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MEASURES TO IMPROVE THE OPERATION OF PASSENGER TRANSPORT AND URBAN MOBILITY

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Resume

The article discusses the types of urban electric transport used in Belarusian cities, gives a detailed classification and comparison of available vehicles. Various options for increasing the share of environmentally friendly transport through the use of electric buses and trolleybuses are considered, an assessment and a comparative analysis of the options are given. Features of the drivers' work planning and drawing up of the schedule taking into account safety requirements are considered.

A methodology for assessing the efficiency of urban passenger transport has been developed, taking into account the development of electric vehicles.

Article info

Received 18 September 2022

Accepted 6 November 2022

Online 5 December 2022

Keywords:

urban electric transport
electric bus
hybrid bus
charging electric buses
safety
schedule
workplan

Available online: <https://doi.org/10.26552/com.C.2023.007>

ISSN 1335-4205 (print version)

ISSN 2585-7878 (online version)

1 Introduction

The creation of a favourable urban space for life and work is impossible without a developed system of route passenger transport, which is a clear and well-coordinated mechanism that combines various types of transport and offers a decent and effective alternative to personal cars. It is known that the share of private car owners depends on a number of factors: cultural, economic, social. The growth of motorization, the increase in the number of privately owned cars, is a challenge to the route of passenger transport, which must respond to it with a systematic approach and rational organization of work, responding in a timely manner to the changing situation.

In the conditions of a vague response to a changing situation, a certain kind of "vicious circle" arises, when the growth of motorization, in the conditions of the existing street network leads to its overload, which inevitably leads to deterioration of conditions for the movement of route vehicles, reduces the speed of route vehicles movement, worsens the quality of passenger transportation services, which, in turn, leads to the loss of passengers of fixed-route passenger transport,

further reducing the number of route vehicles on routes (there is a superficial impression that the existing regular route is not needed, since fixed-route vehicles are not sufficiently filled, etc.), which further removes passengers from the fixed-route passenger transport and determines their choice in favour of personal, which again leads to an increase in motorization and so this circle "closes", aggravating the problems of cities.

In the current situation, it is necessary to take all possible measures and use any available means to break the "vicious circle" and improve the organization of the work of route passenger transport in cities. The concept of sustainable mobility has become highly relevant today. It is worth noting that in this regard, the concept of "mobility" is used in combination with the concept of "sustainability". This suggests that it is no longer enough for people to simply move from one point to another. This movement must meet a number of requirements, such as convenience, accessibility, speed, safety, reliability, environmental friendliness (the corresponding CO₂ emissions per passenger-kilometer are always lower for public transport compared to cars). Moreover, these requirements must be met constantly in time and not

be of a one-time or episodic nature. Therefore, the issues of improving the transport services and choosing the type of transport are relevant for many cities. At the same time, it is necessary to take into account the capabilities of vehicle manufacturers, national specifics and legislation, the physical and financial capabilities of cities for transformation, restrictions, the level of return on investment, the tendency to build the green transport systems.

The studies were conducted in 2017-2018 based on the information available at that time and, in many positions, they have not lost their relevance at the time of publication. Experimental and computational-theoretical studies were carried out, in the direction to improve the work of route passenger (urban) transport of cities (on the example of Polotsk and Novopolotsk). An assessment is made of the possibility of achieving planned indicators for reducing the greenhouse gas emissions from implementation of the pilot project measures aimed at improving the quality and efficiency of the route passenger transport in these cities. A comparative analysis of the possibility of developing various types of electric route passenger transport is carried out. A map has been developed for reducing emissions of pollutants from vehicles with a change in the structure of mobility of the population and an increase in the share of use of route passenger transport, an increase in the speed of movement of route passenger transport. These studies of authors allowed us to formulate a concept and propose specific comprehensive measures aimed at improving the quality and efficiency of the route passenger transport in Polotsk and Novopolotsk, including optimizing the existing route network of route passenger transport. A business model has been developed for implementation of the standard measures, aimed at improving the quality and efficiency of the route passenger transport, a set of measures has been proposed to increase the attractiveness and efficiency of urban passenger transport.

Turning to world research on these issues, it is worth noting that the importance of the issue of efficiency and the methodology of constructing a synthetic model for estimating the operating costs of the operation of route passenger transport are considered in [1]. The study [2] builds a model based on which the efficiency of Norwegian bus companies is evaluated. The paper [3] emphasizes that efficiency of a transport system depends on used technology, strategies and policies, planning process etc. The abundance of bibliographic references in [3] indicates the importance of this issue and attention paid to it in many countries of the world too. Researchers pay great attention to planning of the route network, the development of the timetable. Paper [4] presents a new approach to generating run-time values that is based on analytical development and micro simulations. This works based on the retroanalysis and selection of atypical trips using statistical and modelling methods. Similar approaches are reflected in the study

where an optimization model, based on minimizing the operational and user costs of the system, is proposed [5]. An interesting approach is considered in the study [6], which notes the importance of a differentiated approach to peak and off-peak time. It is also noted that optimal bus passenger capacity lies in-between the capacities obtained when each period is independently optimized. This once again confirms that the research topics of Belarusian and world scientists are directed in the relevant direction.

