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## **OPTIMIZING THE TIME COSTS OF PASSENGER TRANSPORT OF PEOPLE WITH DISABILITIES**

**Summary.** The paper dwells on a mathematical model of the logistical system of transport services for persons with disabilities, and there have been analyzed factors that affect the time spent on their transportation. When developing methodology for optimizing the time costs of passenger transport of persons with disabilities, the following two basic transportation services have been taken into account: (a) "social taxi", which will transport only people with special health; (b) a vehicle system in combination with urban passenger transport, which will transport representatives of the group of people with restricted mobility together with all other passengers. The study found that in the case of insufficient accessibility to the required environment, by the increase in the demand of disabled people for transportation by "social taxi", travelling costs are increased that results in increasing total costs of the carrier. Based on a comparative analysis of logistical costs, optimum relationship between the number of the adapted buses and "social taxi" on the route under study has been established.

### **1. INTRODUCTION**

While addressing the problem of increasing the level of integration of persons with disabilities into normal social life, the improvement of transport services for them occupies a special place, which recently has been the most important and priority of many social policies in many countries.

In recent years, special attention has been paid to solving the problem of increasing the level of accessibility of transport services for disabled persons with public passenger transport. In this regard, the project MAPLE has been implemented in Europe, which analyzes the current state of transport service for disabled persons in a number of countries. The final conference held in London [1] addressed the introduction of innovative technologies in public passenger transport, which should ensure the high-standard services for all categories of consumers, including for disabled persons.

A study on the current situation in the field of transportation services for disabled persons in developed countries [2] (United States of America, Great Britain, Germany, France, Italy, Japan, Netherlands, Sweden, etc.) shows that public transport passenger services are adequately provided with adapted vehicles and appropriate transport infrastructure, as well as with the systems of the organization and management of transport services, which is not the case in developing countries, including Georgia. Thus, by sharing the experience of developed countries [3, 4, 5], it is possible to resolve the problem of the formation of satisfactory systems of transport services for disabled persons and their continuous development.

Despite the important decisions taken recently in Georgia at the government level, the improvement of public transport services sphere for disabled people is not proceeding rapidly enough,

which requires the establishment of the systems of the organization and management of urban passenger transport services based on the scientifically justified logistics approaches and principles [6, 7, 12], equipping them with appropriate technology and taking into account local-specific conditions, which should contribute to increasing the level of mobility and accessibility of transport services for disabled persons.

In order to deal with the above-mentioned problem, an important place in the process of the organization and management of urban transport service for persons with disabilities is occupied by the assessment of the level of logistical service that will enable us to optimize the main indicators of regular passenger transportations [8, 9].

Vehicles intended for the transportation of disabled persons and their modification should meet the requirements of the ecological, accessibility and safety standards [10, 11]; particularly, in the bus passenger compartment, passengers should be able to get up or settle down without hindrance, and it is necessary to ensure their safe transportation both independently and with accompanying persons.

The assessment indicators of transport services for disabled persons include reliability, availability, accessibility, service complexity, well-timed service, minimal travelling time, travelling cost, environmental safety of carriages, and safe-conduct for luggage.

In order to study these indicators, it is necessary to carry out a full analysis of the factors involved and to identify and systematize the main factors. In this case, the use of this type of a systemic approach will allow us resolving the problem of optimizing the time spent on transportation of disabled passengers by city buses, taking into consideration the rational costs of transport services.

## 2. WAYS OF PROBLEM SOLVING

In the urban transport service logistics chain, the level of access of disabled people to transport from the point of departure to the point of destination directly depends on traveler's waiting time for bus and the average time spent on the movement of vehicle. The values of these components are mostly affected by the ratio of different forms of transport services for disabled people. Thus, to determine the optimal time spent on the carriage of disabled persons, it is necessary to determine the number of vehicles with specialized equipment for safe and comfortable transportation of persons with disabilities.

To determine the optimal values of time spent on the transportation of disabled persons, at the initial stage of the study, the main factors that affect the cumulative time of travel were systematized and the structural relationships between them were established. Table 1 presents the list of factors acting on time spent on transportation of disabled people [12].

