

UDC: 656.02 73.43.61.

OPTIMIZING THE TIME COSTS OF PASSENGER TRANSPORT OF PEOPLE WITH DISABILITIES

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ОПТИМИЗАЦИЯ ВРЕМЕННЫХ РАСХОДОВ ПАССАЖИРСКОГО ТРАНСПОРТА ДЛЯ ЛЮДЕЙ С ИНВАЛИДНОСТЬЮ

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Abstract. 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: “Social Taxi”, which will transport only people with special health; b) 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", travel costs are increased that results in increasing total costs of the carrier. When determining the expenses of passengers, it is necessary to take into account the additional time, which the disabled persons need for boarding and alighting in buses at the stopping points, on average 2–3.5 minutes.

Аннотация. В статье рассматривается математическая модель логистической системы транспортных услуг для инвалидов, а также проанализированы факторы, влияющие на время, затрачиваемое на их транспортировку. При разработке методологии оптимизации временных затрат на пассажирские перевозки инвалидов были учтены следующие две основные транспортные услуги: а) «Социальное такси», которое будут перевозить только людей с ограниченной подвижностью; б) система транспортного средства в сочетании с городским пассажирским транспортом, который будет перевозить представителей группы людей с ограниченной подвижностью вместе со всеми другими пассажирами. Исследование показало, что в случае недостаточной доступности требуемой среды, благодаря увеличению спроса инвалидов на перевозки по «социальному такси», транспортные расходы увеличиваются, что приводит к увеличению общих затрат перевозчика. При определении

расходов пассажиров необходимо учитывать дополнительное время, необходимое инвалидам для посадки и высадки в автобусах в пунктах остановки в среднем 2–3,5 минуты.

Keywords: person with disability, mathematical model, optimization, passenger.

Ключевые слова: человек с ограниченными возможностями, математическая модель, оптимизация, пассажир.

Introduction

The degree of civilization of a State is measured by the way in which it treats persons with disabilities, so the problem in the economically developed countries of the world is the transport service of disabled people, which is an essential element of State social policy.

In recent years, particular attention has been paid to the accessibility of transport services to persons with disabilities. In this regard, the project MAPLE has been implemented in Europe, which analyzes the current state of transport service for persons with disabilities in a number of countries. The final conference held in London (1) addressed the introduction of innovative technologies in public passenger transport, which ensure high standards of public transport services for all categories of consumers, including persons with disabilities.

The study of the current state in the field of transport services for persons with disabilities in different countries of the world [1] (USA, UK, Germany, France, Italy, Japan, Netherlands, Sweden, Turkey, Russia) showed that the transport service system for disabled persons is provided with the adaptive means of transport and special pick up and drop off points at stops, modern transportation technologies and so on.

Analysis of international experiences of providing accessibility of transport infrastructure to people with restricted mobility revealed the problems (2-4), solving of which will further improve the levels of transport services for them, as well as will provide them with safe, comfortable and less time-consuming travel.

In spite of important changes that recently have been set in motion in Georgia, there is still no progress towards the development of a new approach to the problems related to persons with disabilities.

Transport facilities intended for the carriage of disabled people, and their modifications should meet the requirements of the accessibility and safety standards (5, 6), namely: the adaptive vehicle is required to ensure boarding and alighting of passengers in buses without any complication, as well as their safe travel independently and with the person pushing a wheelchair.

In the organization and management of transport services for persons with disabilities, of high importance is the assessment of the logistics level, which will facilitate the optimization of transport services for consumers.

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

Ways of problem solving

In the logistics chain, the level of access of disabled people to transport from the point of departure to the point of destination directly depends on traveller's waiting for the carriage motive power and the average time spent on the movement of the 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 persons with disabilities, it is necessary to

determine the number of vehicles equipped with specialized equipment for safe and comfortable transportation of persons with disabilities.

The list of factors affecting the time spent on the carriage of persons with restricted mobility is shown in Figure 1.