It is worth noting that much attention is currently being paid to the issues of electric transport for passenger transportation by the research of well-known scientists. Gnap, Dockalik and Dydkowski in paper [7] say that the setting of minimum targets for EU member states to procure green vehicles within two reference periods ending in 2025 and 2030, should help to promote mobility with low, respectively zero emissions. Research results will find it very difficult to meet the set minimum targets for the share of ecological buses in the total number of buses, included in the sum of all contracts subject to EU Directive 2019/1161 concluded from 2 August 2021. The authors note that the crisis caused by the COVID-19 pandemic, which has and continues to affect bus demand across Europe, may have a significant impact on meeting the minimum targets, especially by the end of the first reference period. The methodology for assessing the economic efficiency of vehicles for the transportation of passengers with electric drive is developed and described in [8]. The paper presents possible models of electric buses purchase financing, taking into account that the purchase prices are higher now than for the case of traditional buses, it also allowed to include issues related to applicability and implications of formulated solutions for managerial practice. In t [9] authors present the possible solutions of daily circulations in terms of the transport ensuring the daily performance of vehicles and staffing. It appears that the analysis of the transport solution is the first step to determine the successful optimal solution of the transport performance volume. Authors of [10] present the methods of operational analysis and especially methods for solving the optimization problems, which were used in the draft of a novel system of lines of public bus transport in the city of Ceske Budejovice that showed benefits of the solutions for transport practice and scientific knowledge.

2 Methodology

The research was initiated in the form of studying the proposed technical solutions in the field of route passenger transport, affecting the issues of infrastructure and vehicles, their technical equipment. Methodologically, research is divided into three related groups: vehicles and technical issue, route network and organization of transportation.

2.1 Vehicles and technical issue

Currently, the Republic of Belarus has established its own production of trams, trolleybuses, trolleybuses-electric buses and electric buses. Various types of urban electric transport are known and widely used in world practice:

1. Tram is the oldest type of electric transport vehicles, which move on the track.
2. Trolleybus is a type of electric transport vehicles, which move on roads and are driven by electric motors that receive electrical energy from the laid contact wires. Trolleybuses, in the classic and known to the consumer representation, are vehicles with feeding in motion - IMF (in-Motion-Feeding). If, to obtain electricity on some parts of the route, contact network and autonomous on-board energy source are not used, such trolleybuses can be considered as trolleybuses-electric buses with dynamic charging - IMC (in-Motion-Charging).
3. Hybrid bus is a type of transport whose vehicles move on roads and are driven by the combined work of an internal combustion engine and an electric motor.
4. Electric bus - it is a type of electric transport, vehicles of which move on roads, driven by electric motors, which receive electric energy from an autonomous onboard source (charging of the onboard source occurs during the stay of an electric bus at special charging stations and requires a certain time).

Recent years have been characterized by the rapid development of electric transport, manufacturers of route vehicles with electric drive also continue to develop this direction and offer customers new solutions. The emergence of new models and modifications of vehicles have led to the fact that within the same scheme according to the existing classification there were vehicles with significant differences in parameters determining their operational properties and qualities, requirements for charging infrastructure and, as a consequence, characterizing the possibility of using vehicles on regular routes of a certain configuration and length [11].

Thus, the existing classification at the moment turned out to be very stingy and, in the opinion of the authors, there was a need to create an extended classification. In the extended classification proposed by the authors, in addition to the designation of the scheme, the concept of a category with a digital designation is introduced, while the higher the value of the category, the greater the margin of autonomous travel the vehicle has.

For trolleybuses, built according to the IMF scheme, two categories are provided:

- IMF-0 - no reserve of autonomous travel;
- IMF-1 - autonomous range up to 1km (this is an emergency mode).

For trolleybuses, built according to the IMC scheme, three categories are provided:

- IMC-1 - autonomous range from 5 to 15 km;

