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A LOGISTIC SERVICE MODEL FOR DISABLED PERSONS IN MOBILITY BY TOWN-SERVICE BUSES

Summary. The paper dwells on the methodology for assessing the efficiency of transport services in transportation of disabled people on the local urban regular bus routes. Proposed methodology is based on the level of organization of transport system and logistics approaches and principles for determining the quality of adaptation to requirements of disabled people transportation. The paper describes the identification of the conditions for coordination of regular urban bus routes for disabled persons with the main urban routes, in light of the principle of one change in the direction. There have also been determined the values of time expenditure for travel for the options of random selection of the change point and the use of GPS information technology.

1. INTRODUCTION

Statistics for recent years showed that in many countries, the problems of active social integration of disabled people are not adequately addressed [1, 2]. In order to resolve them it is necessary provide practical implementation of internationally recognized criteria and indicators of social adaptation, which should contribute to harnessing the potential of people with disabilities in various areas of social life [3]. In our days society faces the particular challenges in the field of transport services for people with disabilities [4], including the field of public transport services [5] due to a low level of the organization and technical support of service to disabled people. Based on this, to improve service to people with disabilities, implementation of scientifically justified recommendations and effective interventions is essentially relevant [6].

Regarding the improvement of transport services to people with disabilities, the following issues have come to the fore: adapting the transport motive power and transport infrastructure to cope with growing demands for service [7, 8]; development of effective methods and techniques for management by using intelligent transport systems [9]; establishing the systems of continuous monitoring and operational service quality control.

In order to successfully tackle with the mentioned issues, it is necessary to use such methods of analytical and experimental research [10], which are based on modelling of transport processes [11] and modern principles and approaches of logistics management [12].

A model of logistical system of urban transport services for disabled people should be constructed on the basis of carried out analysis of logistics chain of transportation of people with restricted abilities from the point of departure to the point of destination, within a system of urban passenger transport.

An analysis of recent experience in the area of transport services has shown that the logistic models of passenger transport in the organization of urban bus routes, which are aimed at ensuring sufficient stability and sustainability of transport services for disabled people [13], as well as high adaptation quality of them to the environment, are as yet little used [14, 15].

2. SUBJECT AND METHODS OF RESEARCH

The way to address the problem is that it is necessary to develop such type of a logistic model of urban bus service, the use of which allows for minimizing the difference between the planned and actual levels of the quality of transport services to people with disabilities. In order to implement this approach, we believe that it would be appropriate to create the specialised regular bus routes for transport services to disabled people maximally adapted to the urban bus route system, as well as to identify the conditions of their logistical control.

The subject of research is represented by the systems of transport services to people with disabilities by urban buses, as well as by the areas for their improvement. The methods of research are: method for assessing the quality of service organization for disabled people; methods for selecting and ranking appropriate criteria for achieving a high level of organization; method for assessing the efficiency of transportation of disabled people; principles and approaches of developing the logistic models.

In order to improve the level of organization R of transport service to disabled people in Kutaisi City, there have been used the deviation of the existing state of organization from the maximally disordered state, which can be determined by the formula:

$$R=1-(H_{p\text{-}o}/H_{max}) = HE/ H_{max} \quad (1)$$

where $H_{p\text{-}o}$–is a purpose-oriented entropy (of infinity), i.e. an instantaneous value of entropy; HE–is a system's negentropy, i.e. the inverse of the entropy value (defines the level of in formativeness); H_{max}– maximum entropy, or infinity, by the system's structure and functions.

To improve the level of organization, it is possible to use real conditions of the results-based management of the collected information flows on a studying system of transport services for disabled people, and subsequently the characteristics of structural links between elements of this system.

Statistical studies reveal that along with the increase in the volume of passenger traffics on the bus lines, the costs are rising as well, therefore, the given approach can be used for justifying the optimal volume of the production of transport service. However, this is not enough for the complete assessment of the transport service efficiency level, to minimize labour and financial expenses under conditions of providing the optimal volume of transport services. This problem can be resolved by determining the relationship between the volume of transport services for disabled people (Q) and the extent of adaptation to service requirements (S). It has been determined that the volume of transport services increases together with an increase in the extent of adaptation, i.e. the relationship between them can be described by the linear equation. Based on statistical analysis of the relationships between the volume and degree of adaptation, and between the volume and costs of services, it is possible to assess the efficiency of transport services within a certain time interval. This could be done by using the following regression dependences:

$$Q=f_q(A, D, K, q, \beta, \eta, T, I / V) \quad (2)$$

and

$$S=f_s(A, D , K ,q,\beta,\eta, T, I / V), \quad (3)$$

where A–the optimal number of buses on the lines, which are equipped with the devices adapted to disabled people; D–the number of working days per year for buses on the lines, which are equipped with the adapted devices; K– coefficient of delivery of buses on the lines, which are equipped with the adapted devices; Q – average capacity of buses on the lines, which are equipped with the adapted devices; β– bus loaded mileage proportion; η –mean value of using bus capacity utilization; T– average shift time of buses, hr; V –the average working speed of buses, km/h; I –the average travel distance on the lines, km; I / V – the average travel time, min.

These dependences for the particular lines are determined in accordance with statistical data, but selection of a function **fs** made in accordance with a criterion of maximization of determination coefficients (linear, polynomial, exponential, etc.).

So, to find the optimum values of quality indicators of transport services for disabled people, the general problem can be divided into two sub-problems:

1. To determine the costs of services to disabled people depending on the calculating parameters, in accordance with a given level of organization (using 2 and 3 dependencies);

2. To find the level of service quality depending on the calculating parameters, in accordance with a given level of organization (using 2 and 3 dependencies).

From an economic standpoint, the solution of a given problem is to determine the minimum costs required for reaching the optimum level of organization.

By using this methodology, it is possible to assess the level of the quality of transport services, but in order to achieve high degree of organization, of no less importance are also criteria required for determining the service quality.

3. MODELLING OF URBAN BUS SERVICES COMPATIBILITY

The main criteria should be: the costs relating to transportation of disabled people; reliability of delivery schedule of buses equipped with the adapted devices; ensuring safe transportation of disabled people, etc. Usually, when choosing service parameters, specially designed ranking system can be used in accordance with the main criteria (Table 1).

Regular bus transport services provided for disabled people within the city's administrative territory, can be delivered on the following three patterns:

1. Organizing irregular special-purpose passenger traffics with account for the priority directions of transportation of disabled people and service time intervals;
2. Determining the optimal number of buses equipped with the adapted devices and organizing their operation on the urban lines;
3. Organizing the new regular passenger traffic lines under conditions of high compatibility of the priority directions of transportation of disabled people with the transportation patterns.

The use of the first pattern is more effective, if in case of the existing level of organization, the total distance of transportation of disabled people and their number have such values, which allow for achieving the minimum costs transport services. Suppose that within one working day, actual value of total distance special-purpose passenger traffics is *I* km, but the weighted average for transportations is *j* passengers, then the transportation schemes for special-purpose passenger traffics and operating regimes should be selected so that under conditions of using the maximum technical capacities, the transport services costs must be minimized F=min. According to this requirement, the following conditions must be met: in case of exceeding the critical limits of $I<I_{cr}$ and $n<n_{cr}$ parameters that is explained by extending the reach of transportations or by the sharp increase in passenger traffics. The use of irregular special-purpose traffics is not effective. In this case, the function of transportation of disabled people must be implemented by the urban transport routes.

According to the second pattern, for route system of urban transport, there should be selected the optimum number of buses equipped with the adapted devices, and they must be redistributed on the existing routes (redistribution condition should be based on a measure of quantity variance of the requested transportations of disabled people). In addition, the operating regimes of the motive power must be adjusted so that judging from specific performance of buses equipped with several adapting devices (increasing running time and intervals due to the extension of the bus standing time at stops during the process of passenger boarding and drop-off), there must be ensured smooth running of the motive power, and decline in the quality of transport services for other passengers must be prevented. In this case, in order to assess decline in the quality transport services for other passenger, it is possible to use such indicator as total time spent on travel t_{tot}. Assume that none of the buses running on the route is equipped with the adapted devices intended for disabled people. In this case, the average value of total time spent on travel is t_{t0}, but when using n buses running on the same route equipped with the adapted devices, the average value of total time spent on travel is t_{tn} As a criterion of the decline in the quality of transport services for other passengers, we can take the condition $t_{tn} - t_{t0} > \Delta t_{cr}$, where Δt_{cr} is a critical value of travel time growth, when other passengers feel uncomfortable.