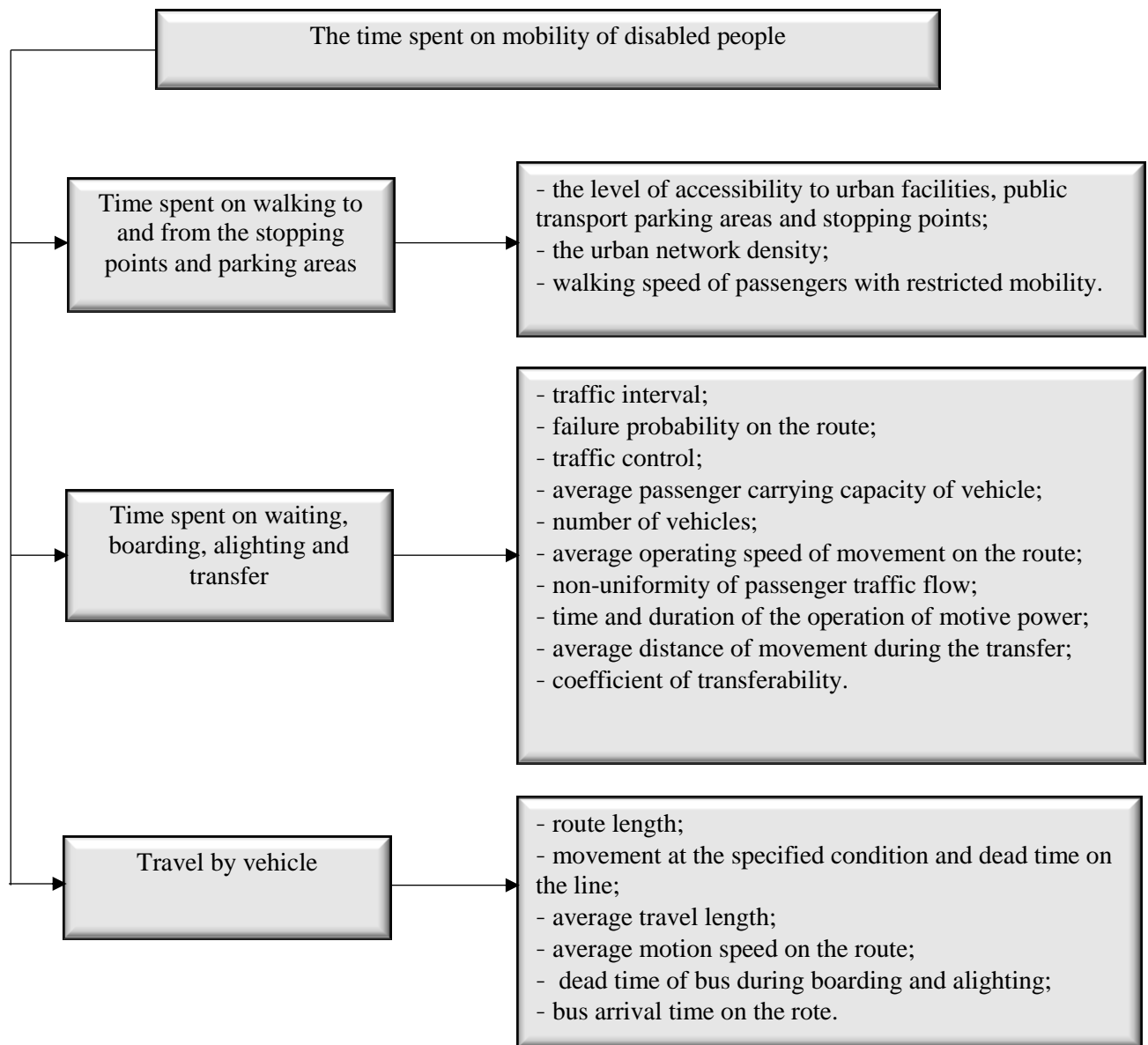


Figure 1. The list of factors affecting the time spent on the carriage of persons with restricted mobility

In the logistical system of transport services for persons with disabilities, the carriage, from the customer's point of view, will be optimal when the service will be provided "dead on time" at minimal cost. 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, they will choose one of the following types of transport services:

1. Private passenger car;
2. Public passenger car — taxi;
3. "Social taxi" — equipped with devices required for comfortable and safe travel for people with disabilities;

4. Public specialized motive power moving on routes designed specifically for people with disabilities;

5 An adapted bus moving on the regular urban passenger routes.

From the perspective of the transport service operator, the optimal is a transport system of persons with disabilities when their travel costs are minimal.

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 urban passenger traffic in the city of Kutaisi.

While developing the methodology of this research, there were taken into account two basic transportation services appropriate for city conditions, particularly: a) "Social taxi" that transports only people with special health; b) 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. Figure 2 illustrates the transportation chain for persons with disabilities along one or several routes.