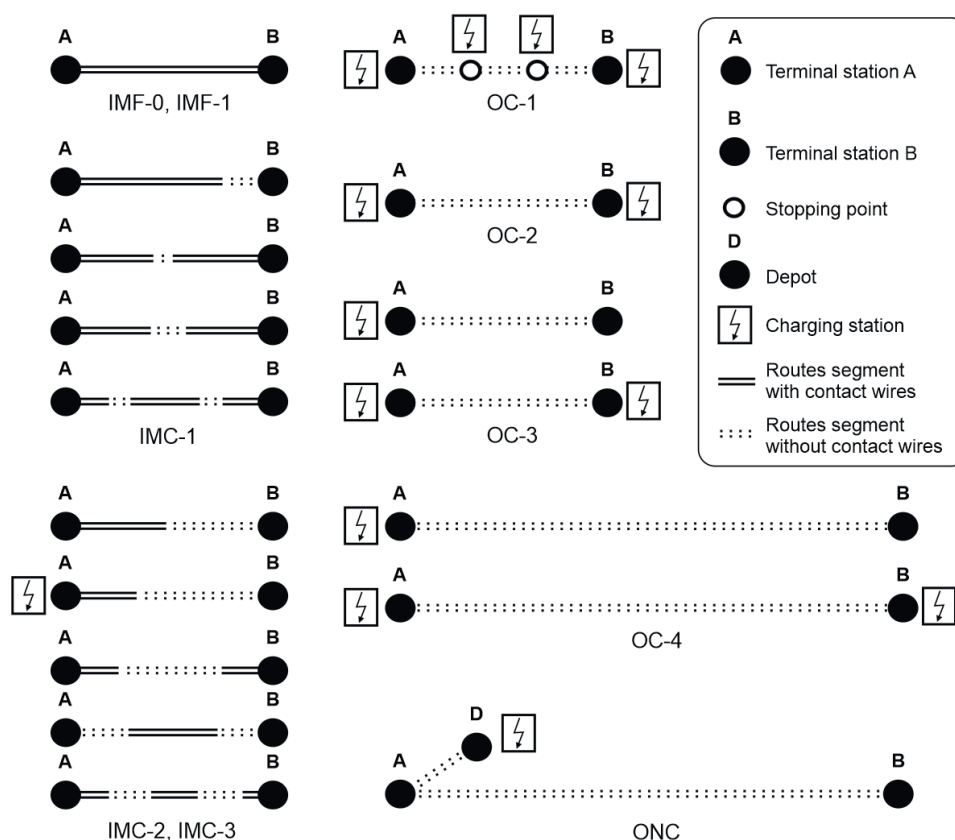


Figure 1 Typical routes configurations for determining parameters of vehicle operation models

Table 1 Infrastructure required to provide traction for IMF trolleybuses, IMC trolleybuses, duobuses and charging electric buses of various versions

Name, Value	IMF	IMC	Duobus	OC	ONC
Traction substation	+	+	+	+	+
Cable network	+	+	+	+	+
Contact wires	+	+/-	+/-	-	-
Charging stations on the line	-	-	-	+	-
Charging stations in the depot	-	-	-	+	+

- IMC-2 - autonomous range from 15 to 31 km;
- IMC-3 - autonomous range from 31 to 51 km.

For electric buses, built according to the OC scheme, four categories are provided:

- OC-1 - autonomous range from 3 to 5 km;
- OC-2 - autonomous range from 5 to 13 km;
- OC-3 - autonomous range from 13 to 21 km;
- OC-4 - autonomous range from 21 to 51 km.

For electric buses, built according to the ONC scheme, two categories are provided:

- ONC-1 - autonomous range up to 170 km (equal to the duration of one working shift);
- ONC-2 - autonomous range from 170 to 250 km (duration of one working day with restrictions);
- ONC-3 - autonomous range from 250 to 350 km (duration of one working day).

The proposed categories are formed based on the solutions offered by manufacturers and the established practice of using the route vehicles with electric drive on regular routes. The emergence of new solutions, which would require introduction of additional categories in the classification under consideration, is not excluded. Typical routes configurations for determining the parameters of vehicle operation models are shown in Figure 1.

The infrastructure elements, necessary to provide traction of trolleybuses and charging of electric buses of various versions, are given in Table 1.

2.2 Route network

In order to obtain reliable information about the route network, formed passenger flows and correspondence, various field studies and experiments were carried out. They were carried out by examining the operation of transport systems, objective and expert assessments, measurements, including using the analysis of video recordings and GPS tracks.

To perform an analysis of the route network, all the routes were classified according to geographical, topographic features, route topology and purpose. The areas of duplication of routes performed by vehicles of different capacity classes have been identified, the degree of duplication of routes has been established. Urban and suburban areas were zoned according to territorial and (or) functional characteristics.

During the survey of stopping points, the general planning parameters of the road network, planning parameters of elements and equipment of stopping points, approaches and pedestrian connections, the presence of systemic interference for the movement of route vehicles, the presence of interference and inclusive barriers, were studied. The main shortcomings identified include the absence of entry pockets on streets with the high traffic intensity, the absence of landing pads, the discrepancy between the level of the landing pad and the floor level of the vehicle, barriers when using vehicles of the M2 category (commercial minibuses). When conducting passenger traffic studies, a continuous and selective method was used. The places of gravity, passenger-forming points, places of intensive passenger exchange, were determined. In the selective method, a capacity score was used (with a differentiated scale from 1 to 6 points for vehicles of different capacity classes), the date, time, route number, vehicle registration plate, number of passengers entering and exiting, occupancy, were recorded. According to the results of the study, the volume of passenger traffic on certain sections of the route network was clarified, dependencies were established reflecting the unevenness by time of day, by directions and by days of the week.

2.3 Organization of transportation

All the routes were classified according to the purpose of the route, according to the frequency of movement (high-frequency with a frequency of more than 6 trips per hour, medium-frequency with a frequency of 3 to 6 trips per hour, low-frequency with a frequency of up to 3 trips per hour). The schedule has been studied for each route and graphical trips charts have been compiled. It was established by which capacity buses each route is served. Trends and dependencies were identified. In particular, it was found that passenger capacity does not always correlate with the frequency of traffic on the route, which is abnormal and should become a trigger for making decisions on reorganization of the route network. Separate studies were conducted to study the time of disembarkation and boarding of passengers. It is established that this time increases when the bus class does not match the capacity of passenger traffic, with an increase in the degree of

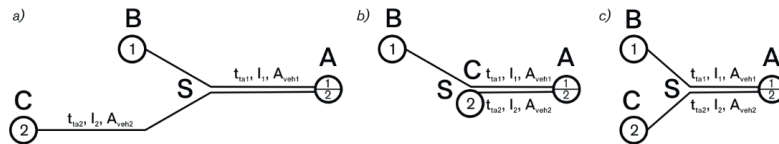


Figure 2 Models of the RPT routes, the work of which is organized by the sectoral method

filling of the vehicle, when using vehicles with a high floor level. A study of the speed of route vehicles with details on the stages was carried out. The factors that affect the speed of movement are established: the type of transport, the number of intersections with traffic light regulation, lack of coordination, green wave, the number of unregulated pedestrian crossings, artificial irregularities, the presence of level crossings, unregulated objects with high traffic intensity, the presence of a narrow carriageway, the presence of randomly parked cars in unauthorized places [12].

