CONSTRUCTION OF THE GEOMETRICAL MODELS OF A MULTIPLE-FACTOR OPTIMIZATION OF THE TECHNICAL AND OPERATING PARAMETERS OF THE TROLLEYBUSES WITH AN AUTONOMOUS MOVE MARGIN

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Resume

While introducing into a system of passenger traffic the ecologically clean vehicles, namely the electric buses, a task of providing them with a rational move margin is actual. This problem is especially acute while using the trolleybuses with an autonomous move at urban and suburban routes.

A constructed multiple-factor model and a proposed algorithm of finding the main parameters allow forming the offers concerning a constructive providing of an additional equipment process with the means of autonomous move. Based on a visual presentation of the multidimensional spaces at Radishchev drawing an effective way is offered of a geometrical interpretation of mutual influence of the optimization factors set on the operating characteristics of the additionally equipped vehicles.

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1 Introduction

The world-wide tendencies in an automobile field look more and more towards a development of ecologically clean technologies, the main direction of which is using of an electric power on the vehicles. Almost all the car manufacturers concentrate their great efforts on creation and development of the electric cars and electric buses. Along with that, many countries in Europe declare or even, on a legislative level, determine the restrictions about using cars in cities or some parts of them. All these factors also need an application of corresponding effective decisions of local authorities, in order to optimally organize traffic on a territory of communes and to assure a necessary level of transport availability.

In Ukraine, in spite of existing economic problems, there are actively introduced the technologies that reduce an ecological burden on environment, including transport. According to National transport strategy of Ukraine, for a period up to 2030, it is possible to distinguish the next tasks concerning a development of ecologically clean transport:

- assuring a priority of the ecological safety requirements, obligation of respecting the ecological standards, norms and limits of using the natural resources when making an economic, administrative and other activity;
- realization of preventive measures concerning the environmental protection in automotive field and creating a mechanism of compensation for damages;
- introducing of mechanism of economic stimulation of changing the freight and passenger traffic to more ecologically clean types of transport;
- implementation of economic and other measures of stimulation for using the ecologically more effective types of transport in cities, namely the electric cars, city electric transport - underground, trams, trolleybuses, electric buses and bicycle transport (system of public bicycle hire);
- introducing a mechanism of economic stimulation of the carriers to reduce the pollutant emissions and the greenhouse gases, to lower the level of the vehicles noise;
- stimulation of using the alternative energy sources and the ecological types of vehicles and specialized transport;
- realization of a complex of regulatory and fiscal measures, namely implementation of the international ecological norms for vehicles,

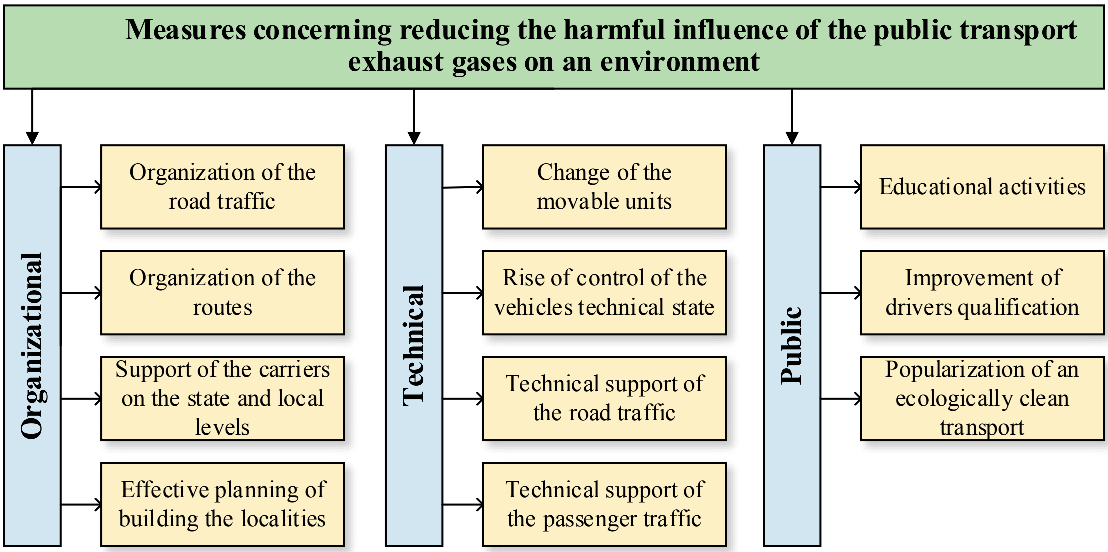

Figure 1 *Measures concerning reducing the harmful influence of the public transport exhaust gases on environment*

Table 1 *The most common types of the city passenger transport and their advantages and disadvantages*

Type of a movable unit	Advantages	Disadvantages
bus	high mobility; big move margin; comparatively low costs of a vehicle;	harmful emissions; considerable level of noise; high value of the traffic costs;
hybrid bus	high mobility; big move margin; ecological compatibility;	high costs of a vehicle; high value of the traffic costs; harmful emissions; considerable level of noise;
trolleybus	ecological compatibility; low level of noise; low cost value of traffic; time-proof in operating;	high costs of a vehicle; low mobility; needs for an arrangement of additional infrastructure;
electric bus	ecological compatibility; low level of noise; low cost value of traffic; high mobility;	high costs of a vehicle; long-lasting charging;

improvement of mechanism of using the alternative engine fuels, introducing of economic stimulus, while putting into operation the vehicles of higher ecological level.

