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Application of the sectoral method to improve the efficiency of route passenger transport

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Abstract: Route passenger transport plays a significant role in the life and economic development of cities, providing movement of population, contributes to improving the environmental situation, and improving road safety. Improving the efficiency of route passenger transport is also essential because the taxpayers' tax subsidizes it. The most researched aspects have always been the choice of the passenger capacity of vehicles, management of their filling, and appointment of route intervals. This research aims to increase the efficiency of route passenger transport. This study identifies ways to improve the efficiency of route passenger transport by reducing costs arising from the imperfect allocation of drivers on routes, irrational use of vehicles working hours, and drivers working hours. Such costs are called unproductive costs. The solution to the problem of increasing efficiency is realized by developing the author's sectoral method described in the article. This article discusses the application of the sectoral method to improve the efficiency of route passenger transport based on the improvement of processes related to the organization of passenger transportation, taking into account the characteristics of various types of route passenger transport, by organizing the work of drivers on routes. Methods, techniques, and algorithms and their application are considered. The use of the sectoral method has made it possible to increase the efficiency of route passenger transport and reduce unproductive costs.

Keywords: route passenger transport, the efficiency of work, sectoral method, bus, tram, trolleybus, electric bus, time of work drivers, unproductive cost of transport operation

1. Introduction

Route passenger transport (public transport) plays an invaluable role in cities' life and economic development, providing basic movement of the population, contributing to improving the environmental situation, and improving the safety of road users. Ensuring sustainable mobility of the population is also of great social importance. Public transport in the Republic of Belarus is becoming increasingly in demand, and new innovative types of

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public transport are now becoming widespread. In this regard, the issues of improving the efficiency of public transport (hereinafter — efficiency), considered from the point of view of technical sciences and aimed at improving the processes of transportation organization, are beginning to be of fair scientific interest.

The issues of the efficiency of the enterprises of route passenger transport are the subject of research by both Belarusian scientists and the world scientific community. Let's focus on some of their advantages.

The importance of the efficiency issue 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 the efficiency of a transport system depends on the used technology, strategies, policies, planning process, etc. The abundance of bibliographic references in [3] indicates the importance of this issue and attention to it in many countries of the world too. Researchers pay great attention to the planning of the route network and the development of the timetable. Paper [4] presents a new approach to generating run-time values that are based on analytical development and micro simulations. This works on the basis of a retro analysis and selection of atypical trips using statistical and modeling methods. In modern Belarusian studies, it has been determined that the costs of the operating enterprises of the public transport (hereinafter — enterprise) for the transportation of one passenger are not only the cost expression of the expenses incurred by the enterprise but also determines the degree of efficiency, allow, on the basis of the identified dependencies, to manage the processes of organizing transportation [5, 6]. Thus, the efficiency is largely determined by such parameters as the unit costs of the route passenger transport per 1 km of mileage, the average distance of the passenger's trip, and the passenger capacity of the vehicles used (hereinafter referred to as the vehicle) of the route passenger transport and its utilization coefficient [7].

The most studied and well-developed aspects in the direction of increasing efficiency today are the choice of optimal passenger capacity based on the balance of benefits and costs, as well as methods for managing the passenger capacity using ratio. This is also confirmed by studies [8] since 1985 that deal with the issue of modeling the optimal interval of movement based on the choice of passenger capacity while maintaining the economic level of profitability. The paper [9] presents an iterative procedure for selecting vehicle sizes for bus system routes with a given network configuration and demand matrix. At the same time, the authors note an important thesis that the number of standard sizes of vehicles should be limited in order to avoid the complexity of the operation and the associated additional maintenance costs. At the same time, the new study [10] highlights those mathematical optimization models that were popular in the 1980s were replaced by opinion in the 1990s when it was concluded that it was more efficient to use smaller vehicles, but with a high frequency of movement. And it was proposed to return to the optimization model for determining the size of buses and adjusting frequencies on each route based on the optimization of the social and operational costs of the system, which are understood as the sum of the costs of the user and operator. Similar approaches are reflected in the study, where an optimization model based on minimizing the operational and user costs of the system is proposed [11]. An interesting approach is considered in the study [12], which notes the importance of a differentiated approach to peak and off-peak time. And 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 the most studied and well-developed aspects in the direction of increasing efficiency today are the choice of optimal passenger capacity based on the balance of benefits and costs, as well as methods for managing the passenger capacity utilization ratio. This is also confirmed by a review of studies. There are separate papers considering the solution of some problems in this field from the point of view of mathematics and programming. However, these works differ in fundamental nature and do not always take into account the peculiarities of operational work.

At the same time, many aspects concerning the identification of non-obvious reserves in the specific costs of enterprise per 1 km of mileage remain insufficiently developed, and the problems of a differentiated approach to reducing the specific costs of enterprise when working on a formed route network according to specified traffic schedules on the basis of improving the organization of transportation taking into account the technical and economic parameters of various types of vehicles, the organization, and planning of the work of drivers, consisting in a rational mode of using working time, which will be discussed further.

2. Possible ways to increase efficiency

The study of the methods of organization and evaluation of the results of the operational work of enterprises and the analysis of development trends indicated the need to find ways to improve the efficiency of both individual sections of their work and the work of route passenger transport as a whole. Taking into account that the enterprise work on an already formed route network according to the traffic schedules brought to them, a detailed study of the mode of operation of the drivers was carried out in close connection with the peculiarities of the routing technology of public service, the results of which indicated the need to take into account the technical and economic aspect of the operational work of the route passenger transport when organizing the work of drivers. In this regard, a detailed study of existing methods, techniques, and algorithms for the organization of the operational work of enterprises was carried out, as a result of which problematic issues were identified, requirements for the organization of the work of drivers were developed, areas of improvement were identified, reserves were identified, and the concept of unproductive costs was introduced in relation to the optional costs of the enterprise arising from certain shortcomings and imperfections in the organization of their work, due to the lack of scientifically based methods that meet modern conditions. As a result, new possible ways of increasing efficiency have been identified, consisting in eliminating the causes of unproductive costs by choosing the type of route passenger transport and managing the mode of using driver's working time (it should be borne in mind that the share of drivers' wages in expenses is 30-50%), which are shown in Figure 1 in the form of a scheme structurally presented using the dependence for determining the unit cost of transportation per unit of transport work C_{ptw} as the most important indicator of efficiency in passenger transportation, proposed in [5].