The following models were used to determine the parameters of the transport processes:

- passenger travel time t_{ptt} , which includes the time of approach to the stopping point t_{apr} , waiting time t_{wait} , time on the move t_{move} , transfer time $t_{transfer}$ (if applicable), t_{fin} final travel time from the stopping point to the destination:

$$t_{ptt} = t_{apr} + t_{wait} + t_{move} + t_{transfer} + t_{fin}, \quad (1)$$

- turnaround time T_{tt} , depending on the time for mandatory technological stopping T_{tsA} at the conditional station A of the route, time for stopping for the sanitary needs of the driver T_{ssA} at the conditional station A of the route, time for movement T_{mAB} from the conditional station A to the conditional station B, time for mandatory technological stopping T_{tsB} at the conditional station B of the route, time for stopping T_{ssB} for the sanitary needs of the driver at the conditional station B of the route, time for movement T_{mBA} from the conditional station B to the conditional station A:

$$T_{tt} = T_{tsA} + T_{ssA} + T_{mAB} + T_{tsB} + T_{ssB} + T_{mBA}, \quad (2)$$

- the number of vehicles on the route n , depending on the hourly capacity of passenger traffic Q in the most loaded stage, the passenger capacity q of the vehicles used, operating ratio of passenger capacity γ (sets the service level), turnaround time T_{tt} :

$$n = \frac{q\gamma T_{tt}}{60Q} = \frac{q\gamma \left(T_{tsA} + T_{ssA} + T_{mAB} + T_{tsB} + T_{ssB} + T_{mBA} \right)}{60Q}. \quad (3)$$

The solution of the optimization problem from the point of view of the organization of transportation, as an objective function, should be used $n \rightarrow \min$. Solving in various ways, optimizing values T_{tt} , minimizing them, setting the level of service $\gamma \leq 0,80$.

Authors' sectoral methods can be used for service of the route network. The route technology of passenger service provides for the operation of the route passenger transport (RPT) vehicle, along the laid routes from terminal station A (hereinafter referred to as Station A) to terminal station B (hereinafter referred to as Station B) and back according to the timetable. For a detailed study of the work of the RPT vehicle on the route, a model was developed, characterized by division of their parking time into stations A and B for mandatory and additional. The possibility of using the sectoral method for organizing the work of the vehicle on the RPT routes is to allocate and combine the routes with common segments based on the rules of "switching" and combining routes within the sector, while maintaining the mandatory sequential alternation of work on them, rational distribution of driving and technical resources of the sector [13]. The implementation of the sectoral method for organizing the work of the vehicle on the RPT routes is considered using the model presented in:

$$\begin{cases} t_{ta1} = t_{lstmA} + t_{lstaA1} + t_{AB} + t_{lstmB} + t_{lstaB1} + t_{BA} \\ A_{veh1} = \frac{t_{ta1}}{T_1} \\ t_{ta2} = t_{lstmA} + t_{lstaA2} + t_{AC} + t_{lstmC} + t_{lstaC2} + t_{CA} \\ A_{veh2} = \frac{t_{ta2}}{T_2} \end{cases} \quad (4)$$

It is carried out by allocating joint segments on the routes AB, AC (a section of the route AS), while route configurations are possible when AC is significantly larger than AB, when the route AC is a part of the route AB and is intended to strengthen it and in fact the common segment AS is the route AC as well as when AC = AB (Figure 2).

At the same time, the proposed scheme of sectoral service provides for the operation of the AB and AS routes in such a way that the AS segment on them is always serviced according to the principle of equality of the network interval $I_1 = I_2$, with the guaranteed exception of the so-called Vernier effect, which entails not only an even distribution of the production load, but also reduces the economic losses of passengers, consisting in wasting their time on excessive waiting for the RPT vehicle at stopping points, while overloading the vehicle and complicating the work of drivers on routes is prevented. Such infrastructural combinations of routes (and even types of the RPT) are also a solution to increase the throughput and productivity of the sector by minimizing t_{lstaA1} , t_{lstaB1} and t_{lstaC2} when the assigned

conditions are met for use of the sectoral method for organizing the work of the vehicle on RPT routes.

At the same time, the model in Equation (5) will already be applicable:

$$\begin{cases} t_{ta12} = t_{lstmA} + t_{lstaA12.1} + t_{AB} + t_{lstmB} + t_{lstaB12} + \\ + t_{BA}t_{lstmA} + t_{lstaA12.2} + t_{AC} + t_{lstmC} + t_{lstaC12} + t_{CA} \end{cases} \quad (5)$$

$$A_{veh2} = \frac{t_{ta12}}{I_{12}}$$

3 Analysis and results

The possibilities of using different types of urban electric transport in the cities of Belarus is proposed to be evaluated on the example of the Polotsk agglomeration (cities of Polotsk and Novopolotsk). This route can be chosen bus route No. 4 “Marynenka-Baravukha-3” in the city of Polotsk. The main parameters of route No. 4 when using different types of urban electric transport

are given in Table 2 and represented in Figures 3 and 4.