The named tasks will contribute to development of ecological transport, namely to a wide introduction of the electric vehicles. Taking into consideration all the aforementioned, a question of ecological influence on environment by passenger traffic is the most prevalent in Ukraine that is caused by a row of reasons, the main of which are:

- dense bus traffic schedule;
- duplication of bus routes, especially in central parts of the cities;
- low passenger flow on a trolleybus transport;
- absence of a complex approach to the cities transport net planning.

At the same time, an influence of automobile transport on environmental pollution of the localities is rather significant. The researches results show this [1-2].

2 Literature review

In modern phase of development of the ecological safety knowledge, there are some ways to solve the questions of reducing the harmful influence of the public transport exhaust gases on environment that are shown at Figure 1.

The list of measures, shown in Figure 1, is not exhausted and can be extended, depending on the concrete circumstances. Certainly, the most effective would be a complex implementation of the offered measures. Along with that, to evaluate their effectiveness in complex, it is possible to exam an influence of each measure separately and the most perspective is, in authors' point of view, a substitution of the movable units by the ecologically clean ones.

In Table 1 there are given the most common types of city passenger transport and there are defined their advantages and disadvantages.

When analyzing Table 1, one can see that the disadvantages of some vehicles are the advantages of the others and vice versa. That is why one of the optimal variants, from the point of view of operation, is using trolleybuses with an autonomous move that will join the ecological features of the electrical buses, the mobility of the buses and the low value of costs and durability of the ordinary trolleybuses.

The present question was examined and clarified in the research works [3-4]. The trolleybuses with an autonomous move are effectively operated today all over the world [5], namely in Poland [6], Greece [7], Sweden [8], Italy [9]. In addition, a question of the electric buses operation in small and average communes by size was investigated in a research work [10] that is actual for Ukraine, especially in today's phase of decentralization. Here is mentioned only a small part of the countries where the trolleybuses with an autonomous move are used, their number is extremely big and investigation of researchers testifies of the interest of scientists to solving the questions of the localities' ecology improvement.

In Ukraine, the trolleybuses with an autonomous move are used in Kryvyi Rih, Lviv, and in Lutsk the electric buses are operated. Along with that, while buying the trolleybuses by the electric transport enterprises of Ukraine, in tender requirements for purchase one of the requirements stands for a presence of an autonomous move not less than 10…20 km. But the declared distance of an autonomous move is not proved by anything, the calculations are not made and the optimal opportunities of a vehicle with an autonomous move are not used.

While analyzing the publications and researches on a given question, it was found that rather often a trolleybus that can use a trolley line and move from a power supply of on-board system, is called an autonomous electrical bus, a trolleybus, a hybrid trolleybus, an electric bus, a hybrid electric bus. In present research work such a vehicle is called a trolleybus with an autonomous move.

On the other hand, an analysis of publications testifies about a great interest of scientists to research the influence of the vehicle's weight on its technical and operating indices. In a research work [11] is investigated an influence of increasing of a trolleybus weight on the power consumption by a drive and the lack of energy during its transmission. According to the researches results, given in [12], the authors affirm that an effectiveness of passenger traffic by buses equipped by the internal combustion engines and by electrical buses, is almost equal, taking into account that 1 kg of modern tractive storage battery has got 0.25 kW-h of energy. That is, to ensure a margin of a bus move by 50 l of fuel, one can use, as an alternative, a battery of 562 kg weight.

It is necessary to notice a research concerning the use of different combinations of the storage batteries and super capacitors for vehicles with a definition of the smallest electricity consumption [13]. Such researches are presented in a work [14]. The analysis of technical characteristics of the electrical buses in real operating conditions is given in [15]. In a work [16] is shown an entire methodology of taking the system decisions to ensure an effective operation of the electric buses in concrete operating conditions.

In a publication [17], the authors has made a research and estimated a possibility of choosing the corresponding types of the storage batteries for concrete routes and operating conditions of the electric vehicles.

Besides that, in many publications there is a rather interested multiple-criteria approach in choosing the effective parameters of electric buses [18-19], the main of which were: margin (range) of move and passenger capacity.

The analysis of the mentioned literature sources testifies that a multiple-criteria approach, in choosing the effective parameters of the vehicles, can be an effective instrument when taking an optimal decision.

On the other hand, based on the research in [12], it is necessary to say that namely an operation of trolleybuses with an autonomous move on the city routes is the most effective while comparing to the other types of the electric wheeled vehicles.