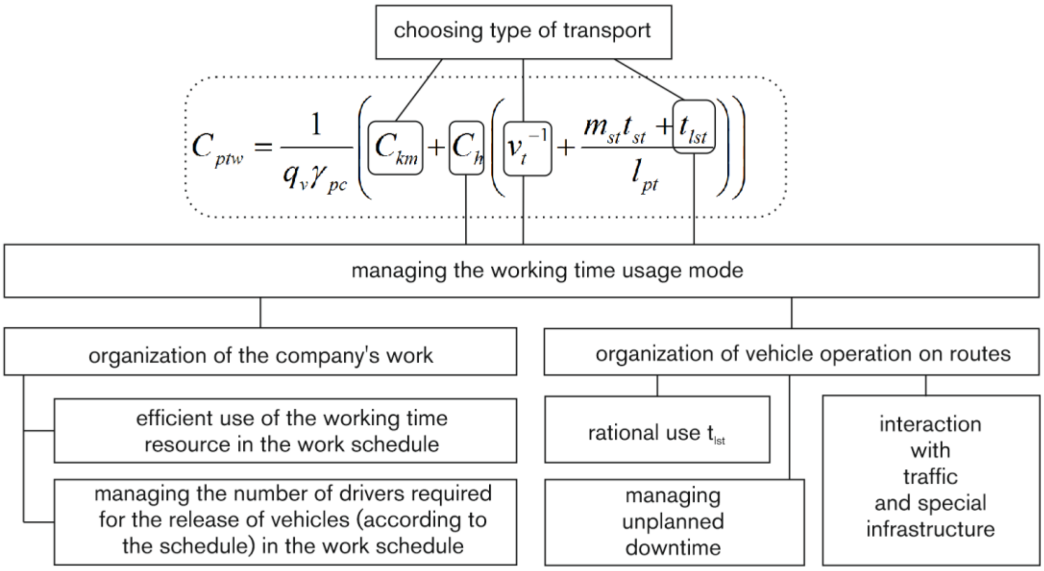

Fig. 1. Possible ways to increase efficiency

q_v — passenger capacity of the vehicle, pass, γ_{pc} — passenger capacity using factor, C_{km} — variable costs per 1 km of vehicle mileage, currency unit/km, C_h — fixed costs for 1 hour of vehicle operation, currency unit/km, v_t — technical vehicle speed, km/h, m_{st} — number of stops, t_{st} — time spent by the vehicle at stopping points, h, t_{lst} — time spent by the vehicle at the end stations, h, l_{pt} — average travel distance of a passenger, km

In the issue of the management of the mode of using working time organization of the work of the enterprise, we will highlight two areas:

(a) effective use of the resource of drivers' working time in the work schedule to reduce unproductive costs associated with overtime payments for individual drivers with incomplete use of the working time fund of others.

When analyzing the work schedules of 1783 drivers of five enterprises over a 3-year period, it was noted that in accordance with the current work organization system, drivers are assigned to certain routes on which they constantly work for a long period. When comparing work schedules, timesheets, and the results of the work of the enterprise, characteristic groups of drivers were identified who constantly work on certain routes, having in each accounting period a working time exceeding the norm established for the same period according to the production calendar (only those cases that were not associated with a shortage of drivers or other random factors were taken into account), paid with the use of an increasing coefficient $k_{inc} \geq 2$, and characteristic groups of drivers who are constantly working on other specific routes that have a flaw. The conducted research revealed the dependence of unproductive costs for paying drivers' overtime on the operating modes of the routes for which they are assigned.

Conclusion: we need a method that will allow us to organize the work of drivers in such a way that it will reduce the described unproductive costs.

(b) managing the number of drivers required to be released to the vehicle line (according to the schedule) in the work schedule to reduce unproductive costs associated with payment using an increasing coefficient k_{inc} work of drivers involved in the work to compensate for the uneven distribution of drivers by shifts and days of the month.

An analysis of the work of five enterprises over a 3-year period showed that in each accounting period, there were cases when there was a shortage or surplus of drivers in the work schedules on certain calendar days of the month (the number of drivers provided for work on a given day was insufficient or exceeded the number of drivers needed to organize the release of a vehicle on the line, taking into account the absenteeism coefficient). It was found that several reasons contributed to this: the unevenness inherent in the planning and provision of vacations, compensation for the shortage of drivers that arose when the staffing level did not meet the existing needs, the disordered alternation of shifts of drivers in work schedules caused by imperfect planning methods (or their absence).

Conclusion: it is necessary to develop methods for medium- and long-term planning of route passenger transport operational work in terms of providing the necessary number of drivers for the release vehicles on the line.

In the matter of managing the mode of using working time organization of the work of the vehicles on the routes, we will highlight three directions:

(a) rational use of the time spent by the vehicle at the end stations to increase their productivity and reduce unproductive costs associated with excessive time spent by the vehicle at the end stations.