The practical implementation of this condition is difficult, even when only two of six buses equipped with the adapted devices are running on the line. When using the second pattern, it is necessary that all buses running on the main urban transport routes, anyway, must be equipped with the adapted devices intended for disabled people that significantly increases the costs of transport services.

Table1

The quality assessment criteria of assessing the efficiency of transportation of disabled people within the urban transport logistics system

No	Criterion content
1	The quality of compatibility of priority areas for transportation of disabled people with the existing transport schemes of urban passenger transport
2	The optimal number of buses running on regular lines for transportation of disabled people and on urban bus routes, which are equipped with the adapted devices.
3	Reliability of delivery time of buses equipped with the adapted devices for transportation of disabled people, and travel time expenditure (the optimal schedule parameters for buses on the line)
4	Safe and comfortable transportation of disabled people by buses equipped with the adapted devices
5	The level of organization of transportation of disabled people (the level of technical availability of bus fleet, maximum utilization of the capacity of buses, etc.)
6	Disable people transportation costs (tariffs)
7	The timeliness of providing information to disabled people about the route time table of buses equipped with the adapted devices
8	The level of implementation of the constant monitoring over disabled people transportation process
9	The possibility of increasing the reach of transport services for disabled people
10	Readiness (flexibility) to conditions of changing transport services in transportation of disabled people
11	Qualification of personnel responsible for safe transportation of disabled people

Logistical principle "to minimize transport costs in conditions that ensure high quality services" is suitable mostly to the third pattern. According to this pattern, construction of a logistic model of transport services for disabled people is based on solving the tasks of organizing new special-purpose routes for transportation of disabled people, at the initial stage of which, there should be implemented the following activities:

1. Organizing and conducting the terminal polling for the purpose of ensuring the maximum compliance of transport services with the needs of disabled people;
2. Determining the places of residence of disabled people in the city's territory and their number (A_1, A_2 … A_n), in accordance with the results of polling;
3. Determining the places of transport attraction points for disabled people in the city's territory and their number (B_1, B_2 …. B_n);
4. Identifying priority transport directions of disabled people, in accordance with the results of polling;
5. Forecasting the number of passenger traffics on each direction by days of the week;
6. Constructing the stress-distribution diagrams of transportation of disabled people and determining the peak load areas, by daylight hours.

A logistic model of transport services for disabled people within the integrated system of urban transport should be an important functional link of a uniform transport system (a new link must be maximally in coordination with the other functional links). At the second stage, there should be implemented the following activities:

1. Determining the optimum number of the regular passenger routes for disabled people;
2. All buses running on the regular passenger routes must be equipped with the adapted devices;
3. Designing new route patterns maximally compatible with the acting urban transport traffic schemes.

To organize a logistic model of transport services for disabled people on the acting routes of urban transport traffic (Fig. 1), at least one bus will be equipped with the adapted devices. The effective functioning of this model requires that a new route scheme must be passed through the points of gathering disabled people (A_1, A_2 … A_n) and, if possible, through the main attraction points B_1, B_2 …

B_n), and besides, it must also cross at least one point, in order to enable a disabled person to move towards any object located in the territory of the town. The functioning of this model allows for replacing the expensive individual services by the relatively affordable transport services, and besides, to ensure intensive integration of disabled people into society.

