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TRANSPORTATION SERVICE SYSTEM MODELING FOR PEOPLE WITH LIMITED MOBILITY

Abstract. The article describes the basic concept of defining the «availability» of urban infrastructure for people with limited mobility (PWLM). The author proposed options to improve existing logistics systems in order to improve the basic level of transportation for people with limited mobility. An algorithm to determine the number of vehicles equipped to transport people with limited mobility in the logistics system of public passenger transport was developed based on a comparison of the carriers' logistics cost calculation results on the transport service of people with limited mobility and total costs of PWLM passenger travelling.
Keywords: people with limited mobility; system modelling; logistic system; passenger transportation.
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МОДЕЛЮВАННЯ ЛОГІСТИЧНОЇ СИСТЕМИ ОБСЛУГОВУВАННЯ МАЛОМОБІЛЬНИХ ГРУП НАСЕЛЕННЯ
Анотація. У статті розглянуто основні поняття, що визначають «моделювання» об'єктів міської інфраструктури для маломобільних груп населення. Запропоновано варіанти поліпшення існуючих логістичних систем із метою підвищення загального рівня пасажирського перевезення маломобільних груп населення. Розроблено алгоритм визначення необхідного числа транспортних засобів, обладнаних для перевезення маломобільних груп населення, у логістичній системі міського пасажирського транспорту. Запропонований алгоритм ґрунтується на зіставленні результатів розрахунку логістичних витрат перевізників на транспортне обслуговування маломобільних груп населення і сумарних витрат маломобільних пасажирів на пересування.
Ключові слова: маломобільні групи населення, моделювання систем, логістична система, пасажирські перевезення.

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МОДЕЛИРОВАНИЕ ЛОГИСТИЧЕСКОЙ СИСТЕМЫ ОБСЛУЖИВАНИЯ МАЛОМОБИЛЬНЫХ ГРУПП НАСЕЛЕНИЯ
Аннотация. В статье рассмотрены основные понятие, определяющие моделирование объектов городской инфраструктуры для маломобильных групп населения. Предложены варианты по улучшению существующих логистических систем с целью повышения уровня пассажирских перевозок маломобильных групп населения. Разработан алгоритм определения необходимого числа транспортных средств, оборудованных для перевозки маломобильных групп населения в логистической системе городского пассажирского транспорта. Предложенный алгоритм основан на сопоставлении результатов расчета логистических затрат перевозчиков на транспортное обслуживание маломобильных групп населения и суммарных затрат маломобильных пассажиров на передвижение.
Ключевые слова: маломобильные группы населения, моделирование систем, логистическая система, пассажирские перевозки.

Introduction. For today, public transport is not fully satisfies the needs of all residents and visitors in many cities. For example, the complicated transport service for people with limited mobility (PWLM), which includes people with disabilities, young children, passengers with prams, pregnant women, the elderly, people with temporarily restricted mobility moving around with crutches, canes, etc. For their transportation special conditions have to be created.

Brief Literature Review. Tasks and problems of logistic availability formation of urban infrastructure were discussed in works of J. J. Coyle (2003) [1], P. Conroy (2004) [2], R. Johnston (2005) [3], J. Levesque (2007) [4], T. Rickert (2007) [5]. However, the problem of formation available urban infrastructure is poorly studied. Application of logistics in the field of passenger transport for people with disabilities resulted in management of public passenger transport improvement using logistic technologies, which was considered in works of Albekova A.U., Wozniak H., Goloskokov V., Gudkov V., Kritsky A., Mirotin L., Shiryaev S. and other scholars and practitioners.

The purpose of the research is to develop guidelines for the formation and evaluation of logistic accessibility for people with limited mobility in modern conditions

Result. The urban passenger transport is the most important component of the cities economy. Currently, urban public transport, does not fully comply with the needs of all residents and visitors in many cities. For example, the complicated transport service for people with limited mobility, as it is quite difficult and sometimes impossible for them to climb into the cabin of passenger vehicles running nowadays on the route. Special conditions must be created for their transportation [6].

From the customer's perspective, the optimal transport logistics service system for PWLM is the one which will provide transportation of PWLM (service) with acceptable quality, «just in time», with minimal logistic costs of transport maintenance. Problem must be solved by consumers' satisfaction, on the one hand, and respect for the interests of transport services providers, on the other hand.

From the perspective of a passenger, the optimal trip will be the one that is made in the shortest possible time with maximum comfort at affordable price. From the operator of transport services point of view, optimal transport service for PWLM is the one where the cost of transport of all people with limited mobility will be minimal. This could be achieved by the use of methodology to find the optimal ratio of different types of passenger vehicles which provide mobility for PWLM.

Problem of determining the optimal ratio types of rolling stock adapted to carry traffic of different groups can be solved by using the logistic approach since, in terms of logistics, passenger transport services should be accessible and convenient to everybody, including people with limited mobility [7].

This study developed the mathematical model of economic and logistic service system for disabled in urban passenger transport, which allows determining the number of different vehicles, equipped for transportation of PWLM with specific conditions. Economic and mathematical model of logistic system service for disabled people in urban passenger transport is based on the analysis of the logistic chain links of PWLM movement from origin to destination in urban passenger transport system [8].