While summing up all the aforementioned, one can make the conclusions:

- for today, a solution of questions of rising the technical-operating and technical-economical parameters of the electric buses and trolleybuses with an autonomous move is actual;
- a passenger capacity and a move margin - are the ones of key factors while choosing the electric vehicles;
- the trolleybuses with an autonomous move are the most effective types of the vehicles for passenger traffic in cities that have a developed contact trolley line.

3 Research methods

The most important factor, from the point of view of the technical and operating characteristics of the trolleybuses with an autonomous move, is an autonomous move margin that directly depends on a number and characteristics of the tractive storage batteries. However, an increasing of the storage batteries number would certainly lead to an increase of the vehicle's weight. Along with that, a part of a weight that falls on a trolleybus axle would be a restrictive parameter.

It is evident that in order to eliminate an overload on the axles, it is necessary to decrease a passenger capacity of a vehicle, that, in turn, according to the requirements of Regulations № 107 would be defined by a compartment area destined for passenger transportation.

All these things stipulate taking into account a whole row of the technological, constructive, compositional, economical parameters and factors for the vehicles that make a decision algorithm of optimal choice of their quantity dependences, proceeding from the operating conditions, namely - a trolleybus autonomous move margin.

A modeling of the multiple-factor problems always includes the elements of optimization. It allows to operate the technical and operating characteristics of the examined objects more effectively, to determine the parameters of their common stable operation, to organize a lookup of conditions to obtain the best results. At the same time, using of classical methods of solving such problems, is often low effective for an optimization of many real multiple-factor processes, due to the necessity to take into account their specific features, for finding out the regularities concerned with influence of a great number of the parameters and for setting the quantity interconnections between them that determine, as a result, a quality of optimization. Besides that, the offered mathematical models are characterized by a great volume of calculating operations and by an absence of a complex visual idea about the research objects.

Recently, in science, while modeling and optimizing the multiple-factor processes, the methods of applied geometry of multidimensional spaces are used more effectively. Firstly, it is due to the fact that the tasks, appearing in practice, are rather difficult to solve by the traditional analytical methods of mathematical modeling, as though a number of the variables and parameters, which reflect the corresponding multiple-space functional dependences, exceeds the dimensions of space where these processes are examined.

At the same time, a multiple-space applied geometry allows investigating the multidimensional objects as the geometrical models with many variables what gives a possibility to represent them visually and clearly, that, with a help of modern computer technique, allows determining promptly the optimal modes, to assort the effective parameters and characteristics of the examined multiple-factors processes.

A literature review showed that there exists a great number of different ways of visual presentation of a multidimensional space and of making the graphic models of multidimensional configurations, based on a projective device of hyper-coordinate planes. A disadvantage of most of them is that, with an increasing of dimensionality of objects or spaces, such models become bulky, there happens an imposition of coordinate planes, narrowing at the same time the possibilities of visual presentation of the multiple-factor optimization problems.

In a research work [20] was offered to represent the discrete or continuous geometric objects in spaces of arbitrary number of spaces in two ways.

The first presentation was related to a coordinate hyper-net where there were fixed the values n of independent reasons and each value of function with this, for example:

$$Z = f(k,l,m....s,t). \tag{1}$$

The second presentation is related to a coordinate axis set, where each value of function was determined depending on one argument. For example, a manifold of Equation (1) can be presented as a system of functions:

$$\begin{cases} Z = \varphi_1(k) \\ Z = \varphi_2(l) \\ Z = \varphi_3(m) \\ \dots\dots\dots\dots \\ Z = \varphi_{n-1}(s) \\ Z = \varphi_n(t) \end{cases}. \tag{2}$$

If a number of independent arguments $(k,l,m,... s,t)$ is equal to p, Equations (1) and (2) would be the models of a manifold in p + 1 dimensional space. Along with that, the most convenient to solve different practical tasks is a presentation of a manifold of Equation (2) at Radishchev drawing [20]. Its feature consists of a fact that a set of improper axes of manifold of Equation (2) constitutes an improper plane of hyper-plane $(k,l,m,... s,t)$. Any hyper-plane that crosses this improper plane would be parallel to a hyper-plane $(k,l,m,... s,t)$ and that is why it is perpendicular to the Z axis. It means that n projections of any point at Radishchev drawing would be situated on one connection line, perpendicular to the Z axis. All the aforementioned would be right and in the case when instead of the Z axis any other axis would be chosen.

According to an aforementioned model, a multiple-factor problem of finding the optimal technical and operating parameters for trolleybuses with an autonomous move margin, can be presented by a function:

$$L_p = f(M_{batt}; M_{\mu 1}; M_{\mu 2}; P; k_s; R; E_{batt} \dots), \tag{3}$$

where:
$M_{\mu 1}, M_{\mu 2}$ - load on the axles of a vehicle, kg;
M_{batt} - weight of the tractive storage batteries;
k_s - parameter of using a compartment area designated for standing and/or sitting passengers;
P - passenger capacity of a vehicle, persons;
E_{batt} - electric capacity of the batteries;
R- indices of recuperation accounting;
and other technical and operating parameters of a vehicle.