In the logistical system of transport services for persons with disabilities, transportation of passengers, from the customer's point of view, will be optimal when the service will be provided "dead on time" at minimal cost [13, 14]. The problem should be solved by meeting the customers' needs and by taking into account the interests of persons providing transport services.

From the point of view of passengers, the optimal is travel executed in minimum time with maximum comfort and acceptable tariff. Therefore, customer will choose one of the following types of transport services:

1. Public passenger car – taxi;
2. "Social taxi" equipped with devices required for comfortable and safe transportation of disabled persons;
3. Adapted buses running on the city routes.

Thus, based on the interests of operators and owners of transport services, the main reason of studying the problem is the creation of a logistical service scheme for city buses, which will enable to minimize the time spent on the transportation of persons.

Table 1

Presents the list factors acting on time spent on transportation of disabled people

The time spent on mobility of disabled people	Acting factors
Time spent on walking to and from the stopping points and parking areas	<ul style="list-style-type: none"> <li>- the level of accessibility to urban facilities, public transport parking areas, and stopping points;</li> <li>- the urban network density;</li> <li>- walking speed of passengers with restricted mobility.</li> </ul>
Time spent on waiting, boarding, alighting, and transfer	<ul style="list-style-type: none"> <li>- traffic interval;</li> <li>- failure probability on the route;</li> <li>- traffic control;</li> <li>- average passenger carrying capacity of vehicle;</li> <li>- number of vehicles;</li> <li>- average operating speed of movement on the route;</li> <li>- non-uniformity of passenger traffic flow;</li> <li>- time and duration of the operation of motive power;</li> <li>- average distance of movement during the transfer;</li> <li>- coefficient of transferability.</li> </ul>
Travel by vehicle	<ul style="list-style-type: none"> <li>- route length;</li> <li>- movement at the specified condition and dead time on the line;</li> <li>- average travelling length;</li> <li>- average motion speed on the route;</li> <li>- dead time of bus during boarding and alighting;</li> <li>- bus arrival time on the route.</li> </ul>

### 3. SUBJECT AND METHODS OF RESEARCH

The objective of the research is to determine the time spent on comfortable and safe transportation of persons with disabilities in the logistical system of passenger urban transportation service in the city of Kutaisi.

When selecting methodology of optimizing time spent on the transportation of disabled persons, in the first instance, two types of transport services most appropriate for Kutaisi City conditions were studied, particularly (a) "social taxi", which is designed only for disabled people, and (b) the city bus system, in which disabled people are regularly transported with other passengers by adapted buses.

For studying this type of service, there have been the schemes of the transportation of disabled persons from the points of departure to their destination on one or several routes [15 - 17] (see Figs. 1a and 1b).

When determining time spent on the transportation of persons with disabilities, the level of accessibility to Kutaisi road infrastructure facilities was taken into consideration, particularly, pedestrian crossings, city bus stations and stops, as well as the degree of adaptation of the points of transfer between city bus routes to people with disabilities.

To study the regular passenger transportation directions according to the determination of number and groups of disabled persons in Kutaisi City and their needs, questionnaire surveys were carried out in 2017. According to the data received, the main directions of travel for persons with disabilities, the number of the points of departure, and destination and their locations have been determined. The following are the groups of persons with disabilities and number of person's involved in them in Kutaisi, by the degree of disability (Table 2):

Table 2  
The groups of persons with disabilities and number of persons involved in them in Kutaisi City, by the degree of disability

Degree of disability	Number of persons
Persons with a prominent degree of disability	1637
2. Persons with a considerable degree of disability	2103
3. Persons with a moderate degree of disability	2427
4. Disabled persons aged 0–18 years	465
Total	6632

On working and non-working days in the months of April, August and October 2017, the studies on passenger flows on the city bus routes, using the tabular method of field observations were carried out.