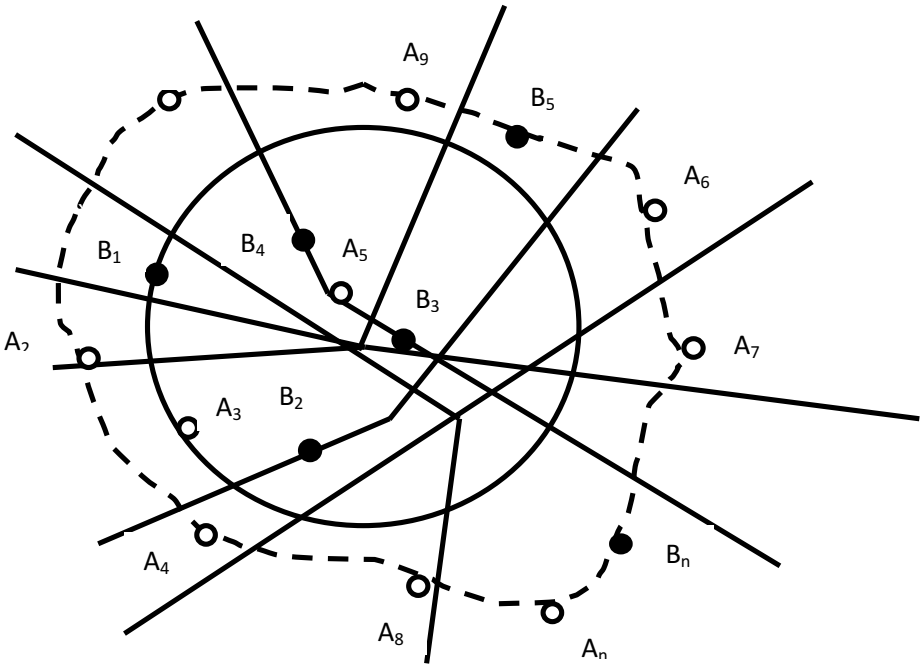


Fig. 1. Transport service patterns in transportation of disabled people by town-service buses

Fig. 2 illustrates the Kutaisi transport network, on which a new special regular transport network scheme intended for disabled people is shown in dotted lines, which was drawn based on the results of the questionnaire-based surveys.

Through the example of Kutaisi City, there were identified 4 sites of compact accommodation of disabled people, as well as such points of the city's sections, where the urban bus transport is accessible to disabled persons living alone.

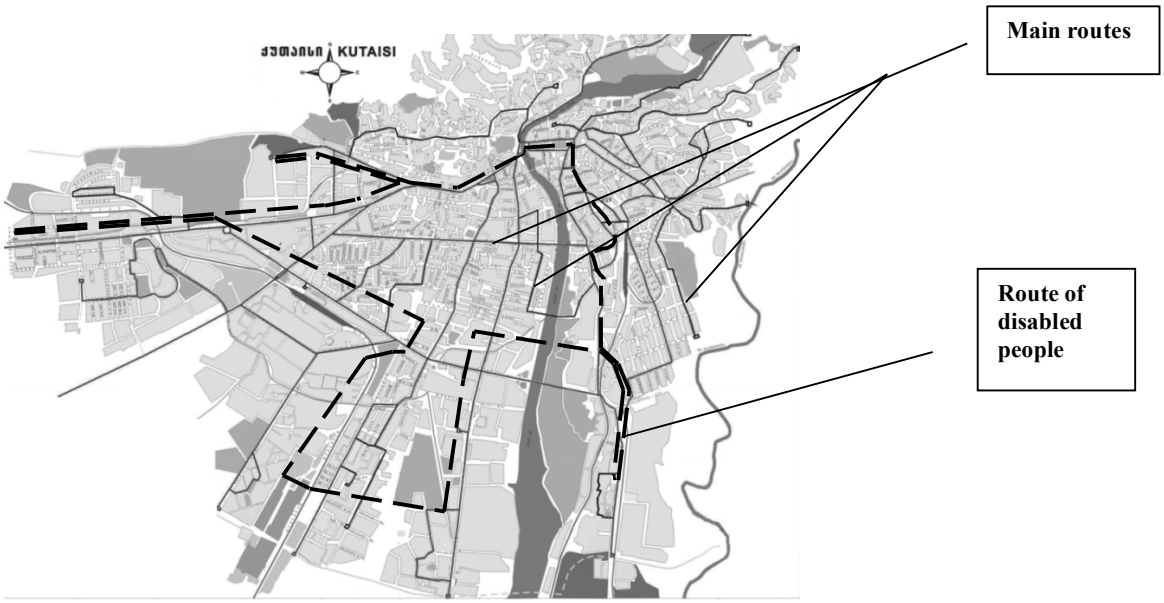
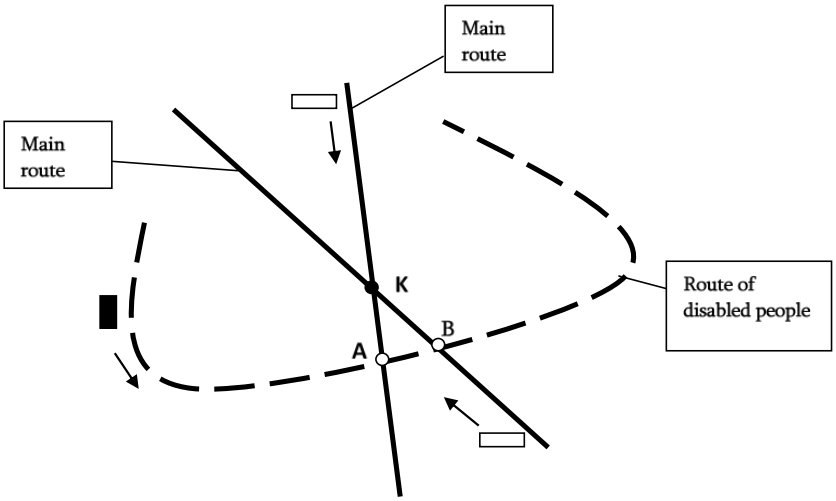