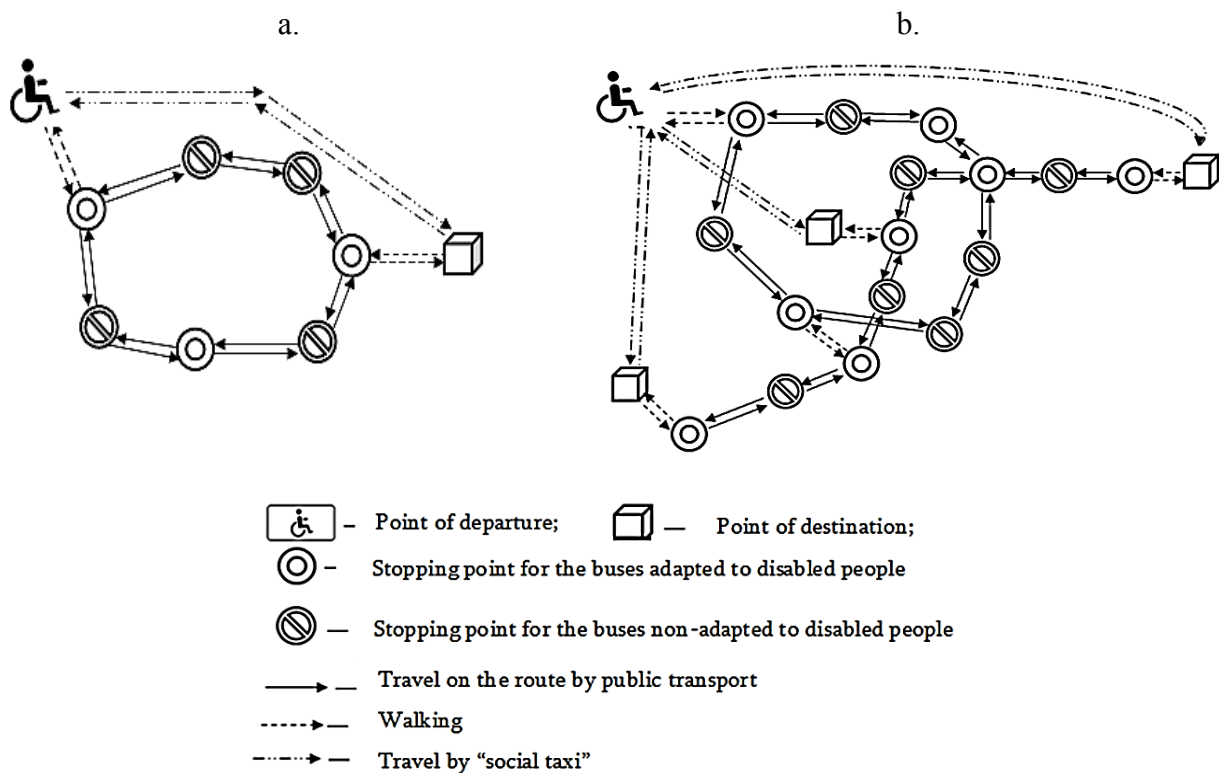


Figure 2. Scheme for choosing the type of passenger transport of disabled people, a) when using one route; b) when using several routes (including transfer)

While determining the time spent on transportation of persons with disabilities there has been taken into consideration the level of accessibility to urban facilities, parking areas and stopping points, and it is also important to know how the points of stopping and transfer on urban bus lines to people with disabilities, distances between their locations and so on.

4. Basic part of research

In particular conditions, the number of different types of vehicles equipped with special equipment must be determined to provide comfortable transportation for persons with disabilities to the point of destination for a short period of time. To deal with this challenge, there has been used a mathematical model of the logistical system for persons with disabilities by urban passenger transport [2-4].

The economic–mathematical model of the logistical system for persons with disabilities in the system of urban passenger transport was constructed in the city passenger transport system based on the analysis of the logistics chain of their travel from the point of departure to the point of destination.