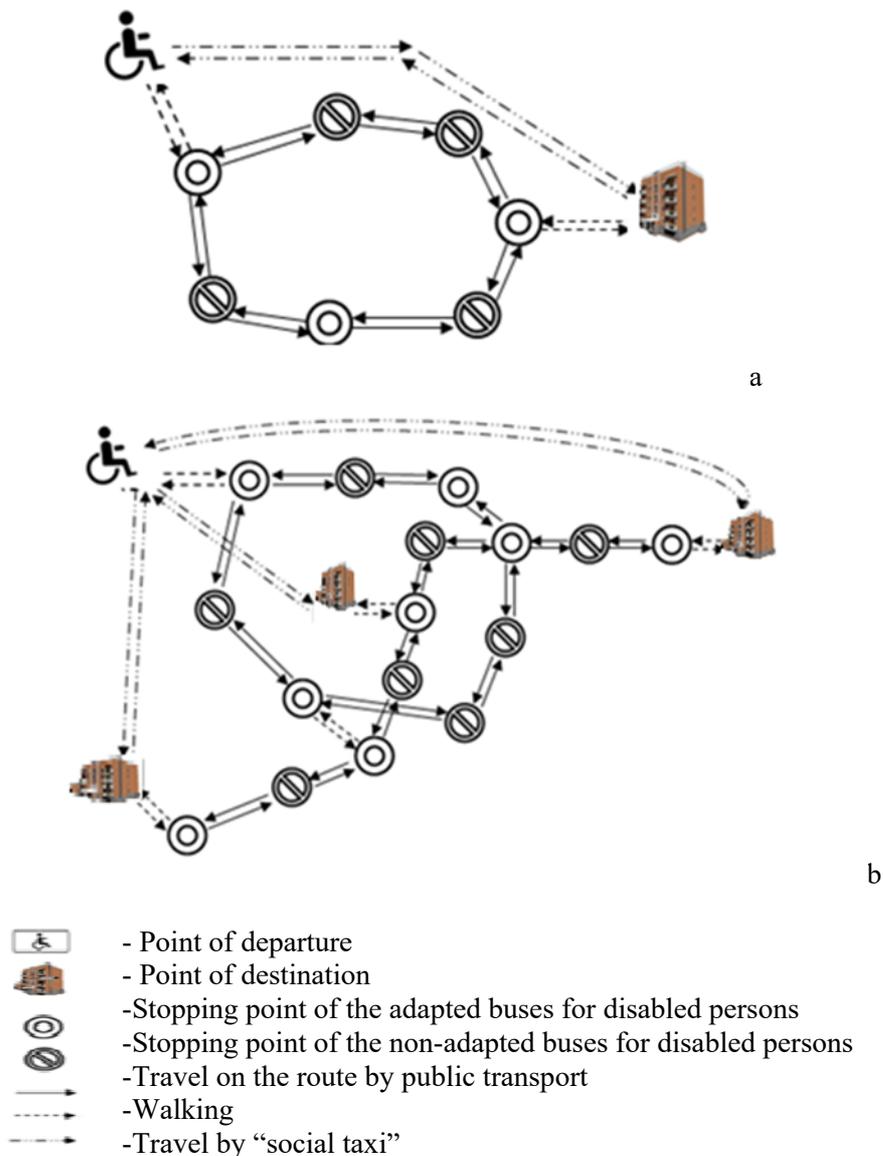


Fig. 1. Transportation schemes of disabled persons using adapted bus on the urban transport routes: a) when using one route and b) when using several routes (including transfer)

The study results revealed that the actual value of the population's transport mobility is  $\mu=250$ , which, based on the number of residents of the city (150 thousand people), is on the low side, which is explained by the fact that due to the ageing bus fleet and poor service standard, most of the population is travelling by a private car. According to the survey results, the priority routes have been established for disabled persons, services of which are highly in demand among disabled persons. These routes include circular routes No. 1 and No. 2 of the city class buses. As the Kutaisi transport network scheme is radial circular, the above-mentioned routes cover a large area of major settlements of the city and provide services to almost 15–18% of the population. In total, 10 midi-buses run on the No. 1 route, the length of the route is  $L = 10$  and 8 km, the bus travelling time is  $t = 36$  min, and traffic interval is  $T=3,6-4$  min. In total, 8 midi-buses run on the No. 2 route, the length of the route is  $L = 9$  and 6 km, the bus travelling time is  $t = 32$  min, and traffic interval is  $T = 3,5-4$  min.