The routing technology of passenger service provides for the operation of the route passenger transport 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 route passenger transport vehicle on the route, a model (1) was developed, characterized by the division of their parking time into stations A and B for mandatory and additional:

$$\begin{cases} t_{ta} = t_{lstA} + t_{AB} + t_{lstB} + t_{BA} \\ t_{lstA} = t_{lstmA} + t_{lstaA} \\ t_{lstB} = t_{lstmB} + t_{lstaB} \\ A_{veh} = \dfrac{t_{ta}}{I} \end{cases} \tag{1}$$

where:

t_{ta} - total vehicle turnaround time on the route [min],

t_{lstA}, t_{lstB} - parking time at the station A and station B, respectively [min],

t_{lstmA}, t_{lstmB} - the time of mandatory parking at the station A and station B, respectively [min],

t_{lstaA}, t_{lstaB} - additional parking time at the station A and station B, respectively [min],

t_{AB}, t_{BA} - travel time from station A to B and from B to A, respectively [min],

A_{veh} - number of vehicles on the route, units,

I - the interval of movement on the route [min].

It is determined that the time of parking t_{lstmA} and t_{lstmB} cannot be less than the time:

- necessary for the sanitary needs of the driver,
- necessary to compensate for possible delay upon arrival of the vehicle at the terminal station of the route, to send it to the next scheduled flight,
- the time required to charge onboard energy storage devices of new types of route passenger transport (for example, for electric buses of the OC-concept of the AKSM-

E321, AKSM-E433 models is 9 minutes, for the AKSM-E321 "Algerd" model is 30 minutes [6, 9,13]).

It is known that the intervals on routes I are chosen in such a way as to ensure the transportation of passengers, taking into account the daily unevenness, passenger capacity of the vehicle, and the configuration of routes. At the same time, the integer values of A_{veh} are provided by coordinating t_{ta} and I. This is implemented in two ways:

– as a result, in addition to the mandatory t_{lstmA}, t_{lstmB}, additional t_{lstaA}, t_{lstaB} arise; however, it should be noted that an unreasonable increase in the time of additional parking t_{lstaA}, t_{lstaB} leads to a decrease in the average operating speed of v_{e} and an increase in unproductive costs,
– by reducing the selected traffic intervals on routes I, which leads to a decrease in γ_{pc}, an unjustified increase in mileage, and the performance of additional (unnecessary) transport work, which together leads to a significant unjustified increase in costs and expenses traffic on routes I, which leads to a decrease of γ_{pc}, an unjustified increase in mileage, the performance of additional (unnecessary) transport work, which together leads to a significant unjustified increase in costs and expenses.

Conclusion: it is necessary to develop a methodology, the application of which will ensure the rational use of the time spent by the vehicle at the end stations.

(b) management of unplanned downtime to reduce unproductive costs and other costs associated with each downtime.

The analysis performed in this direction showed that most of the downtime of the vehicle on the line occurs for reasons unrelated to the work of the route passenger transport itself. At the same time, both enterprise and passengers bear heavy losses, especially during group downtime, when stopping the movement of one vehicle of the route passenger transport makes it impossible to move another enterprise (this problem is particularly acute for rail transport). At the same time, it was revealed that the greatest downtime in cases of road traffic accidents (hereinafter referred to as accidents) falls not on the elimination of their consequences but on waiting for the state traffic inspectorate (hereinafter referred to as the traffic police) and documenting the accident.

Conclusion: it is necessary to study the issue of creating a service whose employees will be endowed with special powers that allow, while assisting the traffic police, to perform actions aimed at reducing the downtime of a vehicle when working on the line.

(c) interaction with traffic and infrastructure to increase efficiency by increasing technical speed $v_{\text{т}}$.

A survey of the traffic conditions of the vehicle on the route network of Minsk, Polatsk, Navapolatsk, Slonim showed that in certain cases, there is a loss of time during the interaction of the vehicle with traffic, the order of which is determined by the relevant schemes and is provided by technical means. Additional restrictions are also imposed by the special infrastructure of certain types of route passenger transport. All this leads to the emergence of short-term "downtime", some kind of delays in the movement of route passenger transport vehicles associated with the expectation of the possibility of further movement, provided that traffic safety is ensured, the need to deviate from the requirements of road signs and markings, the absence of the right of preferential movement, etc. [9, 14].

Conclusion: it is necessary to study in detail the features of the interaction of vehicles of all types of route passenger transport with the organization of traffic and develop a concept and recommendations to ensure their productive interaction.

When deciding on the type of route passenger transport, the technical and economic characteristics of the vehicle are traditionally taken into account, which includes their weight and size parameters, as well as capacity, comfort, maneuverability, pick-up, carrying capacity, while also taking into account the costs associated with the creation of infrastructure, the acquisition of the vehicle, as well as the costs arising during their operation.

The existing approaches, consisting in choosing the type of route passenger transport based on the criterion of carrying capacity, are not comprehensive today, do not fully take into account the possibilities of new types of route passenger transport, and require clarification and development. It is also worth noting that in many cases, the question of choosing the type of transport, in general, for transportation on the existing route network of the city, as well as on individual existing routes or groups of routes, remains relevant [6, 14].

Conclusion: an additional detailed study of the operational capabilities of new, innovative types of route passenger transport vehicles and their impact on efficiency is needed, with the development of a concept for choosing the type of route passenger transport taking into account the effectiveness of investments in the development, operation, renovation of infrastructure, acquisition of vehicles for operation on the route, taking into account the life cycle, assessment of operating costs, as well as methods for improving efficiency through the rational use of the mode of using working time.

3. Management of the mode of use of working time by the organization of the work of the enterprise

The author's sectoral method made it possible to organize the work of the drivers of the public transport vehicle in such a way that it led to a reduction in unproductive costs associated with the inefficient use of their working time resources. It should be noted that the developed sectoral method of organizing and managing the work of drivers is used on an already formed and functioning route network, passenger transportation which is carried out according to approved traffic schedules, which significantly complicates the task, imposing a number of restrictions. The spectral method consists in combining and alternating routes within the sector and ensures uniform alternation of drivers along these routes, taking into account the average duration of the working shift of drivers entering the sector. At the same time, the versatility of the spectral method lies in the fact that it can also be used in the design of new transport systems and routes, greatly simplifying many processes.