Route 4 runs along Marynenka street, Pyatrusya Brouka street, Yubileynaya street, Kastrychnickaya street, Hegal’ street, Kammunistychnaya street, Efrosinnya Polotsk street, Kasmonautau street, Valagodskaya street. The length of the route is 25.19 km; the bus work time in the forward direction and in the reverse direction is 40 minutes. The Current schedule provides for 124 trips, including 62 trips in the forward and 62 trips in the reverse direction. The route works from 05:00 to 00:45. The highest frequency of traffic on the route from 6 AM to 8 AM and from 4 PM to 6 PM, when 9 vehicles are used for passenger service at the same time. In the consolidated calculations, it is assumed that the depot for electric transport will be located in the existing bus fleet No. 2 on Budaunichaya street.

The assessment of possibility of using different types of the urban electric transport in Novopolotsk

Table 2 Comparison of parameters of route No. 4 in Polotsk at service by vehicles of various types of city electric transport

Name, Value	Quantity of vehicles		Min. turnaround time, min.	Average operating speed, km/h	The length of sections, km	
	On the line	Total			with contact network	without contact network
Scenario 1. Service by single 12m length class vehicles						
IMF	12	15	90	16.79	25.19	0
IMC (LTO w/extra rapid charge)	12	15	90	16.79	3.20*	21.99
IMC (LFP)	12	15	90	16.79	12.00*	13.19
OC	14	18	100	15.11	0	25.19
Scenario 2. Service by articulated 15m length class vehicles						
IMF	9	11	90	16.79	25.19	0
IMC (LTO w/extra rapid charge)	9	11	90	16.79	3.20	21.99
IMC (LFP)	9	11	90	16.79	12.00*	13.19
OC	10	13	100	15.11	0	25.19

* It is necessary to build a contact wired

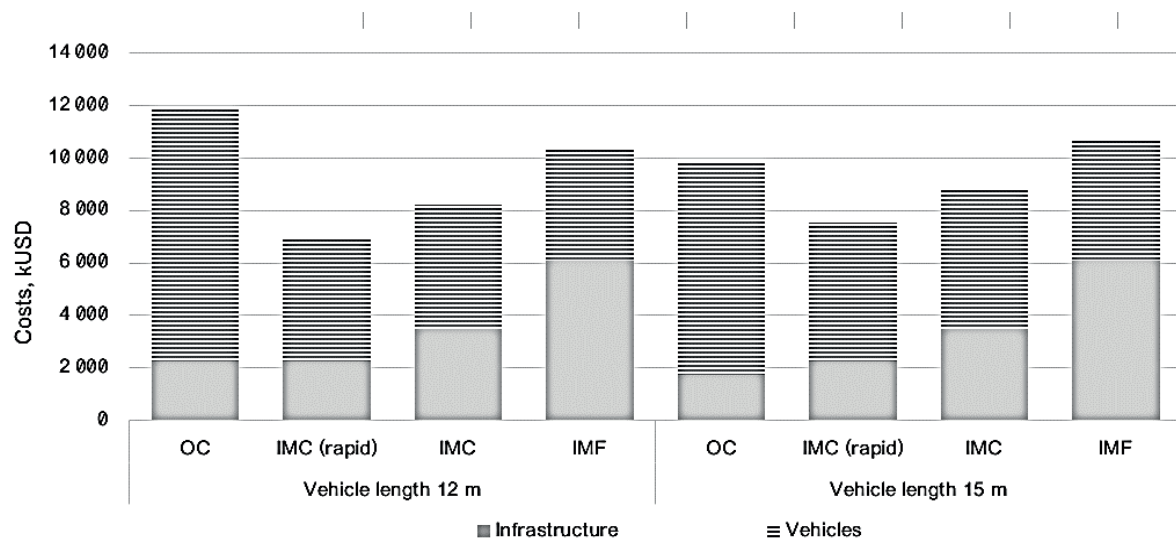


Figure 3 Total investments for Route No. 4 in Polotsk

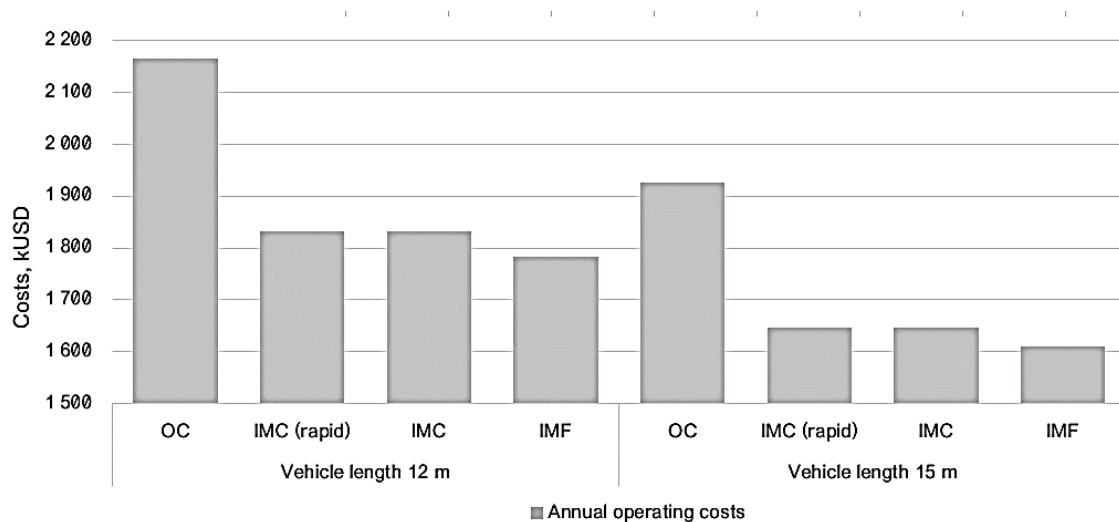


Figure 4 Annual operating costs for Route No. 4 in Polotsk

Table 3 Comparison of parameters of route No. 4 in Novopolotsk at service by vehicles of various types of city electric transport