According to the results of the studies on passenger flows, it has been established that the average number of passengers travelled by one bus during the working days on the No. 1 route amounted to 954–982 passengers and on an average of 47–49 passengers per travel. The average number of passengers travelled by a bus on the No. 2 route during the working day was 895–920 passengers, with average of 44 passengers per travel. On weekends, decline of 15–18% in these indicators was observed. The analysis of the indicators of the transportation of disabled people revealed that only 6–9% of the total number of transported passengers were people with disabilities. On the No 1 route, during the working day, 25–40 persons with disabilities were transported by one bus. According to the study results, it is almost impossible to transport wheelchair users by buses, which is due to a low level of accessibility of travel to them, particularly, only 2 low-floor buses ran on the No 1 route, and the other buses were not equipped with the adapted devices. From above-mentioned groups of disabled persons, only the third group members are more likely to rely on public transport.

In order to resolve the existing problem, the main objective of the present study is to develop the acceptable forms of logistical service for determining the optimal number of the adapted buses on the city routes and for providing minimum travelling time for disabled persons, as well as to determine transport costs required for its implementation.

#### 4. BASIC PART OF RESEARCH

Using a mathematical model of the logistics system used for the transportation of disabled persons by city buses from the point of departure to destination with a minimum amount of time, the optimal number of adapted buses on the routes under study was determined, and to assess the additional expenses incurred on their service, a comparative analysis of the expected costs of “social taxi” service (which is carried out by minibuses) and the adapted bus service was conducted.

Taking the example of Kutaisi City, an analysis was conducted of the transport logistics chain of transportation of disabled persons on the main directions from the points of departure to destinations for selecting the economic-mathematical model of the logistics system of city bus services for disabled persons.

The effectiveness function composed to justify the effectiveness of the economic-mathematical model of the transport logistics system for providing high-quality services for disabled persons can be presented as follows:

$$M_{plm} = \sum_{i=1}^n \sum_{j=1}^m \left[ t_{ij}^{ch} + t_{ij}^{imp} + \left( (0,5 + P_{fail.ij}) I_{int.ij} + \frac{l_{av.i}}{v_{ij}} \right) K_{transf} + t_{ij}^{imp1} \right] \rightarrow \min \quad (1)$$

where  $i = 1, \dots, n$  is the type of the disabled persons groups;  $j = 1, \dots, m$  the option of transport service for disabled persons;  $t_{ij}^{ch}$  the waiting time for choosing the type of transportation, order, and accomplishment of transportation, in sec;  $t_{ij}^{imp}$ ,  $t_{ij}^{imp1}$  the time spent on the travel of  $j$ th motive power from the point of departure and arrival to the point of destination and on choosing the distance

(the road should follow the specially equipped route for disabled persons, if any, in sec);  $I_{int.ij}$  the traffic interval of motive power, which depends on the number of adapted buses on the route, in min;  $P_{fail.ij}$  the probability of failure of passenger boarding due to lack of vacant seats;  $l_{av.i}$  the average travelling distance, in m; and  $V_{ij}$  the travelling speed of  $j$ th motive power, in m/sec;  $K_{transf}$  the coefficient of transfer.

With a view to the requirements of owner of transport services, the effectiveness function can be presented as follows:

$$M_{owner} = \sum_{k=1}^z \cdot \sum_{j=1}^m \cdot \sum_{b=1}^p \cdot [W_{kjb}^{cost}] \rightarrow min, \quad (2)$$

where  $k = 1, \dots, z$  are the types vehicles allocated for services for disabled persons;  $j = 1, \dots, m$  the transport service option;  $b = 1$  the transport service routes for disabled people; and  $W_{kjb}^{cost}$  the costs incurred for the transportation of disabled persons by different vehicles according to service option.

In the designing process of a new route or modifying the existing ones, special consideration should be given to safe and comfortable transportation of disabled people; therefore, while composing the transport logistics scheme, the specific conditions for persons with disabilities should be established.