Fig. 2. Kutaisi transport network (dotted lines - a new special regular transport network scheme intended for disabled people)

Through the questionnaire-based surveys, the following destinations have been identified by purpose of travel: 52% - medical facilities; 30% - recreational, shopping and sports facilities; 12% - social protection establishments; 6% - different destinations. With regard to study and work travels of disabled people, they provided by the appropriate agencies by specialized transport.

Fig. 2 illustrates that this route has at least one intersection point with the main urban routes, due to which any point in the city becomes accessible to people with disabilities. All buses running on special routes are equipped with the adapted devices for disabled persons. On the main city routes, one or two buses must be equipped with adapted devices, for the selection of which the time-use studies were conducted on the process of embarkation-debarkation. In the case of using device with a lifting mechanism, it has been established that the duration of lifting per wheelchair-using passenger is 90 seconds, but for further passenger – 60 seconds, the time required for debarkation –100 and 70 seconds, accordingly.



- bus running on specialized route, which is equipped with the adapted device for disabled persons.
- bus running on a main urban route, which is equipped with the adapted device for disabled persons

Fig. 3. Scheme of the intersection of specialized route with a main urban route (1st case) A and B – intersection points, K – destination

Of course, such delay on the main route creates discomfort for other passengers that is why the debarkation ladder has been selected as the main adapted device for the main routes to enable the wheelchair-using disabled person to freely come on and get off the bus.

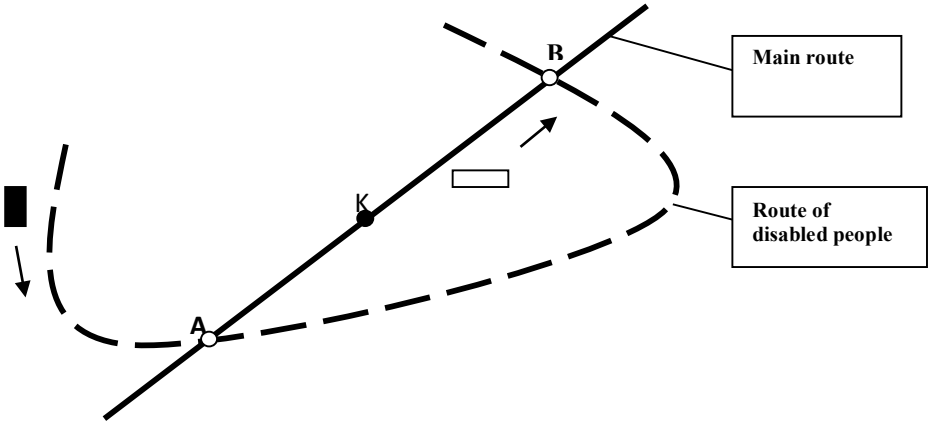
To select the places for changing the bus running on the regular route to the bus running on the main urban route, the cases are considered as follows: 1) when specialized route has one intersection (Fig. 3) with at least two main urban routes each, heading to the destination; 2) when specialized route has two intersections with one urban route heading to the destination (Fig. 4).

Random selection of the places for changing the buses running may lead to the increasing total time spent on travel of disabled persons. To eliminate this, there have been used the operative monitoring system of Kutaisi urban transport (all buses in Kutaisi are equipped with a GIS system).

The disabled person will have the opportunity to access to the urban transport monitoring system via the Internet, and receive reliable information on how far away is the place of changing the buses the vehicle running on the main route and equipped with adapted device for disabled person. By using the GIS information technology, the disabled person has the opportunity to select the optimal way of changing the buses, to reduce time spent on travel.

