УДК 656.025.2=111

PUBLIC TRANSPORT INTERCHANGES FUNCTIONING FROM A SUSTAINABLE DEVELOPMENT PERSPECTIVE

V. Naumov, Prof., D. Sc. (Eng.), G. Samchuk, P.G.,
Kharkov National Automobile and Highway University

Abstract. *The transport interchange functioning has been presented as a gray box cybernetic model. The identified input data characterizes the transport interchange as an infrastructure object and influence the processes both for public transport and passengers. An integrated indicator has been chosen as the efficiency criterion, combining economic, environmental and social costs.*

Key words: *transport interchange, model, efficiency criterion, sustainable development.*

ФУНКЦІОНУВАННЯ ТРАНСПОРТНО-ПЕРЕСАДОЧНИХ ВУЗЛІВ З ПОЗИЦІЇ СТАЛОГО РОЗВИТКУ

В.С. Наумов, проф., д.т.н., Г.О. Самчук, асп.,
Харківський національний автомобільно-дорожній університет

Анотація. *Розглянуто основні транспортні процеси у зоні дії транспортно-пересадочних вузлів як для пасажирів, так і для пасажирського транспорту. Процес функціонування транспортно-пересадочного вузла подано у вигляді кібернетичної моделі сірої скрині.*

Ключові слова: *транспортно-пересадочний вузол, модель, критерій ефективності, сталий розвиток.*

ФУНКЦИОНИРОВАНИЕ ТРАНСПОРТНО-ПЕРЕСАДОЧНЫХ УЗЛОВ С ПОЗИЦИИ УСТОЙЧИВОГО РАЗВИТИЯ

В.С. Наумов, проф., д.т.н., А.А. Самчук, асп.,
Харьковский национальный автомобильно-дорожный университет

Аннотация. *Рассмотрены основные транспортные процессы в зоне действия транспортно-пересадочных узлов как для пассажиров, так и для пассажирского транспорта. Процесс функционирования транспортно-пересадочного узла представлен в виде кибернетической модели серого ящика.*

Ключевые слова: *транспортно-пересадочный узел, модель, критерий эффективности, устойчивое развитие.*

Introduction

The achievement of social and economic institutions sustainable development has been defined as a strategic goal in the majority of countries in the world. Today, it is widely recognized that it is possible to ensure sustainable development by focusing efforts on improving transportation services and introducing innovative technologies [1, 2]. The main task of creating sustainable transport systems is the development of passenger transport, which should become a competitive alternative to private cars, providing transport services at a high level. One of the best ways to increase public transport efficiency is to improve the functioning of public transport interchanges and to form on their basis intermodal and multimodal passenger transport systems that can provide «seamless journey» [3, 4].

It is necessary to improve all forms of integration of different public transport modes, where technical and technological are the most important ones. To date, the organization of transit buses operation along routes is usually executed without regard to a schedule across the entire network and capacity of a bus stop or interchange, thereby there occur congestion and bus bunching on common route segment. It results in reduced safety, congestion occurrence, moreover the amount of different pollutants released into the atmosphere considerably increases. Additionally, the lack of schedule coordination provokes a rise in passenger waiting times during the transfer and passenger fatigability that significantly reduce the attractiveness of public transport for the population.

Until now, the functioning of public transport interchanges from the sustainable development perspective has not been sufficiently studied [5, 6]. This approach allows taking into account economic, social and environmental components and introducing appropriate measures to improve the efficiency of interchanges.

Analysis of publications

The value and importance of the effective functioning of interchanges is recognized in many European countries, the existence and successful implementation of the project NODES, which is co-funded by the European Union's Seventh Framework Programme, confirm it. The project falls under the category called «Ensuring Sustainable Urban Mobility», the International Association of Public Transport (UITP) is the project coordinator. NODES is a three-year research project that was established with aim to build a toolbox to support European cities in the design and operation of interchanges, focusing on the efficient integration of public transport services [7].