Name, Value	Quantity of vehicles		Min. turnaround time, min.	Average operating speed, km/h	The length of sections, km	
	On the line	Total			with contact network	without contact network
IMF	5	7	54	16.58	14.92	0
IMC (LTO w/extra rapid charge)	5	7	54	16.58	2.53*	12.39
IMC (LFP)	5	7	54	16.58	7.00	7.92
OC	7	9	67	13.36	0	14.92

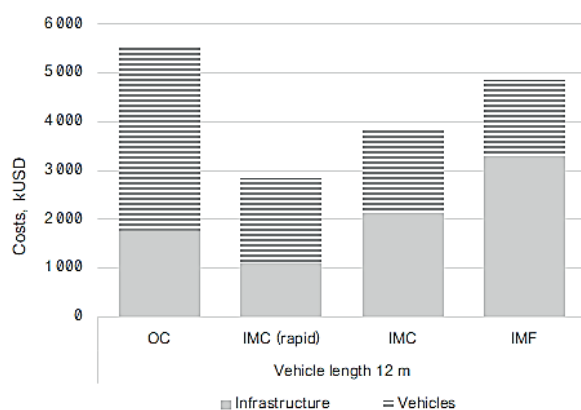


Figure 5 Total investments for Route No. 4 in Novopolotsk

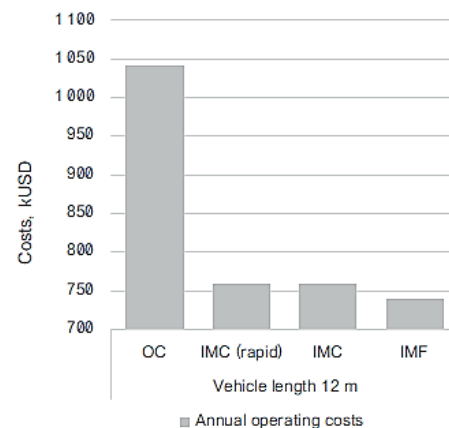


Figure 6 Annual operating costs for Route No. 4 in Novopolotsk

was carried out on the example of the bus route No. 4 “Padkasteltsy-Hospital town”.

The route No. 4 is for Moladzewa Street, Ktatarava Str., Slabadska Str., Haidara str. in forward direction and Haidar Str. and Moladzewa Street in the reverse direction. The length of the route is 14.92 km, the bus travel time in the forward direction is 25 minutes, in the reverse direction - 24 minutes. The current schedule provides for implementation of 106 trips (53 trips in the forward and reverse directions). The route works from 08:24 to 23:52. The highest frequency of traffic on the route from 5 PM to 7 PM, when 5

vehicles are used simultaneously for passenger service. In consolidated calculations it was accepted that the depot for electric vehicle will be located on the terminal station “Padkasteltsy” [14].

The main parameters of the route when using different types of urban electric transport are given in Table 3. The total investments are summarized in Figure 5. When calculating the total investments in infrastructure and vehicles, the costs of contact wires, traction substations, charging stations and the vehicles themselves, required for work on the route, are taken into account. The costs of design and the contract work

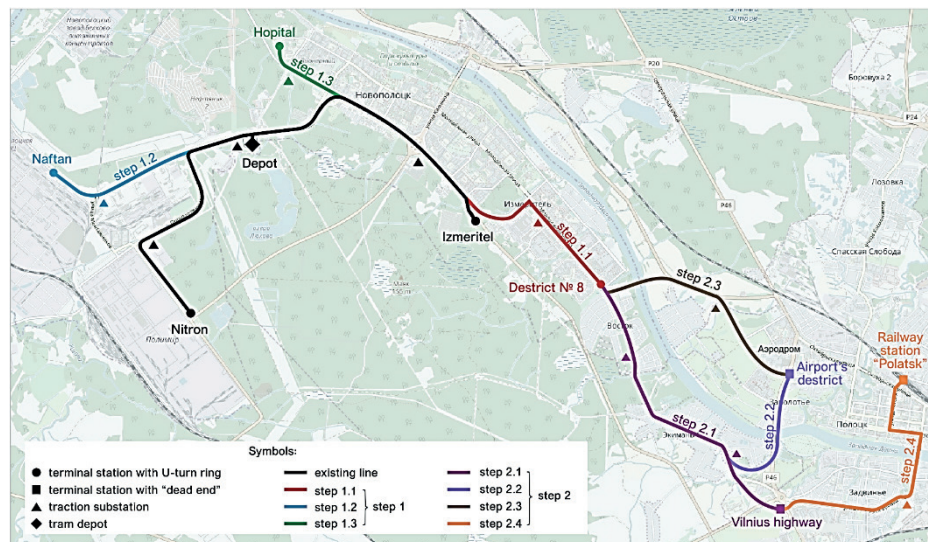


Figure 7 Tram development scheme in the agglomeration of Polotsk-Novopolotsk

to create a base for maintenance and repair of vehicles at the transport enterprise, were not taken into account.