From the perspective of people with the limited mobility, the function of the objective may be presented as follows

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

where $i = 1, \dots, n$ — the category of the group of persons with restricted mobility; $j = 1, \dots, m$ — a transport service option for persons with restricted mobility; t_{ij}^{ch} — transport type choosing, ordering and waiting time; $t_{ij}^{imp}, t_{ij}^{imp1}$ — the time spent on travel by j-th motive power; $I_{int,ij}$ — motive power traffic interval dependent on the number of buses on the line; $P_{fail,ij}$ — failure probability of passenger boarding owing to the lack of free seats; $l_{av,i}$ — average travel distance; V_{ij} — motion speed of j-th motive power; K_{transf} — coefficient of transferability.

From the perspective of the owner of the transport services (city administration) the function of the objective may be presented as follows

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

where $k=1, \dots, z$ — types of urban transport; $j=1, \dots, m$ — transport services option; $b=1$ —routes of transport services for people with restricted mobility; W_{kjb}^{cost} — costs of the transportation of people with restricted mobility by the option of transport services.

The cumulative time spent on transportation of a person with a disability is determined by the formula

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

where t_{walk} — the time spent on walking to and from the point of stopping, min; t_{wi} — bus waiting time, min; t_{tri} — time spent on travel by bus, min; N — number of transfers; K_{transf} — coefficient of transferability.

The time spent on walking of person with restricted mobility to the stopping point for boarding to the bus on average is equal

$$t_{walk} = d \frac{60}{v_n} l_{walk}$$

where v_n — walking speed of person with restricted mobility; d — coefficient of accessibility to the public transport stopping point and parking area; l_{walk} — distance to the stopping point.

The average distance to the bus stopping point

$$l_{walk} = \frac{1}{3\delta} + \frac{l_{asi}}{4},$$

where δ — transport network average density, km^2 ; l_{asi} — the average space interval on the route, km.

The average space interval on the route

$$l_{walk} = \frac{L_r}{n_{sp} - 2}$$

where n_{sp} — the number of stopping points on the route in both directions; L_r — route length, km.

The passenger bus waiting time depends on precise timing operation of driver traffic, traffic interval, passenger carrying capacity and the actual filling of motive power, because when vehicle is crowded, alighting may not be possible, and the waiting time in this case increases by the value of the next bus waiting time.

The time spent by a person with restricted mobility on waiting for boarding is calculated by the formula

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

where l_{av} — bus traffic interval on the route; P_{fail} — failure probability of passenger boarding owing to the limited passenger carrying capacity of vehicle.

The time spent by a person with restricted mobility on travel by bus

$$t_{tr} = \frac{60l_{av}}{v_{mot}},$$

where $l_{\partial\partial\partial}$ — average travel distance, km; v_{mot} — motion speed, kmh.

The motion speed

$$v_{mot} = \frac{60L_r}{t_1 - t_2},$$

where t_1 — time of the movement of vehicle in both directions, which involves dead time caused by time required for boarding or alighting of person with restricted mobility (the average time required for boarding or alighting of person with restricted mobility is 1000 sec; t_2 — dead time on the terminal stopping point.

In the costing exercise of transportation of persons with disabilities, it is important to take into account the level of accessibility to urban facilities, parking areas and stopping points. Owing to the fact that as a result of studies conducted in Kutaisi City, it has been established that there is no transport infrastructure adapted to persons with disabilities, for the calculation with the proposed model, there have been conditionally chosen the routes and the points of stopping and transfer for public transport on them.

Determination of adapted vehicles for the carriage of persons with disabilities in logistical systems of urban passenger transport was based on a comparison of the results of calculating the total logistical expenses on transit and transportation of persons with disabilities.