A vital and important stage in the research process of any object is to determine the objective and efficiency criterion. The difficulty of this stage is that among scientists there is no common understanding on how to assess the efficiency of public transport systems in general and public transport interchanges in particular. Considerably less number of national transport scientists raises a problem of the interchange efficiency in their publications unlike freight hubs. In the paper [8] the basis for evaluation of the interchange efficiency is the assumption that the main factor, which determines the investment amount required for interchanges creation is the cost of land. It is taken into account the specific quantity of clients per unit of investment in public transport interchanges construction when choosing allocation of them.

One of the main tasks when increasing the interchange efficiency is comprehensive solutions to problems of improvement of different public transport modes integration. Most commonly, mathematical models are developed to improve technological forms of integration and reduce passengers waiting time by creating schedules with maximum synchronization correspondingly [9, 10]. In the paper [11] authors present commercial software HASTUS developed by the Canadian company GIRO, these tools can be used to optimize schedule synchronization. Software and computer programs can significantly help when developing adequate models to describe the functioning of complex objects. The modeling quality is largely enhanced by their numerical abilities, namely flexibility, speed and efficiency. The most famous developer of software that is used in the field of transport planning and management is the company PTV Group. It presents a software product line (PTV Visum, PTV Vissim, PTV Viswalk, PTV Vistro, PTV Balance etc.) to create simulation models that vary in purpose. Using PTV Visum it is possible to solve complex tasks with significant level of detail of transportation process of mass transit systems.

The aim and research tasks

The aim of the study is to identify the main model development principles for public transport interchanges functioning from a sustainable development perspective. The object of the study is the interchanges functioning, and the subject is the efficiency of interchanges functioning from a sustainable development perspective. To achieve the aim in this research the choice of the efficiency criterion of interchanges functioning is being justified and decomposition of interchanges functioning is being carried out.

Model of public transport interchanges functioning

The process of establishing the efficiency criterion should take into account needs of all the participants of passenger transport market. There are some focuses when assessing efficiency that shift in case of transformation of society. Cost indicators were the most frequently used. With the transition to market relations not only profit maximization, but also delivering high service quality and promotion of enterprises competitiveness became the transportation service providers' primary goal, therefore social indicators are also used as the efficiency criteria. Considering the current ecological crisis and development direction of a majority of countries, efficiency criteria of any object or system must also take into account environmental indicators. Since a public transport interchange is an element of the passenger transportation system it is correct to establish criterion considering the global aim of the higher level system, namely, to ensure sustainable mobility. Thus, when solving the management problem of modern transport systems it is appropriate to develop the integrated efficiency indicator that includes economic, social and environmental components.

For passengers one of the most significant indicators of service quality is the travel time; the waiting time is the most important of all the components for passengers. Compared to other components of the total travel time, the reduction in the waiting time does not need additional model development of public transport networks and does not require changes in transport infrastructure (for instance, provision of exclusive bus lanes in order to increase service speed). Its value reduces significantly when synchronizing schedule of buses operating along routes. The waiting time at interchanges has been chosen as an indicator of the social dimension. In addition, uncoordinated schedules increase the probability of presence of the number of buses at a stop that exceeds its capacity. It causes the queues that provoke congestion situation adversely affecting the transportation costs. The waiting process in the queue prior to entering the interchange zone significantly increases emissions of air pollutants, their quantitative assessment is needed to reflect the environmental aspects of public transport interchanges functioning.

We propose to determine an integrated criterion of efficiency as the sum of economic, environmental and social costs, in doing so, it is necessary to convert all values of above mentioned parameters (indicators) into monetary units. The objective function is represented as follows:

$$C = C_E + C_S + C_{ECO} \to \min, \qquad (1)$$

where C – total costs at the interchange, UAH; C_E – economic costs, UAH; C_S – social costs, UAH; C_{ECO} – environmental costs, UAH.

A public transport interchange can be defined as a key element of a transport system, in which the interconnection between different public transport lines or modes and redistribution of passenger flows occur. This definition dictates the necessity of identification of processes subsystems in the transport interchanges zone both for passengers and for urban passenger transport. In order to reflect fully and comprehensively the interchange functioning we also define the group of passengers beginning their trip at the interchange and distinguish elementary subprocesses: walking to a bus stop, waiting for a bus and boarding a bus.