Thereafter, the aim of the present research work is to reach the optimal technical and operating indices of the trolleybuses, with an autonomous move margin, by the way of determining the rational dependencies between an autonomous move margin, a vehicle

Table 2 *Models of the vehicles that are manufactured nowadays or were manufactured during the last ten years*

Brand of trolleybus (electric bus)	Overall dimensions, mm		Weight, kg		Passenger capacity, persons		Producing country
	length	width	curb weight	total weight	general	sitting passengers	
Skoda 28Tr Solaris	14590	2550	12700…15500	24000	160…170	41…49	Czech Republic
Skoda 32Tr SOR	12000	2550	10180	17000	100	32	Czech Republic
SOR NB 18	18750	2550	14500	22500	117	44	Czech Republic
Skoda 24Tr Irisbus	11990	2500	11500	18300	99	30	Czech Republic
Skoda 33Tr SOR	18750	2550	16000	24200	120	47	Czech Republic
Oreos 2X	7243	2170	4100	6100	22	13	France
Oreos 4X	9312	2350	9100	13500	49	25	France
Proterra EcoRide	10900	2580	12700	19300	97	60	USA
Solaris Trollino 15	14590	2550	12700…15500	24000	130…150	36…47	Poland
Solaris Trollino 18	18000	2550	15500…18500	28000	160…170	41…49	Poland
Solaris Trollino 24	24000	2550	19100	34000	190…220	60…70	Poland
AKSM-E433	19000	2500	17720	28000	153	38	Belorussia
BKM-42003	11790	2500	13500	18000	115	35	Belorussia
AKSM-321	11755	2500	11100	18000	115	26	Belorussia
BKM-43303	18750	2500	17720	28000	153	38	Belorussia
AKSM-333	17805	2500	16400	28000	164	49	Belorussia
KAMAZ-6282	18725	2550	17800	28000	135	48	Russia
LiAZ3-6274	11990	2500	10720	18200	110	25	Russia
VMZ-5298.01-50 «Avangard»	12950	2530	11300	18600	107	30	Russia
PTS-6281	12920	2550	10100	18600	125	25	Russia
Trolza-5265.0 «Megapolis»	12660	2550	10700	18000	100	36	Russia
T70110	11960	2550	11870	19000	105	34	Ukraine
T70115	11960	2550	11760	18900	105	34	Ukraine
T80110	15000	2550	14200	24000	150	38	Ukraine
T90110	18950	2550	17980	30500	184	50	Ukraine
Dnipro T203	12200	2500	11200	18000	107	31	Ukraine
E183	12000	2550	11200	18000	100	30	Ukraine
E301A2	18750	2550	17750	30000	180	56	Ukraine

passenger capacity, the indices of effective use of its areas, observing the norms of extreme loading on the vehicle axles, the economical indices, a choice of optimal storage batteries and so on.

Given researches are especially actual at solving the tasks of additional equipment of a trolleybus park that are already operated by the electric transport enterprises, by the means of autonomous move. Such formulation of a problem is related to introduction on minimum number of constructive changes in the project requirements with observing the layout schemes of trolleybuses compartments, assuring a control of extreme loadings on the axles and other.

Analysis of open sources has showed that in the countries of Eastern Europe and former Soviet Union the most extended brands of trolleybuses that are operating on urban and suburban routes, are the vehicles manufactured in Germany, France, Czech Republic, USA, Poland, Russia, Belorussia and Ukraine. In Table 2 are shown the weight and overall dimensions indices of the most popular trolleybuses and electric buses manufactured in the aforementioned countries.

The analysis of the weight and dimensions indices of the examined vehicles has showed that for almost all the brands of trolleybuses, from 30 to 40% of their total weight falls on a front axle and the maximum load on the rear axle does not exceed 11500 kg. That is why in this task definition a passenger capacity and an autonomous move margin of an electric vehicle are the interconnected parameters. An increasing of one of these indices automatically leads to a necessity of decreasing the other one; that is why a definition of

Table 3 *Calculation of passenger capacity and weight indices of the passenger transport*

Bus (trolleybus) class	Part of an area that falls on 1 standing passenger, m^2	Mass of 1 passenger, m^2
I	0.15	68
II	0.125	71

Table 4 *Weight and dimensions indices for calculating the passenger capacity of trolleybuses for sitting and standing passengers*

Bus (trolleybus) class	Mass of a sitting passenger, including a mass of seat with a support, kg	Area that falls on a sitting passenger, m^2		Specific weight that falls on 1 m^2 of area designed for sitting passengers, kg/ m^2	
		Individual seat	Double seat	Individual seat	Double seat
I	83.7…91.5	0.325	0.2925	257.5…281.5	286.2…312.8
II	98…103	0.34	0.306	288.2…302.9	320.3…336.6
	Number of standing passengers that falls on 1 m^2, persons/m^2			Mass of standing passengers that falls on 1 m^2, kg/m^2	
I	6.67			453.6	
II	8			568.0	