An overview of annual operating costs is shown in Figure 6. Consider separately the problems of traffic organization, transportation organization and traffic safety arising from the operation of some types of non-rail electric transport. Trolleybuses IMC, IMF, duobuses favourably differ from electric buses OC, which have a limited working reserve and require periodic stops to charge the drives. This stop occurs at each terminal station and its duration is about 10 minutes.

This fact introduces a number of restrictions in the technology of organization of the electric buses movement and in the order of scheduling.

Moreover, from the standpoint of economic efficiency, the use of electric buses with a travel interval of less than 10 minutes requires the construction of not one, but two or more charging stations at the final station, which are necessary for the stable functioning of the route.

In addition, in case of delay, the stability of the system is violated. A delayed electric bus will occupy a slot in the schedule belonging to the next electric bus that operates on the same route. This will lead to it also starting late, as well. Then the “domino principle” will work. Each subsequent electric bus will be late.

From the point of view of the human factor and psychophysiology of the public transport driver, such violations of the traffic schedule will lead to the fact that drivers will begin to reduce delays by increasing the speed of traffic on routes. Experience shows that this will happen in those parts of the route where it is unsafe and will lead to an increase in number of accidents.

At the same time, an alternative scenario provides for the development of tram. At the same time, the tram depot already has the necessary base for the repair and maintenance of trams, as well as the trams themselves in the quantity necessary to work on the new lines. The step-by-step plan of tram transportation is shown in Figure 7 [15].

4 Discussion

Returning to the problems of the Polotsk agglomeration, it should be noted that Novopolotsk enterprises form the largest petrochemical complex in Belarus and this affects the environmental situation. Novopolotsk is one of the cities with the highest density of emissions of harmful substances. Mobile sources of emissions also play a negative role in the overall air pollution. In these circumstances, the increase in the share of environmentally friendly transport is particularly relevant [16].

The analysis of various variants of application of the non-rail electric transport is given in Table 4.

To organize the movement of the non-rail electric transport, it is necessary to purchase vehicles, create a base for their repair and maintenance in bus fleets, construction of traction (and charging) substations, cable networks, training of personnel. The construction of the contact wires along the entire length of the route is required for the IMF trolleybuses and partially for IMC trolleybuses and duobuses. To organize the movement of electric buses, it is necessary to build charging stations in the depot and at the end stations (for the OC electric buses).

Revealing the issues of complex optimization of costs for the maintenance of the route network by route passenger transport, it is necessary to return to the Equation (3).

It is now possible to simulate the operation of two routes leaving the same terminal station according to the scheme of Figure 1a, making the following assumptions: the preparatory and final time for the driver is not taken into account and the time of lunch breaks is not taken into account, the depot is considered adjacent to station A, zero mileage at the beginning and at the end of work is 5km and 18 min. The simulation results show that as a result of organizing the work of routes 1 and 2 by the sectoral method, with the work of each vehicle with

Table 4 Analysis of application possibilities of the non-rail electric transport

Name, Value	Electric bus OC, ONC	Trolleybus IMC	Trolleybus IMF
Experience of operating in the cities	-	-	-
Place of storage of vehicles	+/- (can be placed in the bus depot)		
Operational base (maintenance, repair)	- (need to build)		
Degree of binding to the infrastructure	Binding to charging stations	Partial binding to the contact wires	Full binding to the contact wires
Needing for driver training	Driver's license for Cat. "D" is necessary	Driver's license for Cat. "T" is necessary	Driver's license for Cat. "T" is necessary
Ability to change the route	From charging stations within the range of the autonomous range	From any point of site with the contact wires within radius of autonomous range	Without construction of the contact wires it is impossible to change route
Needing for an one-time purchase of vehicles for open new routes	Necessary	Necessary	Necessary
Equivalent value of the vehicle (for 1 people of passenger capacity)	4.26-4.66	2.20-2.75	2.20-2.75
Period of operation of the vehicles base (extended)	10	10 (15)	10 (15)
Presented (to 1 person of passenger capacity and a basic 10-year service life) the cost of the vehicle	4.26-4.66	2.20-2.75	2.20-2.75
Specific electricity costs for transportation of 100 passengers per 1 km in summer, USD / 100 pass.km	0.18	0.18	0.18
Specific fuel consumption for transportation of 100 passengers per 1 km in winter, USD / 100 pass.km	0.42	0.29	0.29
Ecological issue	+/- - - (emissions of harmful substances during the operation of diesel heating, tires, rubber dust in the interaction of wheels with the road surface)	+/- (disposal of traction batteries, tires, rubber dust by interaction of wheels and the road surface)	+/- (recycling of tires, rubber dust by interaction of wheels and the road surface)

drivers on a sequential route 1+2, there is a daily gain in the number of vehicles on 1 unit, in the number of drivers on 2, in the number of zero trips on 2, reducing the time of additional parking (unproductive time) by 17 hours, machine hours by 17.60 hours, reduction of mileage in 10 hours, increase in operating speed by 1.17 km/h (+9%). At the same time, share of unproductive parking time decreases from 8% to 0% and the share of car hours in traffic increases from 84% to 91%.

The enlarged calculation of the economic effect of the sectoral method introduction was made according to the criterion of the costs of paying drivers and capital investment in the purchase of additional vehicles. Due to the circumstances described above, other indicators are simplified. The expected economic effect of servicing each two routes by the sectoral method, if the necessary conditions were met, is expressed for a bus for a 10-year period (the life cycle of one vehicle) at current prices of 665 000 EUR, for a trolleybus for a 15-year period 968 000 EUR, for a tram for a 30-year period 1895 000 EUR.