For passengers who transfer at the interchange, it is advisable to distinguish the following processes:
– alighting from a vehicle;
– transfer, consisting of walking between transfer stops and waiting;
– boarding a vehicle.

When providing passenger services the following sequence of technological subprocesses are executed:
– arrival of vehicles at bus stops;
– delay at a bus stop (spending time in the queue before entering the stop, passengers boarding and alighting);
– departure process.

The description of processes for two passengers groups and urban public transport is presented in table 1.

Since even the simplest interchange is a complex system in which a set of transport processes is performed using facilities and equipment need for their realization, when modeling its functioning the primarily necessity is to define the parameters that describe the processes for participants of transportation (passengers, public transport) and characterize the interchange as an infrastructure object. The size of the public transport interchanges network can be defined using the numerical values of the following parameters: N – number of public transport interchanges, units; M – number of routes in the network, units.

In this research, the transfer walking time at the i-th interchange, $\{t\text{п}_i\}$, $i=\overline{1,N}$, is defined as the deterministic value.

Table 1 Characteristics of the processes occurring in the public transport interchange

Process	Indicators that characterise the process	Indicators that allows to define the process characteristics
Arrival of passengers at a stop	The number of passengers arriving at a stop during period of time	The intensity of the passengers arrival at a stop, observation period
Waiting for a vehicle (for two groups of passengers)	Waiting time	Headway on the route, interval between buses at stops, the difference between arrivals of vehicles at the interchange
Passenger boarding /alighting	Boarding and alighting times	Passenger load factor, the number of alighting and boarding passengers
Walking between transfer stops	Time spent walking between transfer stops	Transfer distance between routes at the interchange
Arriving at the interchange	Arrival time	Departure time from initial stop, travel time between the initial bus stop and interchange
Delay at the interchange	The time spent at the interchange (for buses)	Stop/station capacity, the presence of other vehicles at the stop, passenger load factor, the number of alighting and boarding passengers
Departure	Departure time	Dwell time

The public transport interchange functioning is presented as a gray box cybernetic model, shown in Fig. 1.

Six parameters have been chosen as input variables:

– departure time from the initial bus stop, $t\text{в}_j$, $j = \overline{1, M}$;

– travel time between the initial bus stop and interchange, $t\text{р}_j$, $j = \overline{1, M}$;

– intensity of the passengers arrival at a stop (transport interchange), N_i, $i = \overline{1, N}$;

– number of transfer passengers, $Q\text{п}_i$, $i = \overline{1, N}$;

– bus stop capacity, $П_i$, $i = \overline{1, N}$;

a set of headways of the j-th route, I_j, $j = \overline{1, M}$.

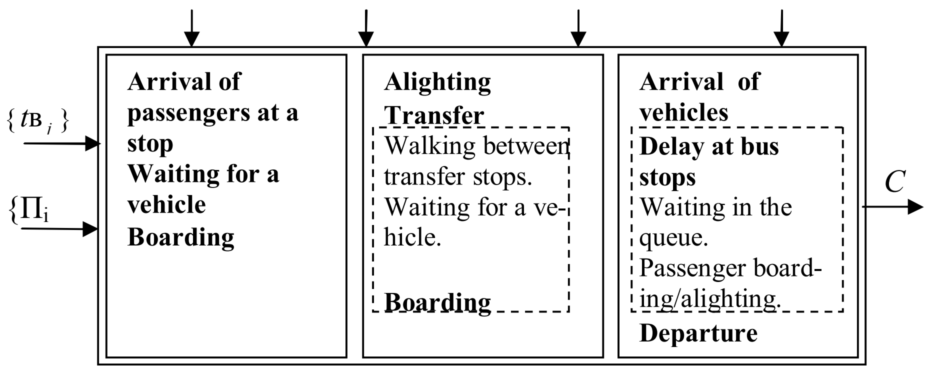

Fig. 1. The transport interchange functioning as a gray box cybernetic model

Among mentioned variables uncontrolled ones are: the intensity of the passengers arrival the stop, the number of transfer passengers, the travel time between the initial bus stop and interchange, headways; controlled parameters include departure time from the initial stop, the bus stop capacity. The public transport operation is affected by a large number of different random disturbances, like natural phenomena, vehicles breakdowns, accidents, the direction and intensity change of traffic flows. This causes the stochastic nature of the travel time between the initial bus stop and interchange $t\text{р}_j$ and headways of the j-th route, I_j. The intensity of a passengers arrival at the stop, N_i and the number of transfer passengers, $Q\text{п}_i$ are also random variables. The output parameter is the total costs, C at the public transport interchange.