Table 5 *Comparison of different types of tractive storage batteries*

Battery type	Rated voltage, V	Specific power W/kg	Specific power intensity, W·h/kg
Pb-acid	2	100…300	20…40
NiCd	1.2	150	40…60
NiMH	1.2	250…1000	30…80
LiCoO2	3.6	800….3000	150…190
LiMnO2	3.8	800….3000	110…135
LiFePO4	3.3	800….3000	90…120
Li-pol	3.6	800…900	N/A
LT	2.4	3000…7000	30…110
Double-layer capacitors for reserve copying of memory (DLC);	1.2…3.3	2000…10000	1.5…3.9
Ultra-capacitors for power applications	2.2…3.3	3000…10000	4…9
Pseudo- and hybrid capacitors	2.2…3.8	3000…14000	10…15

rational relations of the aforementioned and other technical and operating parameters of the vehicles to assure both a necessary autonomous move margin and maximum permissible passenger capacity, is an actual practical task.

According to the Regulations № 107 in a vehicle there should be predicted some seats that correspond to requirements of a point 7.7.8 of the Regulations № 107. In the case of a vehicle of classes I and II, a number of seats should at least correspond to a number of square meters of a floor destined for passengers and (if necessary) for crew, rounded to the closest less integral number; in the vehicles of class I this number can be reduced by 10%. The standard indices, according to the Regulations, of a calculation of passenger capacity and weight indices of the passenger transport, are given in Table 3.

In Table 4 there are given the weight and dimensions indices for calculating the passenger capacity of trolleybuses for sitting and standing passengers.

When analyzing the data of Table 4, it was found out that a relation between the values of specific weight indices, which fall on a unity of area for sitting and standing passengers, fluctuates in a range from 1.45 to 1.97, depending on a vehicle class.

The next phase of the research is a definition of relation between an autonomous move margin of additionally equipped trolleybus and a type of tractive storage batteries and its passenger capacity.

Based on the research materials [21], where a comparison was made of different types of tractive storage batteries, in Table 5 are given values of their principal specific characteristics.

Next is presented a check of effectiveness of the aforementioned multiple-factor model of research of rational relations between the technical and operating parameters and additional equipment of trolleybuses by means of assuring an autonomous move at an example of trolleybus T70110 (Ukraine).

***Table 6** Tests results of trolleybus T70110*

No.	Definable indices	Actual values of indices	
		Equipped trolleybus, M_a = 11800 kg	Trolleybus with technically permissible maximum weight, M_a = 11940 kg
1	Electricity consumption at trolleybus acceleration up to 40 km/h, W·h	380	550
2	Electricity consumption by a trolleybus at control strip (L_{route} = 10.2 km), kW·h	- total: 12.5 - taking into account a recuperation: 10.5	- total: 19.0 - taking into account a recuperation: 17.0
3	Specific electricity consumption by a trolleybus at a given control strip, W·h/t·km	- total: 103.9 - taking into account a recuperation: 87.2	- total: 98.3 - taking into account a recuperation: 88.0

***Table 7** Results of calculating the weight of different types of tractive accumulator batteries to assure an autonomous move of 5, 10 and 30 km*

Battery type	Weight of accumulator batteries without operation of energy recuperation system, kg			Weight of accumulator batteries with operation of energy recuperation system, kg			Influence of recuperation system on a weight of accumulator batteries, kg		
	5 km	10 km	30 km	5 km	10 km	30 km	5 km	10 km	30 km
Pb-acid	498.7	997.4	2992.2	446.45	892.9	2678.7	52.25	104.5	313.5
NiCd	277.05	554.1	1662.3	248	496.0	1488	29.05	58.1	174.3
NiMH	304.75	609.5	1828.5	272.85	545.7	1637.1	31.9	63.8	191.4
LiCoO2	79.3	158.6	475.8	71	142.0	426	8.3	16.6	49.8
LiMnO2	109.7	219.4	658.2	98.2	196.4	589.2	11.5	23.0	69
LiFePO4	129.3	258.6	775.8	115.75	231.5	694.5	13.55	27.1	81.3
LT	282.1	564.2	1692.6	252.55	505.1	1515.3	29.55	59.1	177.3
Double-layer capacitors for reserve copying of memory (DLC)	6137.8	12275.6	36826.8	5494.7	10989.4	32968.2	643.1	1286.2	3858.6
Ultra-capacitors for power applications (UCP)	2401.15	4802.3	14406.9	2149.55	4299.1	12897.3	251.6	503.2	1509.6
Pseudo- and hybrid capacitors (PHC)	1108.2	2216.4	6649.2	992.1	1984.2	5952.6	116.1	232.2	696.6

According to the tests results of a given trolleybus type, made by scientific and testing centre «Urban electric transport» of state enterprise «Scientific-experimental and construction-technological institute of urban economy», the data of its electricity consumption, obtained experimentally are shown in Table 6.

