Estimation of the interaction level between urban passenger transport and city train

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Abstract. In the article the estimation of the interaction level between urban passenger transport and city train was made using the systems approach through application of modern methods of developing adequate easy-to-use mathematical models. Applying the systems approach, the transport node was considered as a comprehensive object, which is a single entity. It was identified that the transport node efficiency depends on the interaction level of the structure and its technology with the passenger traffic that requires designing a rational structure of the node and providing the technological interaction setting. The flow chart of determination the indicators of urban passenger transport modes' operation was proposed in order to improve the passenger service quality by increasing the level of interaction of urban passenger transport modes with each other, also the system of efficient use of urban transport means was developed. The system of criteria for assessing the level of interaction between urban passenger transport and city train was implemented, which consists of criteria for the individual assessment of urban passenger transport and city train and criteria for their system interoperability, including consideration of the system quality from the passenger's point of view.

1 Introduction

Because of great complexity of transport systems (TS), they are difficult to calculations to determine their perspective parameters. But transport science and practice have accumulated specific experience of using certain methodological approaches and models for the implementation of appropriate calculations over the past. As an example, it should be noted that complex transport nodes, where the biggest share of the TS' operation on the redistribution of passenger flows by directions and routes is concentrated, was viewed as mass service systems (MSS). Intrinsically, this is not a fairly accurate consideration of transport nodes (TN) since management plays a significant role in nodes, which is practically not taken into account in the MSS. Therefore, complex structures of TN should be investigated using a systems approach.

The systems approach involves considering such a complex object as a transport node, as an organic whole. In this case, the output parameters of the TN are affected by the interaction of its elements and subsystems, as well as their structures and technologies. Especially the interaction of passenger flows and technological structure should be highlighted. These aspects are practically not subject to formal description. Therefore, when evaluating the investment efficiency in the development of TN, and particularly in improving the passenger service quality in TN, a systems approach

should be implemented using modern methods of developing adequate easy-to-use mathematical models.

2 Literature review and defining the problem

The papers [1-9] suggest approaches to solve the problem of train routing based on genetic algorithms. The authors in [1] proposed a genetic algorithm for routing and scheduling trains to achieve efficient and reliable travel itinerary and schedule. The algorithm can change the start time of trains, as well as some parts of the train trajectory. Computer modelling has shown that the developed algorithm allows reducing train delays.

The results of scientific research given in [2] reveal the ways of solving the issue of finding robust and stable solutions for the flexible job shop scheduling problem considering random machine breakdowns using a two-stage Hybrid Genetic Algorithm to generate the predictive schedule. The author determined that different measures have different sufficient implications on the relative performance of the offered rescheduling method in comparison with other existing methods.

The scientific work [3] is devoted to the high-value issue of the train scheduling improvement through the implementation of hybrid job shop approach. The author developed a constructive algorithm on the base of a disjunctive graph model of train operations and adapted

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Simulated Annealing and Local Search meta-heuristic improvement algorithms allowing more flexible train scheduling which can be realized in real conditions.

The study [4] considering train scheduling issues aimed at determining a periodic timetable for a set of trains based on track capacities and given operational constraints. It is focused on solving the problem of one-way track linking two stations having a number of intermediate stations. It was made with the use of a model on the base of directed multigraph in which the variables in the relaxed constraints are associated only with nodes. The results of applying the proposed model confirm a sufficient relaxation solution speed-up.

The genetic algorithm and the hybrid genetic algorithm proposed by the authors in [9] were used for optimal planning of public transport vehicles based on their actual operating environment. The results of the study provided an opportunity for a smart planning of public transport vehicles based on the proposed algorithms, which eliminated the disadvantages of traditional planning methods.

3 Research aim and objectives

The research is aimed at the comprehensive estimation of the interaction level between urban passenger transport and city train using the systems approach and applying modern methods of developing adequate easy-to-use mathematical models.

Main objectives of the research are as follows: to consider the transport node as a comprehensive object and a single whole applying the systems approach; to develop the flow chart of determination the indicators of urban passenger transport modes' operation and the system of efficient use of urban transport means; to design the system of criteria for assessing the level of interaction between urban passenger transport and city train taking into account the system quality from the passenger's point of view.

4 Overview key findings

4.1 The flow chart of a transport passenger node of a large city

Primarily, the issue of transport nodes' development is closely linked with the beginning of the railway infrastructure development and the emergence of crossing points in the network structure, mergers, branching of several lines and transport modes.

In this regard, the question arises: have transport nodes kept their weight in the society in the result of the transition of the state from the planned to the market economy?

It should be emphasized that the structural reform in transport is aimed at improving the transport service quality of the clientele in its broadest sense: by volumes and duration of passenger delivery, by regularity and transportation costs, compliance with safety requirements. Therefore, it is necessary for the transport

system, an important component of which are transport nodes, to ensure a high speed of passengers' delivery with full and effective use of fixed assets and rolling stock and absolute meeting of the growing demand of users for the provision of high-quality transport service. Based on this, a comprehensive and systems approaches to improving the functioning of transport nodes in large cities provide an opportunity to identify real and economically feasible ways to improve the efficiency of transport operations with passengers and achieve high rank by railways among other transport modes in the state and at the international level.