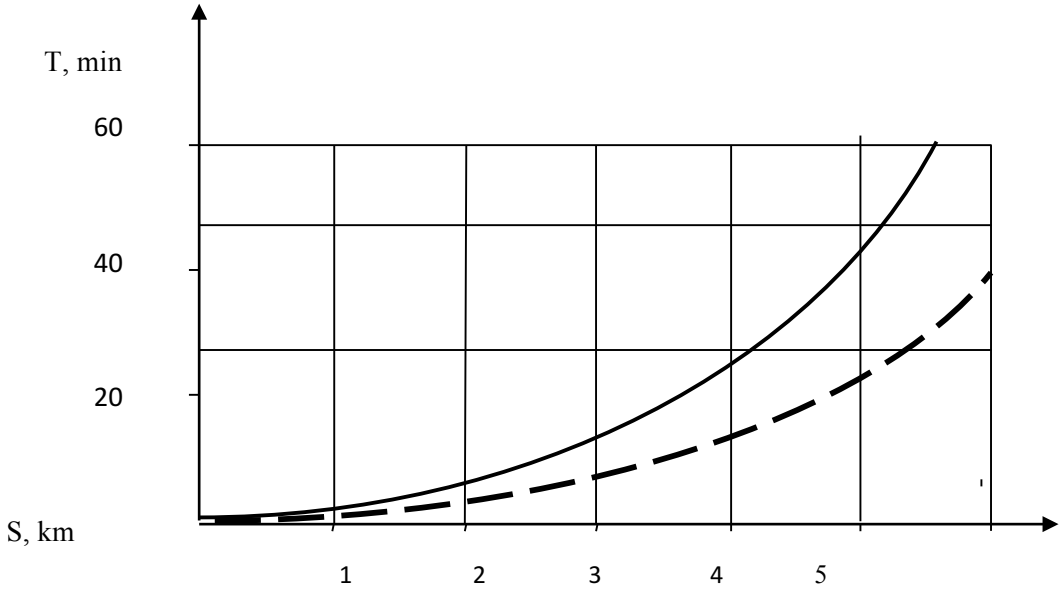
In order to assess time expenditure for travel, the experimental studies were conducted for two cases: 1) in conditions of random change of buses; 2) by using GIS information technology. Fig. 5 illustrates the relationship between total time spent on travel of disabled people and the distance of travel for both cases. As can be seen from the graphs, time expenditures are 60-80% higher than in case of using GIS

information technology. This assessment was taken for the average distance of travel, which for Kutaisi City is 4-5 km.



- bus running on specialized route, which is equipped with the adapted device for disabled persons
- bus running on a main urban route, which is equipped with the adapted device for disabled persons.

Fig. 4. Scheme of the intersection of specialized route with a main urban route (2nd case) A and B – intersection points, K – destination



— In the case of random changing; – – – by using GIS information technology.

Fig. 5. Total time spent on travel

4. CONCLUSIONS

The following conclusions have been made in the article:

1. Through the questionnaire-based surveys, the following destinations have been identified by purpose of travel: 52% - medical facilities; 30% - recreational, shopping and sports facilities; 12% - social protection establishments; 6% - different destinations. With regard to study and work travels of disabled people, they provided by the appropriate agencies by specialized transport.
2. According to the suggested logistic model, there has been developed the scheme of regular route of

transport services to persons with disabilities for their transportation by urban buses, by using the following principle: in the urban bus system, it is necessary to create additionally a new specialized regular route intended for transportation of disabled people, which passes through the accessible to disabled people compact accommodation points and final destinations. This rote should have at least one intersection with the main urban bus routes.

3. The time-use studies were conducted on the process of embarkation-debarkation. In the case of using device with a lifting mechanism, it has been established that the duration of lifting per wheelchair-using passenger is 90 seconds, but for further passenger – 60 seconds, the time required for debarkation –100 and 70 seconds, accordingly.
4. The experimental studies revealed that with account for time spent on changing the bus running on specialized rout to the bus running on the main route, in comparison with a random change, the use of GIS information technology allows for reducing total time expenditures for travel by 60-80%.