To assure a run of a trolleybus for the defined distance, taking into account a coefficient of efficiency of elements and systems of a vehicle, including a storage battery, a tractive electric engine and a transmission, a necessary number of energy would be found as:

$$E_p = E_{Sp} \cdot L_p / \eta \,, \quad (4)$$

where:
E_{Sp} - a specific electricity consumption by a vehicle, kW·h/km;
η - a coefficient of efficiency of elements and systems of a vehicle, including a storage battery, a tractive electric engine and a transmission.

In the general case, taking into account the loading of a vehicle, a relation of Equation (4) would look like:

$$E_p = E_{Sp}^{t\cdot km} \cdot M_a \cdot L_p / \eta \,, \quad (5)$$

where:
$E_{Sp}^{t\cdot km}$ - a specific electricity consumption by a vehicle per unit of mass, kW·h/t·km;
M_a - weight of a vehicle, t.

To provide a vehicle with electricity, a set of tractive storage batteries is necessary, whose weight can be calculated by a relation:

$$M_{batt} = E_p / E_{Sp.batt.} \,, \quad (6)$$

where:
$E_{Sp.batt.}$ - specific power intensity of a battery, W·h/kg.

Thus, based on Equations (4) - (6), a length of a trolleybus autonomous move L_p taking into account given mode of movement and some type of tractive storage batteries, can be calculated by a formula:

$$L_p = \frac{E_{Sp.batt.} \cdot M_{batt}}{E_{Sp}^{t \cdot km} \cdot M_a}. \quad (7)$$

In Table 7 are given results of the weight calculations of different types of tractive accumulator batteries to assure an autonomous move of 5, 10 and 30 km in an additionally equipped trolleybus T70110 when loading it up to its full loaded mass.

As it is shown in Table 7, it is the most effectively, by the weight indices, to use lithium-ionic accumulator batteries. Besides that, using a system of recuperative braking allows reducing a batteries weight for 10 %. For further research, an application of the LiFePO4 tractive accumulator batteries on a trolleybus is accepted.

A problem of finding a trolleybus optimal passenger capacity and of planning a passenger compartment can be presented in the following way. Let, for a trolleybus T70110 be necessary to assure an autonomous move for a distance L_p. At the same time the following restrictions are imposed:

- maximum permissible loading on a supporting surface of one axle is not more than 11500 kg;
- a change of maximum permissible technical weight of a trolleybus is not allowed;
- a change of weight distribution by axles and a displacement of weight center: by axes x and y is not allowed, by the z axis - displacement is only downward;
- dimensions of passenger compartment can be only reduced;
- it is allowed to change of trolleybus class, under the condition of respecting the requirements of the Regulations No. 107.

A multiple-factor problem of finding the optimal technical and operating characteristics for an additionally equipped trolleybus, with a presented number of restrictions, can be visually realized at Radishchev drawing, as multiple-parameters dependence of many values in a multidimensional space (Figure 2), the main of which are:

$$\begin{cases} m_{AB} = \varphi_1(L_{an}) \begin{matrix} - \textit{mass of accumulator battery} \\ - \textit{autonomous move} \end{matrix} \\ P_{st} = \varphi_2(L_{an}) \begin{matrix} - \textit{number of standing passengers} \\ - \textit{autonomous move} \end{matrix} \\ P_{sitt} = \varphi_3(L_{an}) \begin{matrix} - \textit{number of sitting passengers} \\ - \textit{autonomous move} \end{matrix} \\ P = \varphi_4(L_{an}) - \textit{total passenger number} \\ E_{AB} = \varphi_5(L_{an}) \begin{matrix} - \textit{specific capacity of accumulator} \\ \textit{batery} - \textit{autonomous move} \end{matrix} \\ R_{AB} = \varphi_6(L_{an}) \begin{matrix} - \textit{recuperation parameter} \\ - \textit{autonomous move} \end{matrix} \\ k_S = \varphi_7(L_{an}) \begin{matrix} - \textit{parameter of used vehicle area} \\ - \textit{autonomous move} \end{matrix} \end{cases} . \quad (8)$$

A dimensionality of space for such a formulation of a problem - 8. The functions $\varphi_1 - \varphi_7$ are found from the standardized sources and number values, according to calculations, - are given in Tables 3-7.

A dimensionality of a manifold of Equation (8) can be increased by the way of application of other parameters, interesting for a client.

Taking into consideration that in such multiple-factor problems an improvement of one indices automatically leads to a deterioration of the others, a research of rational relations between the basic values of a model is offered to make in two ways.

The first one consists of a determination of the critical boarders of changing the model base parameter, for example the needs in providing an additionally equipped trolleybus with an autonomous move margin from 10 to 22 km (Figure 2). After that, at Radishchev drawing the marginal values of all the other parameters are determined to assure the basic requirement. An analysis of these values and a choice of optimal ones from the conditions of assuring of technical and operating characteristics of a vehicle gives an information concerning the correction of a model basic parameter to its improvement.