Consequently, the systems analysis most closely corresponds to the nature of the tasks for improving the passenger service system in transport nodes. So, their study should be based on the following principles [10]:

- the development of transport nodes is carried out within a single transport system, taking into account the state and prospects of the national economy;
- the development of transport nodes establishes economic, social, political and defence requirements;
- two main subsystems – flows of rolling stock and permanent means – technologically interact in transport nodes;
- capacities of transport nodes via indicators of carrying, throughput and processing capacity influenced by the state and system of technical facilities' operation and organization level are quantitatively assessed;
- the sequence of improving the organization of transport nodes is regular in the phased implementation of the formation of new structures in their composition and the introduction of modern technologies;
- emergence of new qualities and properties, different from the past are important features in the improvement of transport nodes.

In the transport node, the incoming flows of passengers are transformed in outgoing flows, which uses its infrastructure. It is a terminal with a complex structure of various transport modes for the processing and smoothing of uneven passenger flows. In order to determine the capabilities of subsystems and elements of the transport node, their processing and throughput capacities are determined.

In addition, the operation of all components is regulated by scientifically grounded technological processes. The structure of the transport node implies not only the spatial location of its elements, but also performing specific functions by them.

The role of specific elements is determined by the scheme and technology. Therefore, the technology needs to be developed and implemented on a specific scheme, providing an organized passage of flows in the structure of the node in compliance with technological standards (Fig. 1).

Efficiency of the transport node depends on the level of interaction between the structure and its technology with the flows of passengers. For this purpose it is important to build a rational structure of the node and to set up technology on it.

The rational structure of the transport node provides the required throughput capacity and volume of its elements at the lowest operation cost. The transport node's rational structure development involves an

extensive network of its elements for flow passage, as well as the ability of smoothing the unevenness of the incoming and outgoing flows. Herewith, it is important

to consider the interaction of elements, subsystems and management functions and to reflect interconnection and the influence of the node structure parameters.

Fig. 1. The flow chart of a transport passenger node of a large city

The passage and transformation of flows should be carried out with minimal losses, and the node was able to adapt to changes in variable operating conditions, requiring reasonable reserves to ensure a high degree of economic stability and technological flexibility.

The transport node is a complex organizational system with nonlinear dependencies between its subsystems and elements. Its technological parameters (carrying, throughput and processing capacity, etc.) are determined not only by the parameters of its individual elements, but also by the quality of its structure, operation technology and management system.

The quality of management plays an important role in its operation, which provides flexibility, manageability of the implemented technology, and as a result of managerial actions – high economic result of the whole node operation. In addition, the fact that the management creates the availability of reserves should to be taken into account. It will provide passenger service cost savings of railways.

In the transport node of a large city, passenger transfer points (PTP) are important elements where the intersection of the transport routes of various modes of urban passenger transport (UPT) and the distribution of passenger flows between them (transfer of passengers) are carried out. The duration of each passenger's trip depends on the level of interaction between the modes of urban passenger transport in PTP.

4.2 Determining performance indicators of urban passenger transport modes in the node

Based on studying the practice of passenger transport service in large cities and the results of conducted researches on the rationalization of UPT operation [10], a flow chart of determining performance indicators of UPT modes was developed for the purpose of improving passenger service quality by increasing interaction level of UPT modes between each other (Fig. 2).

Fig. 2. Flow chart of determining performance indicators of urban passenger transport modes in the node

The interaction of UPT modes, primarily, will shorten the waiting times for the transport vehicles by passengers in transfer places, and as a result, the connection speed V_s will increase and the duration of

passengers' delivery from places of residence to the places of destination (work, study, etc.) will decrease.

In addition, it should be noted that the implementation of certain measures to improve the functioning of UPT

modes due to ensuring their interoperability will lead to increase in average capacity of transport vehicles, reduction of the need for rolling stock, reduction of transport mileage, and as a result – reduced costs for the UPT operation. The system of effective use of urban transport modes is presented in Fig. 3.

When solving transport problems of the city, it is necessary to study the time costs associated with the movement of the population from the place of residence

to the place of work (study), in order to determine the impact degree of passenger transportation delays. The duration of the displacement of people from their place of residence to the place of work (study) consists of a separate moving by different UPT modes and walking. Separately, the time lost by passengers due to waiting UPT vehicles and city train (CT), as well as the number of transfers are taken into account.

Fig. 3. System of effective use of urban transport modes

4.3 Modelling time costs of urban passengers in the system “Urban Passenger Transport – City Train” considering waiting times for the transport vehicles

To reduce the time spent on all types of trips, it is necessary to solve a complex set of the following issues in the city combined with suburban area due to the close interaction of the UPT with suburban passenger transport (SPT) modes, which is driven by the commonality of passenger flows: rolling stock renewal; increasing culture and service of passengers; improvement of the transport network in conjunction with intermodal interfaces; increase in speed of vehicles; organization of direct connection between the city and the suburban area; provide necessary intervals and regularity of vehicle traffic.