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References

1. *Конвенция о правах инвалидов*. (Принята резолюцией 61/106 Генеральной Ассамблеи от 13 декабря от 2006 года). Available at: http://www.un.org/ru/documents/decl_conv/conventions/disability.shtml. [In Russian: *Convention on the Rights of Persons with Disabilities*. (Adopted by General Assembly resolution 61/106 of 13 December 2006)].
2. Mashiri, M. & Maunder, D. & Venter, C. & Lakra, A. & Bogopane-Zulu H. & Zukulu, R. & Buiten, D. & Boonzaier, D. Improving the Provision of Public Transport Information for Persons with Disabilities in the Developing World. In: *Proceedings of 24th Annual Southern African Transport Conference*. Pretoria, South Africa. 2005. P. 308-322.
3. Кадомцева, С.В. Развитие человеческого потенциала и социальная защита населения. *Вестник Московского университета.* Серия 6. Экономика. 2004. No. 3. P. 116-121. [In Russian: Kadomtseva S.V. Human capital development and social protection of the population. *Messenger of Moscow State University*].
4. Пугачёв, И.Н. Проблемы модернизации транспортных систем городов. *Транспортное строительство.* 2008. No. 8. P. 5-9. [In Russian: Pugachov, I.N. Problems of modernizing transport systems in cities. *Transport construction*].
5. Сафронов, К.Э. Иновационные методы повышения эффективности транспортных систем городов. *Вестник Московского автомобильно-дорожного государственного технического университета.* 2011. No. 3(26). P. 7-12. [In Russian: Safronov, K.E. Innovative methods for increasing the effectiveness of the urban transport systems. *Messenger of Moscow Automobile and Road Construction State University*].
6. Currie, G. Quantifying spatial gaps in public transport supply based on social needs. *Journal of Transport Geography.* 2010. No. 18(1). P. 31-41.
7. Сафронов, К.Э. Обеспечение доступности различных видов пассажирского транспорта для инвалидов. *Вестник Сибирского автомобильно - дорожного государственного университета.* 2015. No. 5. P. 7-12. [In Russian: Safronov, K.E. Ensuring accessibility of different types of passenger transport for disabled persons. *Messenger of Siberian Automobile and Road Construction State University*].
8. Семчугова, Е.Ю. & Солонская, И.Г. & Гайдаев, В.С Логистическое обеспечение транспортной подвижности пассажиров с ограниченными возможностями здоровья. *Известия Ростовского государственного строительного университета.* 2010. No. 14. P.75-

83. [In Russian: Semchugova, E.Yu. & Solonskaya, I.G. & Gaidaev, V.S. Logistic support of transport mobility of passengers with disabilities. *News of Rostov State Building University*].
9. Мун, Э.Е. Актуальные проблемы обеспечения доступности инвалидам транспорта и дорожной инфраструктуры, инновационные решения. *Автотранспортное предприятие.* 2010. No. 6. P. 13-15. [In Russian: Mun, E.E. Actual problems of providing accessibility for disabled people to transport and road infrastructure, innovative solutions. *Autotransport enterprise*].
10. Pattnaik, S.B. & Mohan, S. & Tom, V.M. Urban bus transit route network design using genetic algorithm. *Journal of Transportation Engineering.* 1998. Vol. 124(4). P. 368-375.
11. Carrese, S. & Gori, S. An urban bus network design procedure. *Applied Optimization.* 2002. Vol. 64. P. 177-196.
12. Carmien, S. & Dawe, M. & Fischer, G. & Gorman, A. & Kintsch, A. & Sullivan, J.F. Socio-technical environments supporting people with cognitive disabilities using public transportation. *ACM Trans. Comput.-Hum. Interact.* 2005. Vol. 12. P. 233-262.
13. Гайдаев, В.С. & Семчугова, Е.Ю. Логистическая оценка доступности объектов для маломобильных групп населения. *Вестник Тихоокеанского государственного университета*. 2012. No. 1(24). P. 83-90. [In Russian: Gaidaev, V.S, & Semchugova, E.Yu. Logistical assessment of the accessibility of facilities for low-mobility population groups. *Messenger of the Pacific State University*].
14. Zhou, H.Y. & Hou, K.M. & de Vaulx, C.S. A super-small distributed real-time microkernel dedicated to wireless sensors. *Int. J. Pervasive Comput. Commun.* 2006. Vol. 2. P. 398-410.
15. Levis, P. & Madden, S. & Tiny, OS. An Operating System for Sensor Networks. *Springer Heidelberg Press.* 2005. Part II. P. 115-148.

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