Another approach is based on an optimization of some set or of all the parameters that are presented by functions in a model. An influence of each parameter on all the others is determined; that is why a zone in multidimensional coordinate system of a rational relation of given rating values of a model is found.

Both the first and the second approaches are rather effective when solving the multiple-factor problems of such kind. However, it is just the second one that gives a possibility to take into account not only the optimal relations between the rating parameters, but to form the precise offers concerning an effective technological and operating assuring of them, as well.

For example, for the trolleybus T70110, in the considered problem, the brands and the marginal weights of accumulator batteries from 320 to 640 kg are determined, a number of sitting passengers in a compartment can vary from 27 to 32, a number of standing passengers - from 60 to 64, a power capacity of transport accumulator batteries can be taken in a range from 20 to 52 kWh, as though to restore their charge at final stops of a route, the vehicle has a limited time. A coefficient of using a compartment area should be within the framework from 0.90 to 0.93.

An effectiveness of energy recuperation system significantly depends on a vehicle movement tachogram, which is why a power capacity of batteries taking it into account, in general non-linearly depends on an autonomous move length.

After have reflected on every graph the given conditions and restrictions, an interval of rational value of a trolleybus autonomous move distance was obtained.

A common zone in a given multidimensional system of coordinates allows to receive a rational relation between all the rating parameters of a multiple-factor model (in Figure 2 - a common zone is shaded – the green common zone) and to determine the ways of taking them into account while operating an additionally equipped vehicle.