The cumulative time spent on the transportation of disabled person is determined by the formula:

$$T = 2 \cdot t_{walk} + \left( \sum_i^N t_{wi} + \sum_i^N t_{tri} \right) \cdot K_{transf}, \quad (3)$$

where  $t_{walk}$  is the time spent by a disabled person on walking (on foot or wheelchair) to and from the point of stopping, in sec;  $t_{wi}$  bus waiting time, in min;  $t_{tri}$  the time spent on travel by bus, in sec;  $N$  is the number of transfers; and  $K_{transf}$  is the coefficient of transferability.

The time spent on the arrival of disabled person at the bus stop, with account for the level of accessibility, for a disabled person's bus averages:

$$t_{walk} = d \frac{60}{v_n} l_{walk}, \quad (4)$$

where  $v_n$  is the walking speed of disable person, in m/sec;  $d$  the accessibility ratio of disabled person to a special stand arranged near the city bus stop; and  $l_{walk}$  is the distance to the bus stop, in m.

The average distance to the bus stop equals:

$$l_{walk} = \frac{1}{3\delta} + \frac{l_{asi}}{4}, \quad (5)$$

where  $\delta$  is the transport network average density, in  $m^2$  and  $l_{asi}$  the average space interval on the route, in km.

The average space interval on the route is determined by the formula:

$$l_{walk} = \frac{L_r}{n_{sp}-2}, \quad (6)$$

where  $n_{sp}$  is the number of stopping points on the rote in both directions and  $L_r$  the route length, in m.

The waiting time for the bus depends on the precise timing of operation by driver, the bus traffic interval, and capacity of bus and its actual occupancy, as when the bus is fully occupied, it may be impossible to board disabled persons in the bus, and in this case, the waiting time is increased by the value of time required for the arrival of the next bus at the stopping point.

The time spent by a disabled person on waiting for boarding is calculated by the formula:

$$t_w = I_{ti} (0,5 + P_{fail}), \quad (7)$$

where  $I_{ti}$  is the bus traffic interval on the route, in sec and  $P_{fail}$  the failure probability of passenger boarding owing to the limited passenger carrying capacity of vehicle.

The time spent by a disabled person on travel by bus is

$$t_r = \frac{60 l_{av}}{v_{mot}}, \quad (8)$$

where  $l_{av}$  is the average travelling distance of disabled person, in m and  $v_{mot}$  the bus motion speed on the route, in m/sec.

The travelling speed of bus on the route is calculated in accordance with formula:

$$v_{mot} = \frac{60 L_r}{t_1 - t_2}, \quad (9)$$

where  $t_1$  is the time of the movement of bus in both directions, which involves dead time caused by time required for boarding or alighting of disabled person (the average time required for boarding or alighting of disabled person is 100 sec and  $t_2$  the dead time on the terminal stopping point, in sec.

When calculating the time spent on the transportation of disabled persons, it is necessary to take into consideration the level of accessibility of transport facilities, particularly, the points of bus station–stop and transfer of passengers. The study conducted in Kutaisi found that transport infrastructure adapted to disabled persons is still at the organization stage, and therefore, to conduct the calculating studies by the above-mentioned model, the city bus routes, placement of seats on the points of bus station–stop and transfer of passengers existing there have been chosen, including the distances between them.

The calculating formulas for determining the number of urban transport vehicles for the transportation of disabled people and consistency in the calculation (block design) comprise several phases listed below:

$i = 1, \dots, n$  are the groups of disabled people.

$j = 1, \dots, m$  are transport service options for disabled people.

$l = 1, \dots, u$  are links in the logistic chain of the displacements of disabled people.

$k = 1, \dots, z$  are the types of vehicles used in urban passenger transport.

$b = 1, \dots, p$  are the transport service routes for disabled people.