The total time spent on passenger trip includes: time approach (departure) to (from) the stopping point; getting in (out) the vehicle; transportation waiting time and time for transportation itself. The total time spent on a trip by passenger with limited mobility is calculated by the formula:

$$T = 2t_{ph} + (\sum_{i=1}^{N} t_{oz} + \sum_{i=1}^{N} t_{sl})K_i, \quad (1)$$

where t_{ph} – time spent by PWLM walking to (from) the station, min; t_{oz} – the time spent waiting for boarding the bus, min; t_{sl} – the time required to go in the bus, min; N – the number of stops; K_i – Interchange coefficient.

Time spent on feet movement by PWLM to a bus stop for boarding the bus in average equals the time PWLM walking from arrival station to the purpose of the journey, taking into account the accessibility for people with limited mobility and is calculated by the formula:

$$t_m = d\frac{60}{v_n} l_{ph}, \quad (2)$$

where V_n – walking speed of PWLM; d – parkings and public transport stations arrival (departure) affordability factor; l_{ph} – length approach to the station.

The average length of the approach to the station is:

$$l_m = \frac{1}{3\delta} + \frac{l_w}{4}, \quad (3)$$

where δ – the average density of the route network, km^2; l_W – the average length of move on the route, km.

The average length of move on the route is:

$$l_W = \frac{L_r}{n_s - 2} \quad (4)$$

where n_S – number of stops on the route in both directions; L_r – length of the route, km.

The waiting time depends on the passenger bus punctuality movement by a driver, interval of vehicle traffic and the actual content of the rolling stock, as in the crowded vehicle landing cannot take place and the waiting time in this case increases for the period of waiting for the next vehicle.

Time spent waiting for landing by PWLM is:

$$t_w = I_m(0.5 + P_{dis}), \quad (5)$$

where I_m – range of buses on the route; P_{dis} – probability of failure of the passenger's boarding because of the limited capacity of the vehicle.

Time spent by PWLM on follow:

$$t_f = \frac{60 l_{av}}{v_c}, \quad (6)$$

where l_{av} – average passenger trip distance, km; v_c – communication speed, km/h.

Communication speed:

$$v_c = \frac{60 L_r}{t_{turn} - t_{fin}}, \quad (7)$$

where t_{turn} – turnover time of the vehicle on the route with the additional vehicle downtime for landing – PWLM (average time to boarding or alighting a passenger with limited mobility is 100 seconds), min; t_{fin} – time on finite simple halting points.

Two main most appropriate in terms of the form of a large city transport service with limited mobility were taken into account when developing the methodology, namely transportation «social taxi», carrying only people with disabilities and a set of transportation vehicles of urban passenger transport, carrying all passengers together with representatives of people with limited mobility.

Scheme for selection a kind of transport service for PWLM motion using one or more routes is shown in Figure.

In time of calculating the cost of movement of PWLM, it is important to consider the level of the urban environment accessibility, parks and public transport. For example, selecting the stopping point of the beginning and end of the trip will be an important condition for the degree of availability and equipment for various groups of passengers with disabilities of stops of public transport and the need to perform transportations in the way.

Determination of the number of vehicles equipped for transportation of PWLM, in the logistic system of urban passenger transport is based on a comparison of the results of calculation of logistics costs on transport services carriers of PWLM and total costs on the movement of passengers with limited mobility.

The algorithm of proposed methodology:

1. Initial data input:

– a list of vehicles stops indicating their availability for any PWLM;

– a list of socially important facilities (buildings, etc.) indicating the degree of accessibility for different PWLM;

– a list of PWLM places (residential areas) indicating their availability for any PWLM;

– a list of routes served by vehicles equipped for transportation of people with reduced mobility;

– data to calculate the cost of transportation of the various vehicles (transport distance, route length, capacity and performance of the vehicle, tariff rates of pay drivers, fuel consumption, lubricants and other consumables; standards for maintenance and repair of rolling stock, depreciation and recovery tire repair, depreciation of rolling stock, overhead).

2. Calculation the cost of passengers transportation, including people with limited mobility, on specific routes and destinations of transportation in the «social taxi», depending on the traffic volume and length of the route, technical-operational and economic performance of the rolling stock. Determination of unit costs per passenger in the specific conditions in different variants of transport services for PWLM.

3. Determination the need tor transport PWLM by different means of transport: shuttle vehicles or transportation in the «social taxi» on the basis of the analysis of demand, forecasting growth in demand for transportation of PWLM in connection with the implementation of the social program adaptation for people with disabilities and expand their involvement in the economy and social activities.

4. Quantification the amount of PWLM transportations (pass./day).

5. Calculation the minimum and maximum number of low-floor vehicles and «social taxi» on the basis of vehicles performance, transport demand, factor interchange of passengers and the quality level of passenger service.

6. Determation the ratio of conventional and low floor vehicles on the route.

7. Calculation the ratio of passengers low floor vehicles and «social taxi».

8. Determination the number of buses specifically small capacity, the so-called «social taxi», based on their daily performance and low-floor rolling stock of unsatisfied demand for transportation of PWLM.