5 Conclusions

Thus, a further increase in the share of electric transport in the cities of Belarus is also possible due to the organization of the movement of IMC trolleybuses on some busy routes with the construction of a contact wires for charging energy storage in IMC trolleybuses on certain sections of the route outside the central part of the city. This solution from the point of view of traffic organization, transportation and traffic safety, is the optimal and attractive. The advantages of this solution are: distributed load on the electric network throughout the day, operation of autonomous onboard energy sources in a smooth mode, electric heating and air conditioning, charging of autonomous onboard energy sources during the route without the downtime of vehicles at end stations or depots. This combined solution makes it possible to significantly expand the geography of use of the IMC trolleybuses due to the possibility of including sections of the road network

that are not equipped with contact wires in their routes.

A methodology for assessing the efficiency of urban passenger transport has been developed, including taking into account the development of electric vehicles, which made it possible to determine the need to purchase appropriate vehicles for organizing the movement of the non-rail electric vehicles; create a base for their repair and maintenance; construction of traction substations (new or additional); construction of cable networks; train staff. In addition, for the use of the IMF trolleybuses, it is necessary to build a contact network along the entire length of the route, for the IMC trolleybuses and duobuses - on some routes. To organize the movement of electric buses, it is necessary to build charging stations in parks (for the OC electric buses - and at terminal stations).

It should be noted that the development of a network of the tram lines will attract additional passengers and increase the annual volume of passenger traffic (according to preliminary expert estimates) by approximately 4.1 million passengers. during the implementation of all the stages of stage 1 (in Novopolotsk) and 6.7 million passengers. during the implementation of all the stages of stage 2 (in the agglomeration). The most efficient operation of the tram will become when it starts to be used for "agglomeration" transportation on the sections with the highest passenger traffic (for example, along the route of the existing bus route N°. 5 and route taxis N°. 5t). The "agglomeration" rail passenger system of Novopolotsk-Polotsk will be the only one in Belarus and may become one of the ways to develop the tourist potential of cities.

In addition, an algorithm has been developed for implementation of the least costly activities at the initial stage with limited funding. The studies performed allowed to formulate a concept and propose specific comprehensive measures aimed at improving the quality and efficiency of the route passenger transport in Polotsk and Novopolotsk, including optimizing the existing route network of route passenger transport.

Studies of the effectiveness of measures, aimed at reducing delays in route passenger transport, have been carried out, criteria and places of their application in Polotsk and Novopolotsk have been determined, as well as an assessment of the technical and economic indicators of the proposed options using the international Cost Benefit Analysis (CBA) methodology.

A business model has been developed for implementation of standard measures aimed at improving the quality and efficiency of the route passenger transport, a set of measures to increase the attractiveness and efficiency of urban passenger transport has been proposed.

The proposed expanded classification system for route vehicles with electric drive will allow classifying and categorizing various solutions offered by manufacturers

of route vehicles with electric drive, which will facilitate the work when making decisions by both operating organizations and design bureaus, since the designation of the scheme, supplemented by the category number, will make it easy to determine the scope and capabilities of this vehicle, the need for charging infrastructure.

The IMC-2 and IMC-3 trolleybuses are of the greatest interest for cities with trolleybus traffic, which allow expanding the route network of an environmentally friendly trolleybus and replacing a number of bus routes with trolleybuses.

Improving the traffic safety by development of the route passenger transport will be achieved by deterring motorization. Statistics show that there are fewer road accidents per route vehicle than per vehicle for personal use. Drivers of the fixed-route vehicles are professional drivers; they are well prepared and trained. A further increase in the share of route passenger transport will contribute to an increase in the number of trips using route vehicles. This will contribute to further unloading of the road network, improving the traffic conditions on the streets of cities.

For a comprehensive assessment of the quality of decisions taken, a loss assessment methodology, based on accounting for the economic costs arising from the use of each type of transport, should be used [17]. Costs differ from expenses in that costs take into account all costs (explicit and implicit, which cannot be accounted for transparently). All such costs, which are losses, can be classified into accidents, environmental, economic, operating and social. Total losses by definition represent the sum of all the types of losses and are used for a comprehensive assessment of the quality of traffic.

The results of the study can be useful for developing the concept of electrification of the route network in cities that are beginning the transition from diesel buses to electric transport. Of particular interest is the information systematized in this study for cities that have a trolleybus network and can diversify it through the use of new types of trolleybuses. The organization of work on the route network, when drawing up a schedule using the sectoral method will reduce both operating costs and the costs of purchasing vehicles.

Grants and funding

The authors received no financial support for the research, authorship and/or publication of this article.

Conflicts of 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.

Nomenclature:

- IMF - in Motion Feeding - trolleybuses as vehicles with feeding in motion
- IMC - in Motion Charging - trolleybuses with autonomous on-board energy source (battery) as vehicles with dynamic (in motion) charging
- OC - opportunity charging - electric bus with a relatively small autonomous running resource, requiring frequent and fast charging
- ONC - overnight charging - an electric bus with a power reserve sufficient to operate during a shift, requiring a long, usually overnight charge
- LTO - Lithium Titanate Oxid battery
- LFP - Lithium Iron phosphate battery
- NMC - Nickel Manganese Cobalt battery
- RPT - route passenger transport

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