1. The number of disabled people transported per day;  $Q_{1kb} = Q_{1kb}^a + Q_{1kb}^t$ .  
 $Q_{1kb}^t$  is the number of disabled people transported per day by social taxi.  
 $Q_{1kb}^a$  is the number of disabled people transported per day by a low-floor bus.
2. The minimum  $A_{minkb} = 0$  and maximum  $A_{maxkb} = A_W$  number of low-floor vehicles, where the total number of vehicles on the  $A_W$ -route is
3.  $s = A_{minkb}$ .
4. Depending on the obtained ratio of vehicles, the maximum  $Q_{2maxkb}^t = Q_{1kb}$  and minimum  $Q_{2minkb}^t = Q_{1kb} * k$  number of disabled people transported by “social taxi” per day, where  $k$ -coefficient of transferability.
5. Depending on the obtained ratio of vehicles, the maximum  $Q_{2maxkb}^a = Q_{1kb} - Q_{2minkb}^t$  and minimum  $Q_{2minkb}^a = 0$  number of disabled people transported by low-floor bus per day.
6. The maximum  $M_{maxkb} = Q_{1kb} / W_M$  and minimum  $M_{minkb} = Q_{2minkb}^t / W_M$  throughput performance of “social taxi”, where  $W_M$  is the throughput performance of vehicle adapted to disabled people with a very low carrying capacity, the so-called social taxi, disabled person per route.
7. The number of low-floor vehicles,  $A_{kbs} = s$ .
8. Depending on the obtained ratio of vehicles, the number of disabled people transported by low-floor bus  $Q_{2kbs}^a = A_{kbs} * W_A$ , where  $W_A$  is the throughput performance of vehicle adapted to disabled people, disabled person per route.
9. Depending on the obtained ratio of vehicles, the number of disabled people transported by “social taxi”  $Q_{2kbs}^t = Q_{2maxkb}^t - Q_{1kbs}^a$ .
10.  $M$  is the number of vehicles adapted to disabled people with a very low carrying capacity, the so-called social taxi,  $M_{kbs} = Q_{2maxkb}^t / W_M$ .
11. When  $Q_{2kbs}^a \geq Q_{2maxkb}^a$  there is taken  $Q_{2kbs}^a = Q_{2maxkb}^a$ .
12. When  $Q_{2kbs}^t \geq Q_{2minkb}^t$  there is taken  $Q_{2kbs}^t = Q_{2minkb}^t$ .
13. Calculation of expenditure of carriers  
 $P_{kbs1} = Q_{2kbs}^a * S_{akb} + Q_{2kbs}^t * S_{tkb}$ , where  $S_{akb}$  and  $S_{tkb}$  are, respectively, the cost price of one passenger transported by low-floor vehicle and “social taxi”, GEL/passenger.
- 14 Calculation of expenditure of passengers.
- 14.1. The average total time expenditure of one passenger when using low-floor vehicle, in hr:

$$T_{A_{kbs}} = 2 \cdot t_{walk.a.kbs} + \sum_{h=1}^N t_{w.a.kbsh} + \sum_{h=1}^N t_{r.a.kbsh}$$

where  $t_{walk.a.kbs}$  is the time required for reaching the bus stop for person with restricted mobility, in sec;  $t_{w.a.kbsh}$  the waiting time for the bus for person with restricted mobility, in sec; and  $t_{r.a.kbsh}$  the travelling time by bus for person with restricted mobility, in sec.

14.2. The average total time expenditure of one passenger when using “social taxi”, in hr:

$$T_{T_{kbs}} = 2 \cdot t_{walk.t.kbs} + \sum_{h=1}^N t_{w.t.kbsh} + \sum_{h=1}^N t_{r.t.kbsh}$$

where  $t_{walk.t.kbs}$  is the time required for reaching the “social taxi” stop for person with restricted mobility, in sec;  $t_{w.t.kbsh}$  the waiting time for “social taxi” for person with restricted mobility, in sec;  $t_{r.t.kbsh}$  is the travelling time by “social taxi” for person with restricted mobility, in sec.