9. Calculation the logistics costs of all carriers at various ratios of different types of rolling stock.

10. Calculation the cost of passenger travel time, hours.

11. Determination the cost of passengers based on the cost of service hours.

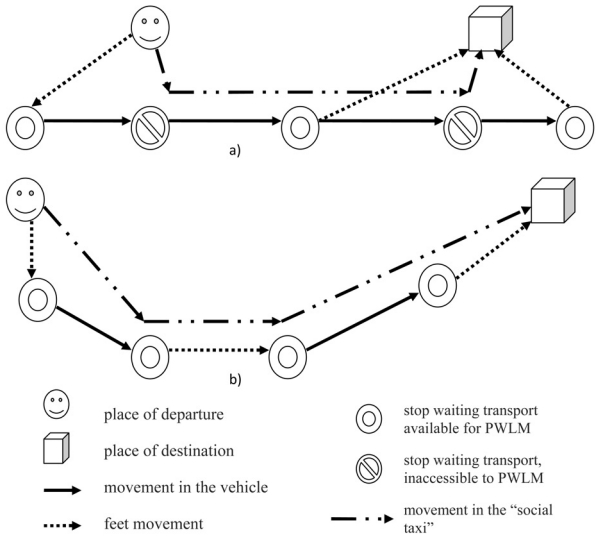

Figure: **Scheme for selection a transport service kind for PWLM: a) when driving a vehicle with one route; b) for carrying out the transportation**
Source: Own research

12. Construction joint graphs of carriers' and passengers' logistics costs at different ratios of the number of low-floor vehicles and «social taxi».

13. Determination the optimal number of different types of rolling stock, depending on the level of carriers' and passengers' logistics costs.

Using the proposed method allows determining:

– Cost carriers and passengers at different ratios;

– Optimal ratio based on the minimum logistics costs on the movement of PWLM;

– Ratio – existing and low-floor vehicles equipped to transport PWLM.

At the first stage the level of availability of transport infrastructure from (to) objects located directly in the path of a specific route of urban transport was defined. All the barriers encountered on the road by PWLM were considered in calculation. On the basis of full-scale studies time costs of passengers with limited mobility to overcome them has been identified. The ability to move people with disabilities to (from) the various stopping points of the route based on their availability was further evaluated. Calculations of the total cost of transportation in the organization of movement are carried in two ways: first – a trip of people with disabilities only by «social taxi» with minimal cost for passenger, but maximal for carriers and the second – a trip using low-floor rolling stock of public urban passenger transport, when the total costs of all carriers decreases with decreasing the necessary number of «social taxi».

Analysis of results of the proposed economic-mathematical model calculation led to the following conclusions:

1. The ratio of different vehicles to serve a reduced mobility varies depending on the demand for transport by people with limited mobility. Demand for transportation PWLM in turn increases from improved accessibility to the urban environment and transport infrastructure and the quality of passenger service.

2. When a level of the number of «social taxi» is fixed, ratio of conventional and low floor vehicles can vary and depends on the traffic demand and availability of facilities for people with reduced mobility.

3. Increasing of availability of transport infrastructure for PWLM leads to reduction in costs for the transportation of passengers and the need for «social taxi», hence in the ratio of AS:MKS meaning of the number of low-floor vehicles becomes larger, while the total logistics costs of transport services PWLM reduces.

4. Increasing the share of low-floor vehicles in total mobility needs of AO requires its correction, so reduces the overall carrying capacity of rolling stock on the route by reducing the nominal capacity of vehicles when transporting wheelchairs (wheelchair or baby) by an average of 8%.

5. At a low level of availability of the urban environment for PWLM, low demand for transportation in route vehicles leads to the quality of life deterioration for people with reduced mobility, increases costs of transport services providing for PWLM.

6. The greatest carriers cost and the lowest passengers with limited mobility cost result in full satisfaction of demand for transportation of PWLM by specially equipped rolling stock of specifically small capacity. In this case, the maximum amount of financing of the urban transport logistic system and the best quality of passenger service is achievable [9].

7. Implementation of opportunities to leave feedback about the level of transport service on the websites of the dispatch centre or transport companies is needed in order to assess the logistics of passenger service for PWLM, identify and promote the best drivers, improve the quality of passenger services, etc.

8. As the demand for transportation of PWLM and availability of the urban environment and transport infrastructure is constantly changing, it is necessary to periodically recalculate the required amount of vehicles to meet the demand for transportation of PWLM, and to determine the optimal ratio of vehicles of various options of transport services for PWLM.

Conclusions. The decision is proposed by the author on the adjustment of the number of rolling stock operating on the various options of transport services received after the implementation of various measures to improve the accessibility of urban and transport infrastructure for PWLM (equipment of stopping points, ground, underground and elevated pedestrian crossings with means of availability for different people with reduced mobility, equipment of sidewalks and ramps and walkways with slip roads, etc.), as well as when resizing financing logistics transport system services for people with disabilities.

Application of the developed logistic system model will improve the service of people with limited mobility and generally increase the level of passenger transportation in urban infrastructure.

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