The time spent on the moving of passengers for labour purposes should be defined as the amount of time on transportation, vehicle waiting considering the number of passengers who are at the UPT stop, the duration of pick-up and drop-off, the vehicle capacity and load factor, and the duration of the pedestrian passage, and pick-ups (drop-offs) in a vehicle:

$$t_{mov} = t_{ped}^{dep} + t_{dep}^{wt} + t_{pup} + t_{tra}^{UPT} + t_{stp} + t_{tr}^{PTP} + t_p^{CT} + t_{tra}^{CT} + t_d^{CT} + t_{ppg}^{dst} \quad (1)$$

For passengers using the system “Urban Passenger Transport – City Train” it is important that the following condition is met:

$$t_{ats} \leq t_{sts}, \quad (2)$$

where t_{ats} – actual duration of the passenger transportation by UPT and CT considering real delays (waiting periods) in PTP; t_{sts} – scheduled transportation duration of the passenger by UPT and CT considering real transfer duration in PTP.

$$t_{ats} = t_{ats}^{UPT} + t_{awt}^{PTP} + t_{ats}^{CT}, \quad (3)$$

where t_{ats}^{UPT} – actual duration of passenger transportation by UPT; t_{awt}^{PTP} – actual waiting periods (transfers) of the passenger in the PTP; t_{ats}^{CT} – actual transportation time of the passenger by CT.

$$t_{sts} = t_{sts}^{UPT} + t_{tr}^{PTP} + t_{sts}^{CT}, \quad (4)$$

where t_{sts}^{UPT} – scheduled duration of passenger transportation by UPT; t_{tr}^{PTP} – duration of passenger transfer in PTP; t_{sts}^{CT} – scheduled duration of passenger transportation by CT.

Passenger costs when transporting by the “UPT – CT” system:

$$\Delta t_{cst}^{pss} = t_{ats} - t_{sts} \text{ at } T = const, \quad (5)$$

where T – tariff for transportation of one passenger, UAH.

Effectiveness criteria of the “UPT – CT” system operation (from city authorities’ point of view):

$$K_{mun} = \frac{D_b}{K_b} \geq 1, \quad (6)$$

where D_b – receipt of funds to the municipal budget in the form of taxes paid by transport enterprises, UAH; K_b – funds sent from the municipal budget for commercial payments to carriers (subventions for subsidized transport of certain population categories, UAH).

Transport service coefficient (in terms of UPT):

$$K_{tra} = \frac{P_e}{B} \geq 1, \quad (7)$$

where P_e – profit of the transport enterprise from activity, UAH; C – transportation costs of the transport enterprise, UAH.

Quality criteria by the transportation duration in providing transport services by the “UPT – CT” system (from passenger’s point of view):

$$K_q^{tra} = \frac{t_{sts}}{t_{ats}} \leq 1. \quad (8)$$

The level of providing transport services by the “UPT – CT” system in terms of the passenger taking into account can be estimated as follows:

$$K_{pss} = \frac{(t_{sts} - t_{ats}) \cdot (B_{tra}^{UPT} + B_{tra}^{CT})}{T^{CT} + T^{UPT}}, \quad (9)$$

where $B_{tra}^{UPT} + B_{tra}^{CT}$ – cost of a 1-time passenger transportation by UPT and CT respectively, UAH; $T^{CT} + T^{UPT}$ – transportation tariff of one passenger by UPT and CT respectively, UAH.

Integrated efficiency criterion of the “UPT – CT” system on the basis of is determined as follows:

$$K_i = K_{mun} B_{mun} + K_{tra} B_{tra} + K_{pss} B_{pss}, \quad (10)$$

where W_{mun} , W_{tra} , W_{pss} – weight coefficients of efficiency criteria components.

The value of weight coefficients is determined taking into account the conditions of UPT and CT operation in the city using real statistics (it can be set by the value of determination coefficient R^2).

Also the functioning of UPT and CT should take into account the criteria for assessing their level of interaction, as well as providing quality service for the passenger. Further, a system of criteria for assessing the interaction level between UPT and CT should be proposed.

The railway and UPT interaction option should estimate the time spent by passengers on the trip. Moreover, it is necessary to take into account additional capital investment and operating costs caused by the development of a specific transfer station on the railway ring at the node, which will be carried out in further scientific researches.

5 Conclusions

The results of observations on the carriage of passengers in large cities testify to the following:

- there is a regularity of the influence of the city size on costs of citizens for their transportation (the greater the city, the more time spent on travel to the city and from the suburban area to the city;
- assessment of the population transport service level should be carried out according to the criterion of total transportation time, which varies significantly in different cities due to differences in the industrial structure of these cities;
- passengers use all available UPT modes in intra-city transportation of large cities;
- passengers in most cases use two transport modes (railway or bus and one UPT mode) to travel from a suburban area to the city;
- cultural and domestic movements within the territory of a large city are very complex, which depends on numerous factors and, above all, on the location and purpose of cultural and community establishments.

The above mentioned factors affecting the passenger transportation quality in large cities and necessary priority tasks for its increase influence on the economic justification of volumes and direction of investment in the urban passenger transport development.

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