14.3. Total expenditure

$$T_{kbs} = Q_{2kbs}^a * Q_{2kbs}^t + Q_{2kbs}^t * T_{T_{kbs}}$$

$P_{kbs2} = T_{T_{kbs}} * C_h$ , where  $C_h$  is the cost price of one passenger, GEL/passenger, hr;

15.  $s = A_{maxkb}$

$A_s : M_{s1}$ ; where  $s = A_{min}, \dots, A_{max}$ ;  $s_1 = M_{min}, \dots, M_{max}$  – the appropriate s-th design ratio of the number of low-floor vehicles to the number of the so-called social taxi;

The use of the proposed block-design allows for determining:

- expenditure of carriers and passengers  $A_s : M_s$ , at different ratios;
- an optimal ratio  $A_s : M_s$ , based on minimum logistics costs for the transportation of disabled people.

According to the proposed model, the calculations were made, using the example of the city route of Kutaisi.

In the urban passenger transport logistics system, the problem of determining the optimal number of the adapted buses for the transportation of disabled persons was based on a comparison of the results of the cumulative costs of “social taxi” services on the city bus routes with the expected cumulated costs in conditions of the adapted city bus services.

According to the study results (Fig. 2a, b), it has been established that due to insufficient accessibility of urban transport in Kutaisi, the demand for "social taxi" from disabled persons is increasing and costs of transportation services are increasing correspondingly.

From the figures (Fig. 2a), it is gathered that in the case of a fixed request, 5 low-floor buses are required from 10 buses running on the city route, as well as 5 "social taxi". For the same route equipped with the well-adapted devices (Fig. 2b), 3 mini buses (“social taxi”) are required, which allows for reducing total logistics costs for the transportation of passengers. In the first option, total cost at the crossing point of expenditure of carrier and passenger is GEL 1850 (Fig. 2a), whereas in the second option, total cost is GEL 1450 (Fig. 2b). Therefore, total logistics cost of passenger transport is reduced by  $(1450/1850) \times 100 = 23\%$ . At the same time, by increasing the number of low-floor buses from 5 to 7, it is possible to improve the quality of transportations.

The studies carried out found that the actual number of persons with disabilities on one route averaged 2–3 passengers, and, in this case, the traffic interval of buses did not exceed the upper limit of 4 minutes. Of interest is the analysis of the process, when the optimal number of the selected adapted buses is running to fully satisfy services for disabled persons, it will be possible to minimize the level of discomfort of transportation of other passengers, in this case, the level of discomfort of transportation of other passengers on the route, the indicators of increasing the actual values of the travelling length and traffic interval per travel are taken. In the case of using such an approach, while increasing the number of persons with disabilities to be transported per travel, it is necessary to assess the indicators of increasing the travelling time and traffic interval caused by the costs of disabled persons loading and unloading and time spent on traveling by bus per travel. In order to resolve this problem, on a single route, in the case of the same number of motive power, it is possible to carry out

studies for both cases when using the adapted buses and non-adapted buses, and by comparing the obtained results, it is possible to assess the indicators to be found.

According to methodology used for the implementation of the above approach [13], the traffic on the route should be organized in a way that provides the minimum of the amount of costs of carrier  $G_{car}$  and time spent on transportation of passengers  $G_{pass}$ . The use of this principle is based on the optimization condition, in order to achieve the minimum value of traffic interval by determining the required number of buses on the route:

$$f(I) = G_{car} + G_{pass} \rightarrow \min \tag{10}$$

$$0 \leq I \leq \frac{q\gamma\eta}{Qk}, \tag{11}$$

where  $q$  is the capacity of bus;  $\gamma$  the bus capacity utilization factor;  $\eta$  the passenger turnover factor along the route;  $k$  the passenger turnover hourly change factor; and  $Q$  the number of passenger turnover calculated for one hour period of running buses on the route.

The formula for calculating the minimal interval of bus traffic on the city bus route is as follows:

$$I_{min} = \sqrt{\frac{t_{tr} (S_{const} l_{tr} + S_{var} t_{tr})}{0,615QC}}, \tag{12}$$

where  $t_{tr}$  is the travelling time, with account of bus standing time at the route terminal point, in sec;  $l_{tr}$  the travelling length, in m;  $S_{const}$  the permanent constituent of the cost of production of transport service per hour;  $S_{var}$  the variable constituent of of the cost of production of transport service per hour; and  $C$  the cost of one passenger-hour.