Within the framework of the sectoral method, mathematical models of the work of the vehicle and the driver on the enterprise routes were developed and verified, and the concept of the sector was defined as a technical and economic unit operating on the principle of equivalent production load, which consists in combining within the sector exactly such routes (or their separate releases), which, with uniform alternation of drivers along with them during the accounting period, will compensate for the existing irregularities in the duration of working shifts on individual routes.

The sector is considered as a symbiosis of routes, vehicles, and drivers, each of which is interchangeable within the boundaries of the sector. At the same time, a high degree of their compatibility gives the right to talk about the sector as a universal ecosystem that ensures the implementation of the principle of equivalence at the economic level and congruence —

at the transport level. The basic principle of the sector: weighted "switching" of routes and "switching" of drivers assigned to this sector. As a result, the sector is a controlled closed system "vehicle-driver-route-mode of operation", which has the ability to manage and monitor the state of individual elements of the sector with operational efficiency analysis, which allows you to resolve problems arising within the sector. Within the framework of the sectoral method, the laws of the organization of the "vehicle–driver–route–mode of operation" system are formulated: the isotropy of the working time within the sector system, the preservation of the equality of mileage within the sector system.

The sectoral method determines that each sector will meet the following requirements: complementarity (combining routes into a sector based on the commonality of significant parameters), scalability (the possibility of increasing the number of sector elements due to individual releases or routes based on taking into account significant criteria to ensure the stability of the properties of the sector), productivity (ensuring the required values of work efficiency), manageability (enabling both centralized and decentralized sector management, monitoring the state of the sector, opportunities for effective management of the human resource of the sector, planning and development), readiness (the period of time for which work in the sector can be deployed), versatility (based on the interchangeability of vehicles and drivers), fault tolerance (the ability to quickly respond to the failure of individual elements of the sector), safety (the ability of the sector to ensure a high level of traffic safety by increasing drivers' awareness of traffic conditions on routes within the sector, selection of drivers based on the driver safety rating and the sector safety rating, which is an element of a proactive approach to ensuring traffic and transportation safety), reliability.

Given the high degree of heterogeneity of routes (as a rule), sector design is a complex and responsible task, which is solved using the developed sector design methodology, which ensures the formation of sectors equivalent in their parameters and is implemented using the developed sector formation algorithm (Figure 2).

In detail, the sectoral method and the procedure for applying the sector design methodology are described in [14].

Management of the number of drivers required for the release on the dates of the month of the vehicle on the line according to a given schedule in order to reduce unproductive costs is carried out on the basis of the joint application of the author's methods developed within the framework of the sectoral method:

(a) methods of drawing up a schedule of driver vacations, characterized by the definition of the period of the beginning of a working vacation with clarification to a 10-day period (decade), which allows you to evenly distribute 39-day vacations throughout the year, taking into account seasonality, based on the application of the balancing algorithm "employment of free cells", which leads to a significant reduction in the uneven distribution of the number of drivers on the days of each month.

(b) methods for determining the regular number of drivers, taking into account the routing technology of service, the use of which allows you to respond to external factors.