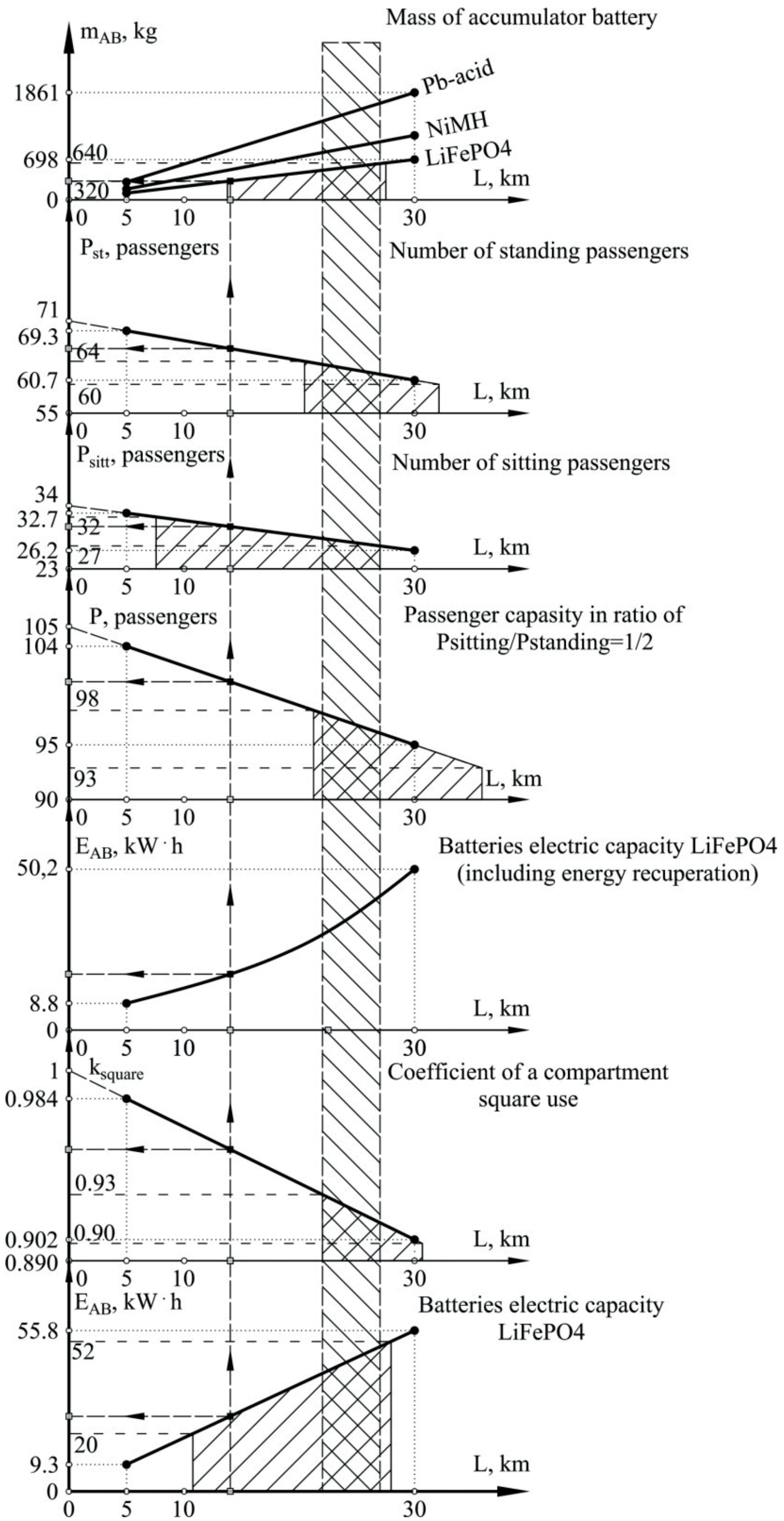

***Figure 2** Radishchev drawing*

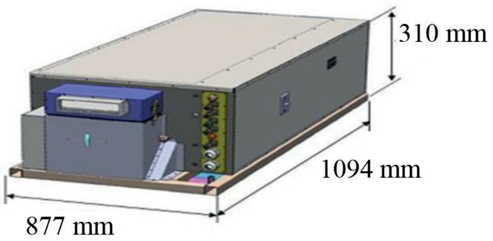

***Figure 3** Blocks of accumulator batteries*

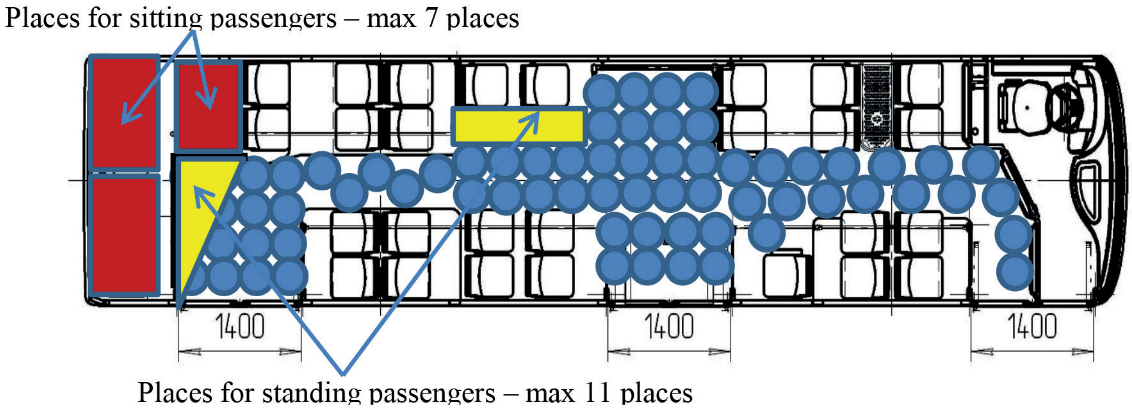

***Figure 4** Trolleybus salon planning*

4 Research results

A construction of a multiple-factor model and offered algorithm of determining the main parameters allows forming the offers concerning a constructive assuring of an additional equipment process of such a type of trolleybus. Thus, without a significant interruption in a vehicle construction of brand T70110, in rear part of a compartment there is a place for two blocks of accumulator batteries of the necessary type (Figure 3).

The next variants to assure the loading restriction conditions on the axles of chosen vehicle are possible: to reduce a number of standing passengers (maximum number is 11), while restricting along with that, an operating area of passenger compartment; to reduce a number of places for sitting passengers (maximum number is 7); to update an arrangement drawing, after having partially changed the areas for standing passengers by the passenger seats (Figure 4).

In Figure 4 are shown the possible variants of changing a number of sitting places in a compartment of T70110 by the red zones and by yellow - those of a number of standing places, to assure in a multiple-factor model the conditions of the maximum permissible loading on a rear axle 11500 kg. A satisfaction of given restriction is assured by a way of installation in a trolleybus of special hand-rail - restrictors, with the possibilities to quickly transform their construction to correct an arrangement drawing.

The chosen rating parameters of assuring a trolleybus autonomous move will be situated in the most rational relations at its operation on the accumulator batteries in a range from 21 to 27 km (Figure 2), that is completely enough for a majority of cities that have a developed infrastructure of trolleybus routes.

As though a given multiple-factor model is not attached to any particular brand of a trolleybus that have to be additionally equipped and is not restricted by a number and a list of optimization factors, it can be used as a universal one, to calculate the necessary parameters of the random brand vehicles.

5 Conclusions

The presented research work is devoted to an actual problem of additional equipment of the trolleybuses by the means of assuring an autonomous move in the conditions of their practical operation by the electric transport enterprises. In this work is offered a multiple-factor optimization model for finding the rational relations between the determinative technical and operating parameters, while making an additional equipment of the ordinary trolleybuses.

Based on a visual presentation of multidimensional spaces at Radishchev drawing, an effective way is offered for geometrical interpretation of mutual influence of an optimization factors' manifold on the operating characteristics of the reequipped vehicles. It allows to quickly and effectively assort the restrictions of multiple-criteria problem, to range by significance and by meaning the chosen optimization factors for an enterprise, to quickly correct an influence of each technical and operating parameter on a final result that is an assuring of a vehicle by the means of an autonomous move.

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