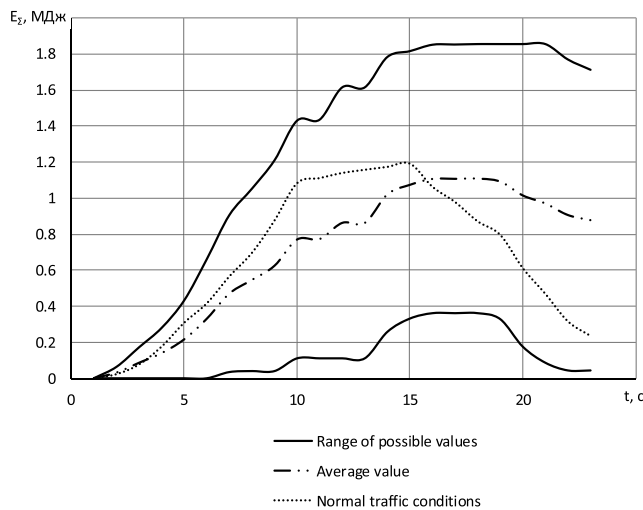


Fig. 3.10. Power consumption during the normal traffic conditions by a chosen elementary driving cycle.

The above shown on Figs. 3.7, 3.8, 3.9 graphs reflect the results of modeling of 122 variants of a trolleybus traffic taking into account an influence of external factors that change randomly with a frequency of 1 s. The received results demonstrate the significant divergences between maximum and minimum power consumptions during a vehicle traffic. On Fig. 3.10 there is given a curve that reflects the averaged accumulated values of power consumption. On Fig. 3.9 there is given a range of supposed values of power consumption during a vehicle traffic by a shown on Fig. 3.2 elementary driving cycle.

On Fig. 3.10 there is shown an accumulating graph of power consumption during the normal traffic conditions. While modeling, the next things are taken for normal traffic conditions:

- a vehicle is running by a straight part of road, that is a slope is equal to 0;
- a wind speed is equal to 0;
- a coefficient of rolling resistance and of acceleration (deceleration) receive the random values according to Table 3.1.

Table 4.1

Theoretical specific power consumption by a vehicle T70110.

Value	Power consumption for covering an elementary driving cycle			Run, km	Specific power consumption kW*h/km
	J	kW*h	W*H		
Maximum	1,710,915	0.475254	475.254	115	4.132646
Minimum	43,504.5	0.012085	12.0845	80	0.134273
Average	742,925.8	0.206368	206.368	102.5	2.013349

Results

The power consumptions during the normal traffic conditions are within a range of supposed values, but they roughly differ from the average values. Taking into consideration this fact, there was taken a decision to determine the specific power consumptions for 1 km of run and for 1 t*km. While modeling, taking into account a change of acceleration (deceleration), a passed distance by the time of covering an elementary driving cycle is equal to 90...115 m. In a Table 4 below there are given the results of calculations of the specific power consumption by a vehicle.

To compare the calculated values of specific power consumption there were used the results of the experimental tests of power consumption by a trolleybus T70110, given by a scientific-testing center «Urban electric transport» of state enterprise «Research and design-engineering institute of city services». The tests were made in Lutsk city on a control route, during a traffic by this route a vehicle was loaded up to maximum permissible mass and was running in a mode of urban electric transport. The results of the experimental researches and their comparisons with theoretical ones are given in a Table 4.2 below.

As one can see from a given Table 4.2, the received experimental data are very well correlated with an average value of a power

Table 4.2

Comparison of theoretical and experimental data.

Value	Specific power consumptions				Deviation,% kW*h/km
	Theoretical data		Experimental data		
	kW*h/km	W*h/t*km	kW*h/km	W*h/t*km	
Maximum	4.132646	218.1967	1.9	103.4	117.5
Minimum	0.134273	7.089401			-92.9
Average	2.013349	106.3014			6.0

consumption where a deviation is equal to 3...6%. Along with that the significant, almost double deviations are seen at maximum and minimum points. This fact is explicated by a significant variation of external factors that have had no influence during an experiment, that is the external factors did not vary in the ranges indicated in Table 3.1.

In a research work [1] there are given the data concerning the specific power consumptions by the commercial vehicles. The specific power consumptions received during the calculations (Table 4.2) are compared with the specific power consumptions presented in [1]. Moreover while comparing there was made a conversion from the American system of units into the system of units SI, there was taken that 1 mile = 1.6093 km. The comparison results are presented on a Fig. 3.11.

From a figure above one can see that the results received during the given researches are very well correlated with the results received by other scientists using another methods, that gives evidence about the adequacy of received data.

Discussion

The received researches results give a possibility to predict the power consumption by the buses and trolleybuses taking into consideration their operating conditions. The main value of this work is that while calculating the power consumption there was used a multi-criteria approach, during it there were determined the ranges of variation of the guided, unguided and conditionally guided factors.