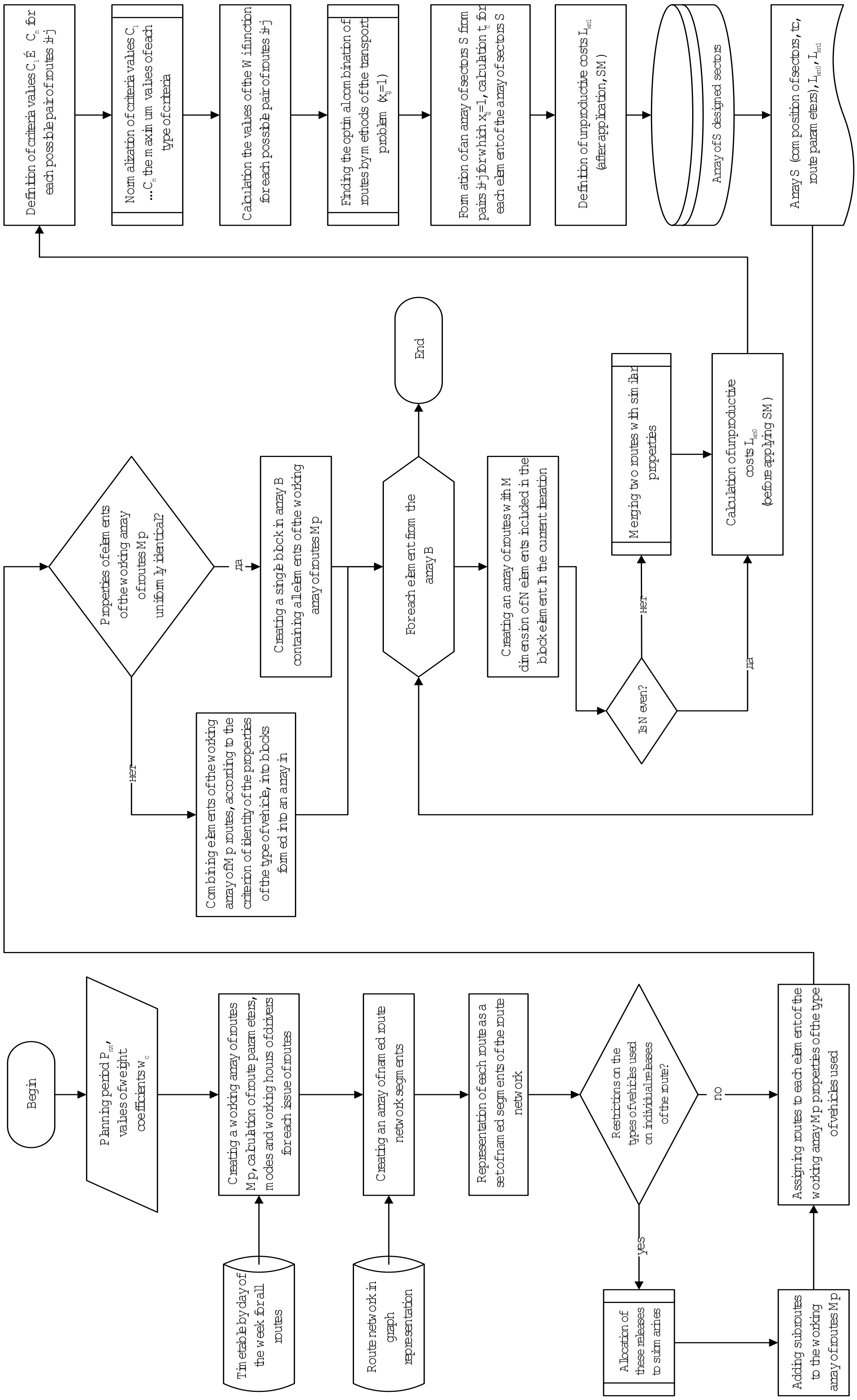

Fig. 2. Algorithm of sector formation

$$ {}_{n}^{m}G_{d} = \begin{pmatrix} g_{11} & \dots & \dots & \dots & g_{1d} \\ \dots & \dots & g_{ij} & \dots & \dots \\ g_{n1} & \dots & \dots & \dots & g_{nd} \end{pmatrix} \tag{2} $$

where:
i - driver's serial number,
j - the serial number of the working day in the cycle,
g_{ij} - state of the driver's operating mode,
m - unique number (index, designation),
n - number of team drivers,
d - cycle duration.

The typology of teamwork modes has been developed with the allocation of all possible non-repeating sequences of work shifts and days off into sequence templates based on the implementation of the principle of harmonization of drivers' work schedules, ensuring not only the reliability of drivers by strict observance of drivers' work and rest regimes, systematic provision of continuous rest periods to restore efficiency, but also the uniform distribution of drivers by calendar days of the month (including based on taking into account the irregularities of "working-weekend" days, "first-second" shift, etc.), combined into classes based on the generality of the cycle duration and the number of drivers in the team, typical representatives of which are given in [15].

Studies have found that the most rationale for organizing teams of drivers is the joint use of operating modes with a 12-day cycle (in the variants of teams for three drivers and two drivers) to ensure the operation of the route passenger transport vehicle on all days of the week, and with a 14-day cycle to strengthen shift work on weekdays. It is advisable to organize the work of drivers with the division of the working day into parts to ensure the transportation of passengers at peak times according to a special mode of operation with a 7-day cycle.

To determine the modes of operation of the vehicle and drivers, each sector is described by a conditional formula of the sector, for the formation of which an algorithm has been developed (Figure 3), characterized by the selection of such a number of sequence templates encoded from among those that ensure the implementation of the principles described above.

An example of a sector formula compiled for 22 drivers formed into eight teams (1 - with a template with the designation "A", 2 – "B", 1 – "C", 2 – "D", 2 – "T") is given in (3):

$$ 1\,{}_{3}^{A}G_{12}\,2\,{}_{3}^{B}G_{12}\,1\,{}_{3}^{C}G_{12}\,2\,{}_{3}^{D}G_{12}\,2\,{}_{2}^{T}G_{14} \tag{3} $$

The selection of drivers for each vehicle within each sector is carried out only within the boundaries of the schedule grids formed according to the formula of the sector, taking into account the restrictions imposed (availability of access to work on the vehicle, access to work on the routes of the sector, taking into account the indicators of the safety rating of the sector, based on the given number of accidents on the routes of the sector, taking into account the indicators of the professional safety rating of the driver, etc.).