$S_{const}$ ,  $S_{var}$  and  $C$  parameters are calculated using a special methodology.

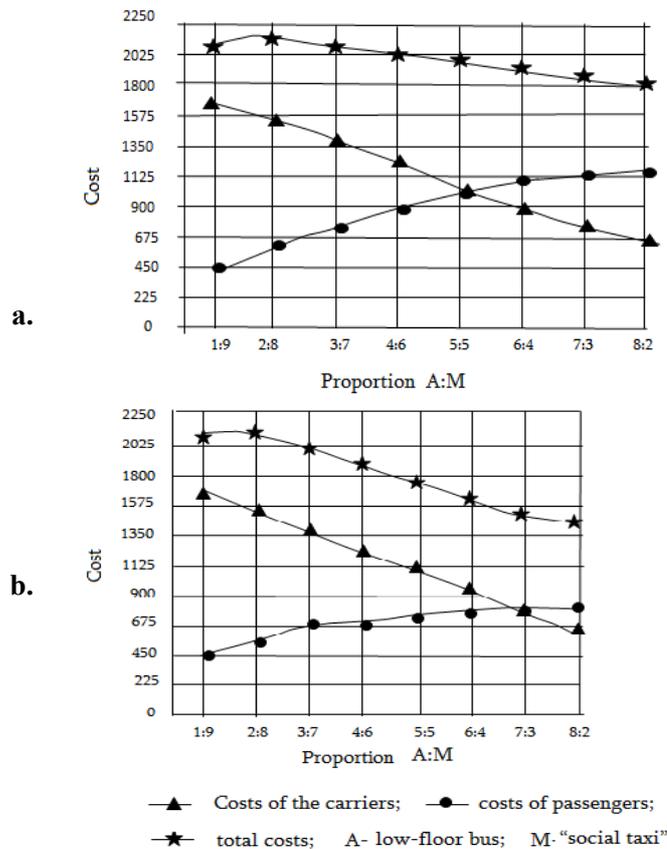


Fig. 2. The ratio of the number of motive power depending on the costs of transportation of people with limited mobility and costs of the carriers.

Travelling time is largely dependent on loading  $t_{load}$  and unloading  $t_{unload}$  of persons with disabilities, including the wheelchair users. In this context, taking into account the number of transported disabled persons  $n$ , the increase in time spent on travel can be calculated in accordance with the formula  $\Delta t_{tr} = n(t_{load} + t_{unload})$ . When determining the travelling time, the condition is taken into account that extra time required for loading–unloading of disabled persons at the bus is 2-3, 5 minutes, on average. With account of these conditions, equally important is that the city bus transport schemes should pass through the main points of departure of disabled persons, which will allow for boarding of one or two disabled persons in the adapted bus for a small period of time.

Studies have shown that taking into account the particularities of the route transport scheme and the places of residence of disabled persons oriented to this route transport services, of 20 stopping points, there have been identified 4 main points. By using this scheme of services, time expenses are 30–40% less than at the stopping points located along the route, in the case of redistribution of disabled persons. In the case of using such a scheme, the calculation results indicate that the increase in the bus traffic interval does not exceed 4 minutes, which may be practically acceptable for other passengers.

## 5. CONCLUSIONS

1. By using the economic–mathematical model and the calculation algorithm compiled on its basis, the costs of city bus and “social taxi” logistic services for transportation of disabled persons have been determined. The factors affecting the cost growth data have also been established.
2. Based on a comparative analysis of logistical costs, the optimum relationship between the number of the adapted buses and “social taxi” on the route under study has been established.
3. In case of using 7 adapted buses of 10 buses running on the city route and 3 units of “social taxi”, total logistics costs of passenger transportation are reduced by 23%. At the same time, by increasing the number of low-floor buses from 5 to 7, it is possible to improve the quality of transportations.
4. It is established that if the transportation scheme of urban routes is on the main points of departure of disabled people, the total time spent on travel is decreased by almost 30–40% because of the reduced boarding times of these passengers. This is compared to the case of distributing stops for disabled people on the entire length of the route.

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