During the investigations there were applied the well-known statements of a vehicle theory to determine the forces that have an affect during the vehicle movement. The factor were varying in the ranges shown in Table 3.1 using the random number generator. Such method assures a precision of obtained results, but also a possibility of using the methodology with another input data.

According to the researches results, the forces of vehicle inertia and the braking forces can get the highest values in the determined ranges. When the forces of inertia lead to the increasing of power consumption, the braking forces, using the energy recuperation systems, will cause the decreasing of a total power consumption. While analyzing the data of conducted researches, taking into consideration the motor vehicle operating conditions, it is possible to introduce the measures concerning the minimization of the vehicles power consumption: due to a using of the economical movement modes, a route choosing; to determine a necessary (rational) cruising range of a bus during its operating by the determined courses; to make a comparative analysis of the vehicles technical characteristics etc.

The offered method of evaluation of the vehicles power consumption can be effective to solve different problems as though it gives a possibility to change a factors variety range, to introduce the new factors, to analyze an influence of separate factors while having the fixed values of

another ones, depending on the given researches tasks.

The proposed method can be implemented during various tasks, for example:

- planning of cargo and passenger transportation routes. Changing the parameters of the route, in particular the speed, the slope of the road, the state of the road surface, the values of electric energy consumption at the specified characteristics of the vehicle are determined. The optimal route is chosen based on the results of the comparison. It is possible to solve the reverse problem, which consists in the selection of a vehicle with optimal characteristics for use in certain conditions;
- development of vehicle structures. In this case, according to the design characteristics of the vehicle, it is possible to obtain its operational indicators for various operating conditions;
- determination of performance indicators of vehicles of their comparison for various conditions, in particular, the type of transportation (freight, passenger), traffic conditions (on established routes, on selected routes, taking into account the lane for public transport, chaotic traffic conditions);
- study and comparison of transport infrastructure of settlements (depending on the number and density of population, area of the settlement).

These are just a few examples of practical application of the proposed approach.

It is also known that vehicle manufacturers during tests determine energy consumption. The obtained values are indicated in the technical characteristics of the vehicle, as well as used for advertising purposes. However, these indicators differ significantly in real traffic conditions. Vehicle manufacturers point to tests conducted under normal standardized conditions. At the same time, the graph shown in Fig. 3.10 shows a wide range of changes in electric energy consumption by the vehicle, depending on the change in operating conditions.

The main innovation of the work consists in the analyzed approaches of modern scientists to the research of energy consumption by electric vehicles and the creation of a multi-criteria model for determining energy consumption with a wide range of variability of factors.

During the further researches the authors plan to pay attention at the time and space frames of the factors variation, as though one parameters change slower, the other ones do it sooner.

In future the methodology would be improved by the increasing of the factors change range and by taking into account the curvilinear movement trajectory of a vehicle.

Conclusion

Theoretically with taking into consideration the law of large numbers, there were determined 7000 values for every force that influences a vehicle during its movement, taking into account a random influence of external and internal factors. There was made a modeling of power consumption during the vehicle movement under the influence of external factors that change randomly. Moreover by the results of modeling of 122 variants of a vehicle movement there was determined a range of power consumption change from 0.1 to 1.9 MJ for a chosen elementary part of a driving cycle. The received theoretical results are very well correlated with an average value of a power consumption where a deviation is equal to 3...6%. Along with that the significant, almost double deviations are seen at maximum and minimum points of a driving cycle. The significant power consumptions determined by a theoretical way, are within 7...218 W*h/t*km, in addition to this the average value of specific power consumptions received by an experimental way is 103.4 W*h/t*km. The adequacy of received theoretical data is confirmed by their correlation with the experimental data and results received by other scientists using another methods.

The offered multi-criteria approach allows to make a vehicle

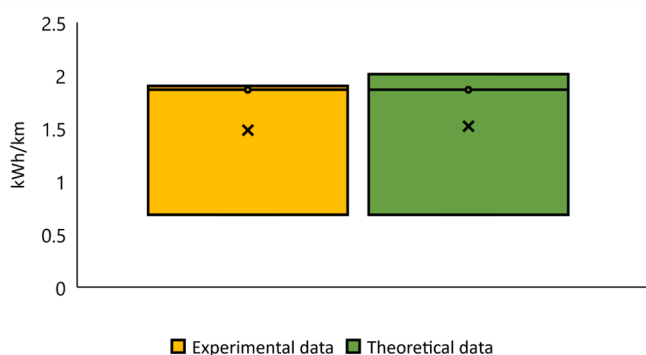


Fig. 3.11. Comparison of the researches results with the results received by other scientists.

movement modeling in the determined operating conditions. It is planned to focus the further researches within given problem on the other vehicle types, especially on the cars and trucks, to take into consideration the other types of pavement, and also to make an analysis of the constructive factors influence on the vehicles power consumption. The authors believe one more perspective research direction is the introduction of the probabilistic laws of factors change that will allow to significantly increase the calculations exactness.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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