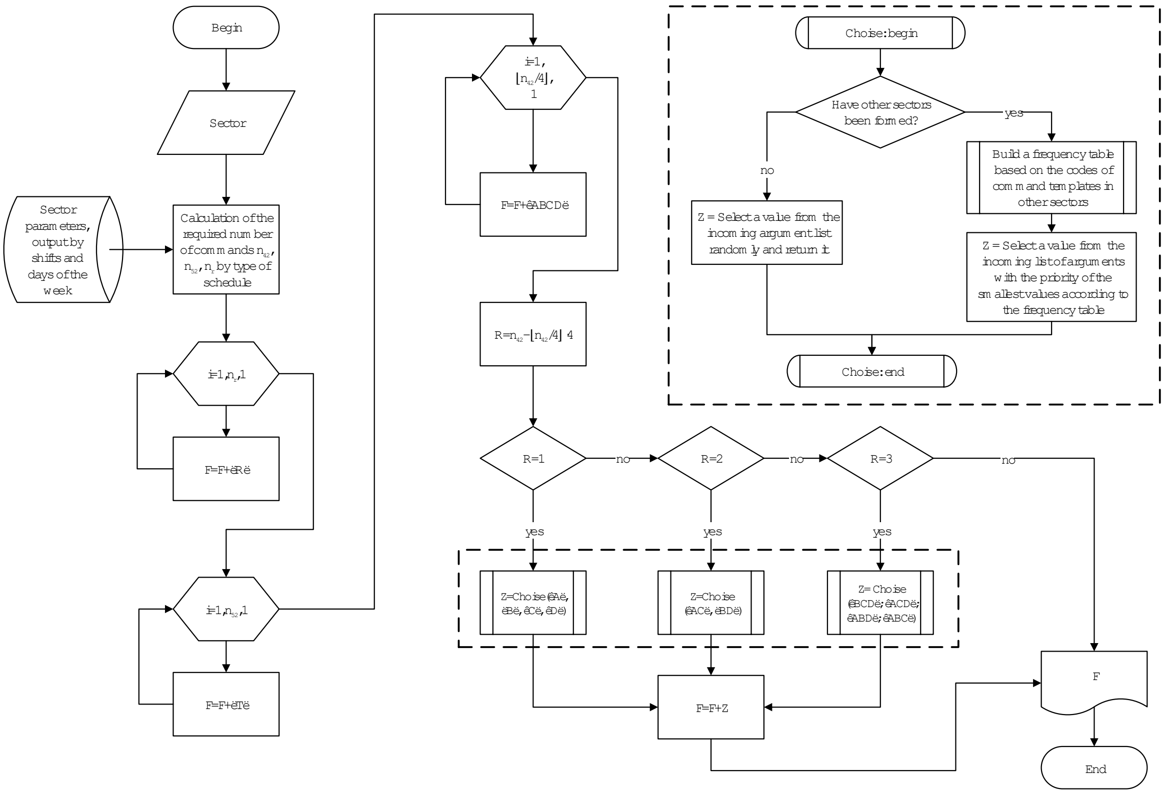

Fig. 3. Algorithm for forming a sector formula for drawing up work schedules of vehicles and drivers by the sectoral method

4. Management of the mode of using working time organization of the work of the vehicle on the routes

The universality of the principles of the sectoral method makes it possible to use it to reduce unproductive costs associated with excessive time spent by the vehicle at the end stations and to increase the productivity of the vehicle by optimizing the time spent by the vehicle at the end stations t_{lstaA}, t_{lstaB} in the model (1) of the vehicle on the route.

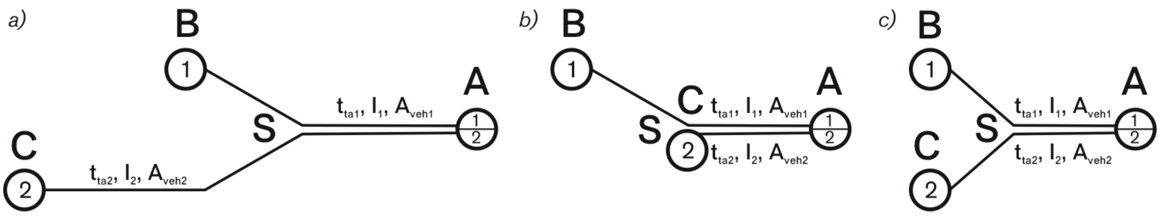

Fig. 4. Models of routes, the work of which is organized by the sectoral method

The possibility of using the sectoral method for organizing the work of the vehicle on the routes is to allocate and combine the routes with common segments on the basis of 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. The implementation of the sectoral method for organizing the work of the vehicle on routes is considered using the model presented in Figure 4 and in dependencies (4) and 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 part of the route AB and is intended to strengthen it, and in fact, the common segment AS is the route AC, and also when AC = AB.

$$\begin{cases} t_{ta1} = t_{lstmA} + t_{lstaA1} + t_{AB} + t_{lstmB} + t_{lstaB1} + t_{BA} \\ A_{veh1} = \dfrac{t_{ta1}}{I_1} \\ t_{ta2} = t_{lstmA} + t_{lstaA2} + t_{AC} + t_{lstmC} + t_{lstaC2} + t_{CA} \\ A_{veh2} = \dfrac{t_{ta2}}{I_2} \end{cases} \quad (4)$$

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 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 route passenger transport) 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 the use of the sectoral method for organizing the work of the vehicle on routes. At the same time, model (5) will already be applicable.

$$\begin{cases} t_{ta12} = t_{lstmA} + t_{lstaA12.1} + t_{AB} + t_{lstmB} + t_{lstaB12} + t_{BA} + \\ \qquad + t_{lstmA} + t_{lstaA12.2} + t_{AC} + t_{lstmC} + t_{lstaC12} + t_{CA} \\ A_{veh12} = \dfrac{t_{ta12}}{I_{12}} \end{cases} \quad (5)$$

Table 1. Initial data and calculations of model indicators for various scenarios

Scenario	**Name of indicator**	**Notation**	**Unit**	**Initial scenario**			**Sectoral method scenario**	**Δ**
Route				**Route 1**	**Route 2**	**Total for Route 1, Route 2**	**Route 1&2**	
Sequence of points				**ASBSA**	**ASCSA**		**ASBSA SCSA**	
Segment AB	the time of mandatory parking at station A	t_{lstmA}	min.	5	–	–	5	0
	additional parking time at the station A (unproductive time)	t_{lstaA}	min.	10	–	–	0	-10
	travel time from station A to B	t_{AB}	min.	40	–	–	40	0
	the time of mandatory parking at station B	t_{lstmB}	min.	5	–	–	5	0
	additional parking time at the station B (unproductive time)	t_{lstaB}	min.	0	–	–	0	0
	travel time from station B to A	t_{BA}	min.	40	–	–	40	0