The source of data for the departure time from the initial stop $t\text{в}_j$ is an existing schedule. If the headway is fixed it is possible to change the schedule by shifting the start time of a trip by a value not exceeding the headway on the route. Consequently, the range of variation of this variable is

$$t\text{в}_j^{\,1} - I_j < t\text{в}_j < t\text{в}_j^{\,1} + I_j\,, \qquad (2)$$

where $t\text{в}_j^{\,1}$ − current departure time from the initial bus stop of the j-th route, hrs; I_j – headway of the j-th route, hrs.

The travel time between the initial bus stop and interchange, $t\text{р}_j$ can be calculated or defined using chronometric analysis, measurements and calculations allow to determine the bus stop capacity Π_i. Field observations are the source of data on the intensity of the passengers arrival at a stop N_i. Questionnaires or field observations are best used for collecting factual data on the number of transfer passengers, $Q\text{п}_i$. The interval of variation is between the minimum and maximum values of all above mentioned parameters.

The transfer walking time between stops $t\text{п}_i$ is determined on the basis of field observations and analytical calculations. The model assumption is the invariance of the transfer walking time value.

Conclusions

The public transport interchanges are an important part of transport infrastructure and complex technological system, where processes of servicing passengers and vehicles are performed. Interchanges could become a significant component that contributes to sustainable mobility, so their studies are quiet important.

The modern conditions dictate the necessity of complex assessment of the interchanges functioning, so the integrated indicator has been chosen as the efficiency criterion, which combines economic, social and environmental costs. The selected inputs characterize each element of the transport interchange, namely public transport, passengers and a set of stops.

For further investigations of functioning of the public transport interchange network it is advisable to use the software PTV Visum, integrating all transport processes in the zone of the interchange into a single mathematical model.

References

1. United Nations Conference on Environment and Development. Agenda 21: Programme of Action for Sustainable Development; Rio Declaration On Environment and Development; Statement of Forest Principles: The Final Text of Agreements Negotiated By Governments At the United Nations Conference On Environment and Development (UNCED), 3-14 June 1992, Rio De Janeiro, Brazil. New York, NY: United Nations Dept. of Public Information, 1993. Available at: https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.
2. ECMT (2001) Sustainable Transport Policies. European Conference of Ministers of Transport. Paris: OECD. Available at: http://internationaltransportforum.org/pub/pdf/00Sustain.pdf.
3. European Commission: White Paper on transport − Roadmap to a single European transport area − Towards a competitive and resource-efficient transport system. – Luxembourg: Publications Office of the European Union, 2011. – 28 p.
4. Hine J. Seamless, accessible travel: users' views of the public transport journey and interchange / J. Hine, J. Scott // Transport Policy. – 2000. – Vol. 7, Issue 3. – P. 217–226.
5. UNWCED: United Nations World Commission on Environment and Development. Our Common Future (Brundtland Report), Oxford: University Press, 1987. Available at: http://www.un-documents.net/our-common-future.pdf.
6. Sharachchandra M. Lélé. Sustainable development: A critical review. World Development. – 1991. – Vol. 1, Issue 6. – P. 607–621. Available at: http://www.atree.org/sites/default/files/pubs/slele/journal-publications/Lele_SusDev_review_ WDev.pdf.
7. Nodes (project) Available at: http://www.nodes-interchanges.eu.
8. Горбачев П.Ф. Рациональное размещение транспортно-пересадочных узлов в городах / П.Ф. Горбачев, В.Ф. Далека, И.Г. Гузненков // Восточно-Европейский журнал передовых технологий. – 2011. – Вып. 4/3 (52). – С. 4–6.
9. Ceder A. Creating bus timetables with maximal synchronization / A. Ceder, B. Golany, O. Tal // Transportation Research Part A:

Policy and Practice. – 2001. – Vol. 35 (10). – P. 913–928.
10. Schuele I. Synchronization of regional public transport systems / I. Schuele, M. Schroeder, K.H. Kuefer // Urban Transport XV – Urban Transport and the Environment in the 21st Century: 22–24 June 2009, Bologna, Italy, Fifteenth International Conference on Urban Transport and the Environment Southampton: WIT Press. – 2009. – P. 301–311.
11. Fleurent C. Transit Timetable Synchronization: Evaluation and Optimization / C. Fleurent, R. Lessard, L. Seguin // GIRO Inc. − 2007. Available at: http://www. researchgate.net/profile/Charles_Fleurent/publication/248584397 _Transit_ Timetable_ Synchronization_Evaluation_and_ Optimization/links/ 0046353875f4f7e5ea000000.pdf.

References

1. United Nations Conference on Environment and Development. (1993). Agenda 21: programme of action for sustainable development; Rio Declaration on Environment and Development ; Statement of Forest Principles: The final text of agreements negotiated by governments at the United Nations Conference on Environment and Development (UNCED), 3-14 June 1992, Rio de Janeiro, Brazil. New York, *NY: United Nations Dept. of Public Information.* https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf. (accessed 20.08.2015).
2. ECMT (2001) Sustainable Transport Policies. European Conference of Ministers of Transport. Paris: OECD. Available at: http://internationaltransportforum.org/pub/pdf/00Sustain.pdf. (accessed 20.08.2015).
3. European Commission. White Paper on transport – Roadmap to a single European transport area – Towards a competitive and resource-efficient transport system. *Luxembourg: Publications Office of the European Union*, 2011, 28 p.
4. Hine J., Scott J. Seamless, accessible travel: users' views of the public transport journey and interchange *Transport Policy*, July 2000, Vol. 7, Issue 3, pp. 217-226.
5. UNWCED: United Nations World Commission on Environment and Development (1987) Our Common Future (Brundtland Report), *Oxford: University Press.* Available at: http://www.un-documents.net/our-common-future.pdf. (accessed 20.08.2015).
6. Sharachchandra M. Lélé. Sustainable development: A critical review. *World Development*, 1991, Vol. 1, Issue 6. pp. 607-621. Available at: http://www.atree.org/sites/default/files/pubs/slele/journal-publications/Lele_SusDev_review_WDev.pdf. (accessed 11.08.2015).
7. Nodes (project) Available at: http://www.nodes-interchanges.eu. (accessed 10.08.2015).
8. Gorbachev P.F., Daleka V.F., Guznenkov I.G. Ratsional'noe razmeshchenie transportno-peresadochnykh uzlov v gorodakh [Rational placing of bus lining-out knots in cities]. *Vostochno-Evropeiskii zhurnal peredovykh tekhnologii*, 2011, Vol. 4, no 3(52), pp. 4-6.
9. Ceder A., Golany B., Tal, O. Creating bus timetables with maximal synchronization. *Transportation Research Part A: Policy and Practice*, 2001, Vol. 35, no. 10, pp. 913-928.
10. Schuele I., Schroeder M., Kuefer K.H. Synchronization of regional public transport systems. Urban Transport XV – Urban Transport and the Environment in the 21st Century: 22-24 June 2009, Bologna, Italy, *Fifteenth International Conference on Urban Transport and the Environment Southampton: WIT Press*, 2009, pp. 301-311.
11. C. Fleurent, R. Lessard, L. Seguin Transit Timetable Synchronization: Evaluation and Optimization. GIRO Inc, 2007. Available at: http://www.researchgate.net/ profile/Charles_Fleurent/publication/248584397_Transit_Timetable_Synchronization_Evaluation_and_Optimization/ links/0046353875f4f7e5ea000000.pdf. (accessed 31.08.2015).

Рецензент: П.Ф. Горбачев, профессор, д.т.н., ХНАДУ.

Статья поступила в редакцию 21 сентября 2015 г.