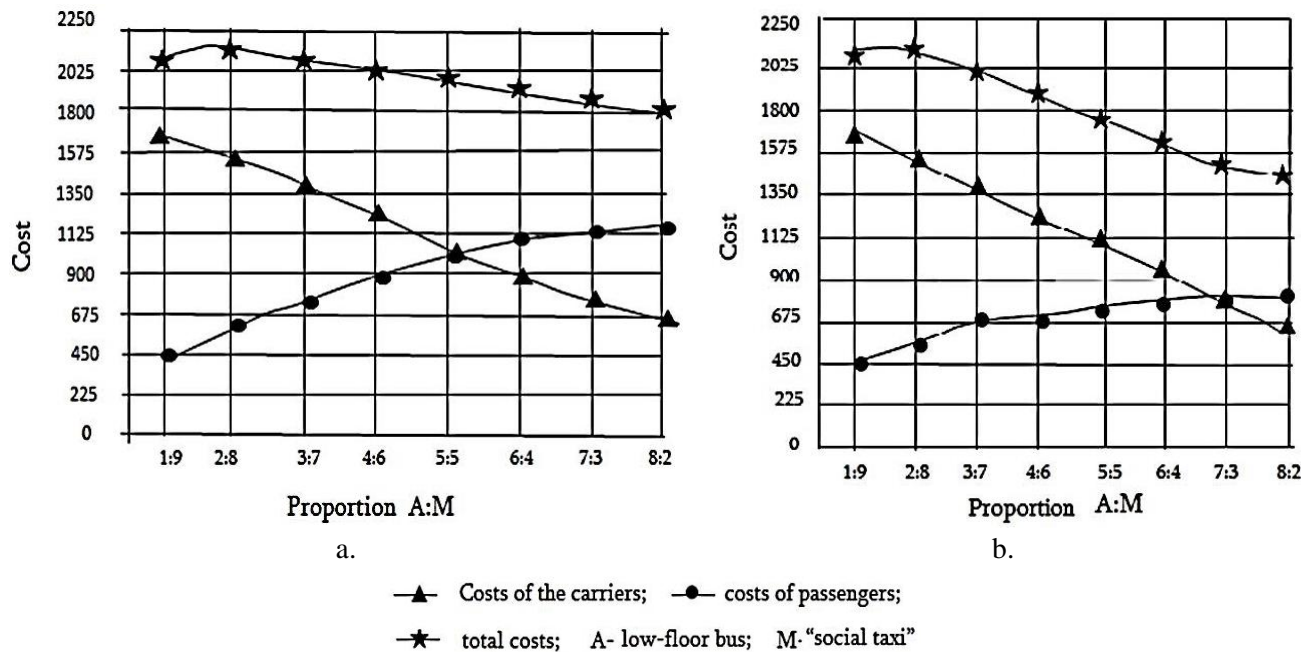


Figure 3. The ratio of the number of motive power depending on the costs of transportation of people with limited mobility and costs of the carriers

The results of the research shown in Fig. 3a, b allow us for making the conclusion that in the case of insufficient access to the required environment, due to numerous obstacles to be overcome and by the increase in the demand of disabled people for transportation by "social taxi", travel costs are increased that results in increasing total costs of the carrier. The graphs (Figure 3.a) show that in case of a fixed request, it is necessary to have 5 low-floor bus of 8 running on the line, and 5 "social taxis". According to the same data for the same route (Figure 3. b), but equipped with well-adapted transport facilities, there are required 3 "social taxi" minibuses to reduce total logistical expenditures on passenger transportation. At the same time, by increasing the number of low-floor buses from 7 to 8, it is possible to improve the quality of transportations.

5. Brief conclusions

Using the economic-mathematical model, and by the calculating algorithm created on its basis, according to the maximum costs of the carriage of people with limited mobility, there has been determined the optimal ratio of the numbers of the low-floor buses and "social taxis" on a particular route.

When determining the expenses of passengers, it is necessary to take into account the additional time, which the disabled persons need for boarding and alighting in buses at the stopping points, on average 2–3.5 minutes per person with a disability;

The maximum costs of the carriers and the minimum costs of travel of disabled people are arisen in the case of total satisfaction of the needs of travel and transportation of persons with disabilities, especially by small–capacity motive power. In this case, it is necessary to provide the maximum funding of a logistical system of urban passenger transport and achieve the best level of passenger service.

Acknowledgment

This work was supported by Shota Rustaveli National Science Foundation (SRNSF) [No 217764, Adaptation of Disabled People in the Logistics System of Passenger Transport].

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*Работа поступила
в редакцию 28.07.2018 г.*

*Принята к публикации
02.08.2018 г.*

Cite as (APA):

Gogiashvili, P., Chogovadze, J., Lekveishvili, G., & Kbilashvili, D. (2018). Optimizing the time costs of passenger transport of people with disabilities. *Bulletin of Science and Practice*, 4(9), 161-169.

Ссылка для цитирования:

Gogiashvili P., Chogovadze J., Lekveishvili G., Kbilashvili D. Optimizing the time costs of passenger transport of people with disabilities // Бюллетень науки и практики. 2018. Т. 4. №9. С. 161-169. Режим доступа: <http://www.bulletennauki.com/gogiashvili-chogovadze> (дата обращения 15.09.2018).