Segment AC	the time of mandatory parking at station A	t_{lstmA}	min.	–	5	–	5	0
	additional parking time at the station A (unproductive time)	t_{lstaA}	min.	–	10	–	0	-10
	travel time from station A to C	t_{AC}	min.	–	60	–	60	0
	the time of mandatory parking at station C	t_{lstmC}	min.	–	5	–	5	0
	additional parking time at the station C (unproductive time)	t_{lstaC}	min.	–	0	–	0	0
	travel time from station C to A	t_{CA}	min.	–	60	–	60	0
Indicator for network	the interval of movement for segment AB	I_{netAB}	min.	–	–	20	20	20
	the interval of movement for segment AC	I_{netAC}	min.	–	–	20	20	20
	the interval of movement for segment AS	I_{netAS}	min.	–	–	10	10	10
	total vehicle turnaround time on the route	t_{ta}	min.	100	140	240	220	-20
	interval of movement on each route	I	min.	20	20	20	20	-20
Days Indicator	number of vehicles	A_{veh}	veh.	5	7	12	11	-1
	number of drivers	A_{driv}	driv.	10	14	24	22	-2
	number of turnaround trips on noted sequence of end points	N_{tat}	t/a-trip	51	51	102	51	(n/a)
	number of "zero" trips (from depot to A and from A to depot)	N_{zt}	z-trip	10	14	24	22	-2
	travel time (without parking at the end stations)	T_{tt}	h	68,00	102,00	170,00	170,00	0,00
	parking time on the end stations	T_{pt}	h	17,00	17,00	34,00	17,00	-17,00
	mandatory time	T_{ptm}	h	8,50	8,50	17,00	17,00	0,00
	additional time (unproductive time)	T_{pta}	h	8,50	8,50	17,00	0,00	-17,00
	“zero” trips time	T_{zt}	h	3,00	4,20	7,20	6,60	-0,60
	machine hours	T_{mh}	h	88,00	123,20	211,20	193,60	-17,60
	mileage	M_{vh}	km	1138,34	1702	2840,34	2830,34	-10,00
	operational speed	V_{op}	km/h	12,94	13,81	13,45	14,62	+1,17
	the share of machine hours in motion (useful work)			81%	86%	84%	91%	–
	the share of unproductive time in machine hours			10%	7%	8%	0%	–

Now it is possible to simulate the operation of two routes leaving the same terminal station according to the scheme of Figure 4a, 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 5 km and 18 min. The remaining initial and calculated data are given in Table 1.

A fragment of the timetable for stations A, B, and C for the initial version (vehicles of route 1 are designated 101..105, vehicles of route 2 are designated 201..207) is presented in Table 2. A fragment of the schedule for stations A, B, and C after applying the sectoral method is presented in Table 3 (vehicles are designated 301..311).

Table 2. Fragment of the original timetable

Vehicle number	**Dep. A**	**Arr. B**	**Dep. B**	**Arr. A**	**Dep. A**	**Arr. B**	**Dep. B**	**Arr. A**	**Dep. A**	**Arr. B**
101	**5:00**	5:40	5:45	*6:25*	**6:40**	7:20	7:25	*8:05*	**8:20**	9:00
102	**5:20**	6:00	6:05	*6:45*	**7:00**	7:40	7:45	*8:25*	**8:40**	9:20
103	**5:40**	6:20	6:25	*7:05*	**7:20**	8:00	8:05	*8:45*	**9:00**	9:40
104	**6:00**	6:40	6:45	*7:25*	**7:40**	8:20	8:25	*9:05*	**9:20**	10:00
105	**6:20**	7:00	7:05	*7:45*	**8:00**	8:40	8:45	*9:25*	**9:40**	10:20

Vehicle number	**Dep. A**	**Arr. C**	**Dep. C**	**Arr. A**	**Dep. A**	**Arr. C**	**Dep. C**	**Arr. A**	**Dep. A**	**Arr. C**
201	**5:10**	6:10	6:15	*7:15*	**7:30**	8:30	8:35	*9:35*	**9:50**	10:50
202	**5:30**	6:30	6:35	*7:35*	**7:50**	8:50	8:55	*9:55*	**10:10**	11:10
203	**5:50**	6:50	6:55	*7:55*	**8:10**	9:10	9:15	*10:15*	**10:30**	11:30
204	**6:10**	7:10	7:15	*8:15*	**8:30**	9:30	9:35	*10:35*	**10:50**	11:50
205	**6:30**	7:30	7:35	*8:35*	**8:50**	9:50	9:55	*10:55*	**11:10**	12:10
206	**6:50**	7:50	7:55	*8:55*	**9:10**	10:10	10:15	*11:15*	**11:30**	12:30
207	**7:10**	8:10	8:15	*9:15*	**9:30**	10:30	10:35	*11:35*	**11:50**	12:50

Table 3. Fragment of the timetable after applying the sectoral method

Vehicle number	Dep. A	Arr. B	Dep. B	Arr. A	Dep. A	Arr. C	Dep. C	Arr. A	Dep. A	Arr. B
301					**5:10**	6:10	6:15	*7:15*	**7:20**	8:00
302					**5:30**	6:30	6:35	*7:35*	**7:40**	8:20
303					**5:50**	6:50	6:55	*7:55*	**8:00**	8:40
304					**6:10**	7:10	7:15	*8:15*	**8:20**	9:00
305	**5:00**	5:40	5:45	6:25	**6:30**	7:30	7:35	*8:35*	**8:40**	9:20
306	**5:20**	6:00	6:05	6:45	**6:50**	7:50	7:55	*8:55*	**9:00**	9:40
307	**5:40**	6:20	6:25	7:05	**7:10**	8:10	8:15	*9:15*	**9:20**	10:00
308	**6:00**	6:40	6:45	7:25	**7:30**	8:30	8:35	*9:35*	**9:40**	10:20
309	**6:20**	7:00	7:05	7:45	**7:50**	8:50	8:55	*9:55*	**10:00**	10:40
310	**6:40**	7:20	7:25	8:05	**8:10**	9:10	9:15	*10:15*	**10:20**	11:00
311	**7:00**	7:40	7:45	8:25	**8:30**	9:30	9:35	*10:35*	**10:40**	11:20

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 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, the 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 introducing the sectoral method was made according to the criterion of the cost of paying drivers and capital investment in the purchase of additional vehicles. Due to the circumstances described above, other indicators are simplified. The calculation data are summarized in Table 4.

Thus expected economic effect of servicing every two routes by the sectoral method, if the necessary conditions are met, is expressed for a bus for a 10-year period (the life cycle of one vehicle) at current prices of 670 kEUR, for a trolleybus for a 15-year period 980 kEUR, for a tram (15 m length) for a 30-year period 1890 kEUR.

Table 4. Calculation of the economic effect of the introduction of the sectoral method

Name of indicator	Unit	Bus (12 m)	Trolleybus (12 m)	Tramway (15 m)
Initial scenario				
Machine hours (per year)	hours	77088,00	77088,00	77088,00
The required number of drivers (taking into account the absenteeism rate of 1,18)	drivers	45	45	45
Drivers' labor costs (per year)	kEUR	493,36	493,36	493,36
The number of vehicles taking into account the output coefficient	veh.	14	14	14
The cost of one vehicle	kEUR/veh.	250,00	350,00	630,00
Investments in vehicles	kEUR	3500,00	4900,00	8820,00
Vehicle life cycle	year	10	15	30
The cost of paying drivers for the life cycle	kEUR	4933,63	7400,45	14800,90
Costs of training drivers for life cycle maintenance	kEUR	135,00	202,50	405,00
Total costs of drivers' labor and driver training for the life cycle	kEUR	5068,63	7602,95	15205,90
Total capital investments in vehicles and driver costs over the life cycle	kEUR	8568,63	12502,95	24025,90
Sectoral method scenario				
Machine hours (per year)	h/year	70664,00	70664,00	70664,00
The required number of drivers (taking into account the absenteeism rof ate 1,18)	drivers	42	42	42
Drivers' labor costs (per year)	kEUR	452,25	452,25	452,25
The number of vehicles taking into account the output coefficient	veh.	13	13	13
The cost of one vehicle	kEUR/veh.	250,00	350,00	630,00
Investments in vehicles	kEUR	3250,00	4550,00	8190,00
Vehicle life cycle	year	10	15	30
The cost of paying drivers for the life cycle	kEUR	4522,50	6783,74	13567,49
Costs of training drivers for life cycle maintenance	kEUR	126,00	189,00	378,00

Total costs of drivers' labor and driver training for the life cycle	kEUR	4648,50	6972,74	13945,49
Total capital investments in vehicles and driver costs over the life cycle	kEUR	7898,50	11522,74	22135,49
The economic effect of the introduction of the sectoral method				
Total costs of drivers' labor and driver training	kEUR	-420,14	-630,20	-1260,41
Investments in vehicles	kEUR	-250,00	-350,00	-630,00
Total capital investments and costs for drivers	kEUR	-670,14	-980,20	-1890,41

Models of the operation of new types of vehicles have been developed, the use of which involves charging with a certain frequency, on the basis of which boundary values of route parameters have been identified that ensure the effective use of these vehicles.

In order to increase the reliability of route passenger transport, increase the attractiveness and popularity of public transport, and reduce unproductive costs associated with paying for the downtime of the drivers of vehicles, it is proposed to create a service of emergency commissioners (emergency audit service), which will be endowed with certain powers to assist the traffic police when registering an accident, which will reduce the downtime of the vehicle. This will reduce significant time losses when the vehicle traffic is stopped caused by an accident, for which a clear algorithm of actions of all services is proposed in the event of an accident and the period following it before the restoration of regular traffic of the vehicle, the concept, structure and working procedure of the service of emergency commissioners authorized to issue an accident (without victims), without involving traffic police officers, proposals for making necessary changes have been prepared, giving emergency commissioners the appropriate legal authority to issue an accident.

In order to increase the efficiency by increasing the technical speed of the v_t while improving the conditions of interaction with traffic and special infrastructure, a detailed study of the features of the interaction of vehicles of all types of public transport with the organization of traffic was carried out, which is described in detail in [15] and a concept and recommendations for ensuring their productive interaction were developed.

A detailed study of the problems of the effective use of new, innovative types of public transport vehicles was carried out with the development of the concept of choosing public transport based on the costs of deployment, development, operation, renovation of infrastructure, acquisition of vehicles for operation on the route, taking into account the life cycle, as well as through the rational use of the mode of using working time, which is additionally described in [5, 13, 14, 15], the boundaries of the effective use of different types of public transport vehicles are determined. It is also worth noting that the development of innovative types of electric transport, which is a priority for our country, is promising due to the development of nuclear energy. For mass passenger transportation, the advantage is the use of IMC trolleybuses, which provide a uniform distributed load on the electric network during the day, do not increase the time of mandatory parking at terminal stations, which does not cause an increase in unproductive costs, and do not require additional time for long-term charging and additional investments in infrastructure, as well as rail types of public transport (light rail transport and trams) in appropriate conditions [16-19].

5. Conclusions

The use of the concept of unproductive costs has been introduced in relation to the optional costs of the enterprise arising as a result of certain shortcomings and imperfections in the organization of their work, the possibilities of improving efficiency by managing unproductive costs have been identified, methods of accounting, investigation, and analysis of incidents related to the work of transport have been developed.

A sectoral method has been developed that allows organizing both the work of enterprise drivers on an already formed route network according to an existing schedule and organizing the work of the vehicle at the network design stage or the development of schedules. To use the sectoral method, the sector design methodology, algorithms for the formation of the sector, and the formation of the formula of the sector for drawing up work schedules by the sectoral method have been developed. As part of the development of methods, a number of models of the work of the vehicle on routes, including new types, have been developed.

The universality of the sectoral method is emphasized by the fact that its principles are also valid for the design of algorithms for the operation of promising unmanned vehicles, for which the sector design methodology will also be applicable, balancing repair intervals in time, ensuring rational planning of maintenance and repair.

The availability of accessible and understandable author's methods makes it possible to significantly reduce the time and cost of implementing a sectoral method, which is not capital-intensive but knowledge-intensive; therefore, it is implemented easily and quickly [18], in connection with which not only significant but also rapid results are provided to increase efficiency.

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