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IMPROVEMENT OF THE TRANSPORT-TRANSFER HUBS OPERATION DURING MULTIMODAL PASSENGER TRANSPORTATION WITH THE PARTICIPATION OF THE RAILWAYS AND MOTOR TRANSPORT

The article proposes to improve the technology of multimodal railway passenger transportation with the participation of the motor transport by coordinating the schedule of traffic of all types of transport. Harmonization of the schedule is carried out under conditions of transport-transfer hub applying modeling of passenger traffic in the process of interaction of various kinds of transport. This allowed to rationalize the capacity of vehicles, reduce the waiting time for passengers by 30% at the points of transfer, and reduce the requirements for the throughput and processing capacity of the transport-transfer hubs.

It is established that to systematize and optimize the routes of complex passenger traffic it is necessary to establish a systematic collection of information about passenger traffic using modern means of computer equipment, communication and satellite navigation. This will allow the creation of a multimodal technology for the operation of the passenger transportation network in suburban and interurban routes with the participation of railways and motor transport. In its turn, this technology should be based on the ideology of a "single ticket" and a comprehensive liability for compliance with the conditions of passenger transportation.

The calculations made for conditions of the transport and transfer center of the city Dnipro gave an assessment of the economic effect at the level of 3.2 million UAH in a year when the load on transport infrastructure is reduced by 9.2%. This will facilitate the creation of multimodal passenger transport operators and the attractiveness of the transport industry for investors.

Key words: *passenger transportation, railroad, bus transportation, transport-transfer hub, multimodal transport, single ticket, agreed schedule of traffic.*

Introduction. Operation of all types of transport is aimed at satisfaction of the needs of the regions of the country, that is why, the development of the passenger traffic on the railway transport requires the solution of the problem dealing with the implementation of complex transport facilities with the corresponding level of service [2]. Nowadays the transport infrastructure of the country requires reformation, it can be achieved as a result of the renovation of the commuting hubs, stations and railway rolling stock, it is necessary to make capital investment in technical and technological components of the passenger transportation.

Problem set up and its importance. Organization of passenger transportation is performed by various types of communication (international, long-distance traffic, regional, suburban, Intercity traffic) and by the corresponding level of service during the provision of the main service (business-class, economy-class, etc.). But the tasks of the rational organization of the commuting hub operation, means of travel documents selling, comfortable transfers between the routes of different transport operators requires the application of the information technologies. Provision of modern services to the passengers, creation of a single information environment, coordination of the schedule of the transport facilities traffic, selling of the single travel documents are priority directions in the sphere of the passenger transportation.

Incomplextransportnetworksincaseofuncoordinatedoperationofcarriersthetransferfromonetypeoftransporttoanothercreatesnumerousproblemsfor the passengers – namely, arrangement of various travel documents, luggage registration difficulties, motion of the luggage between different transport facilities, all this leads in the travel time increase. On the other hand, demand on the greater part of transport directions can be provided only at the expense of using several types of transport, that is why, it is necessary to create the preconditions for high quality transportation system, involving several types of transport, applying the logistic technology of multimodal passenger transportation.

Analysis of the research and publications. Application of the logistic principle of passenger transportations, management, forecast and control over the passengers and trains traffic, creation of the smart information environment in the transport systems [3, 5, 8] – it is one of the main directions in the studies, carried out by our researches.

Station complexes on railway and other types of transport are often transformed into multifunctional commuting hubs, which provide convenient and safe transfer of the passengers [4, 5]. For rational passenger traffic in the commuting hub it is suggested to increase the level of the information support [3, 6, 9]. This enables to take into account the characteristic features of the multimodal technology of passenger transportation [8, 10], by means of the coordination of the traffic of the passenger transportation facilities.

The process of the creation of mathematical optimization models or synchronization of the schedules of the transport facilities traffic in the network is described in the studies of many scientists. For instance, for bus transportation the mathematical model of the synchronization of the linear integer programming is used [13]. As the most frequent case is the interaction of the transport facilities in the systems with one commuting hub, the problem of matching is solved by means of the corresponding system of Kolmogorov equations [14], applying the decomposition theory by means of the minimization of the efficiency function of the weighted number of the delayed requirement [12] or using «singedevice» methods with the reserve maximization criteria [11].

The aim of the article is study and improvement of the conditions to be created at the commuting hub for the formation of the efficient multimodal passenger transportation with the participation of the railways and autotransport according to the single schedule.

Main part. Large-scale realization of the passenger traffic with the participation of several type of transport is blocked by the practically complete lack of the legal-normative acts, regulating this sphere. In accordance with [2] «multimodal transportation – it is a sort of the transportation, realized by two or more types of transport by a single transport document on the interstate or international communication». The important role in the organization of such communication is played by the operator of multimodal traffic – «any person, including forwarding agent, who signs the contract for multimodal transportation and assume obligations by this contract as the carrier and forwarding agent» [2]. Nowadays such operator can be railway carrier according to the requirements of the article 913 [1]. Passenger transportation contract in the direct, mixed communication must become independent kind of the transportation contract and will regulate the process of the passenger transportation process by a single travel document. The complexity of the situation is explained by the different technological level of each type of transportation, that is why, there exists the objective complexity in meeting the requirements of the passenger by one type of transport. Thus, according to the article 913 [1] all the carriers (initial and the following) distribute among themselves the obligations, regarding the transport of the passenger, his baggage and provide safe transfer from one kind of transport to another.

Multimodal transportation in passenger communication – it is transportation of the passengers in one separately taken direction by the transport facilities of one or several carriers on the base of logistic principles [4]. This transportation is based on the coordinated integrated schedule of the traffic of the involved transport facilities, the most widely used variant now is the railway transportation and bus transportation. That is why, the integrated schedule of the transport facilities traffic must include technological time for the processing of trains, carriages and buses, transfer of the passenger as well as reserve technological time, taking into account the waiting for the transport facilities at the transfer point.

The improved classification of the main types of the passengers transfers with the participation of the railway transport is shown in Fig. 1.

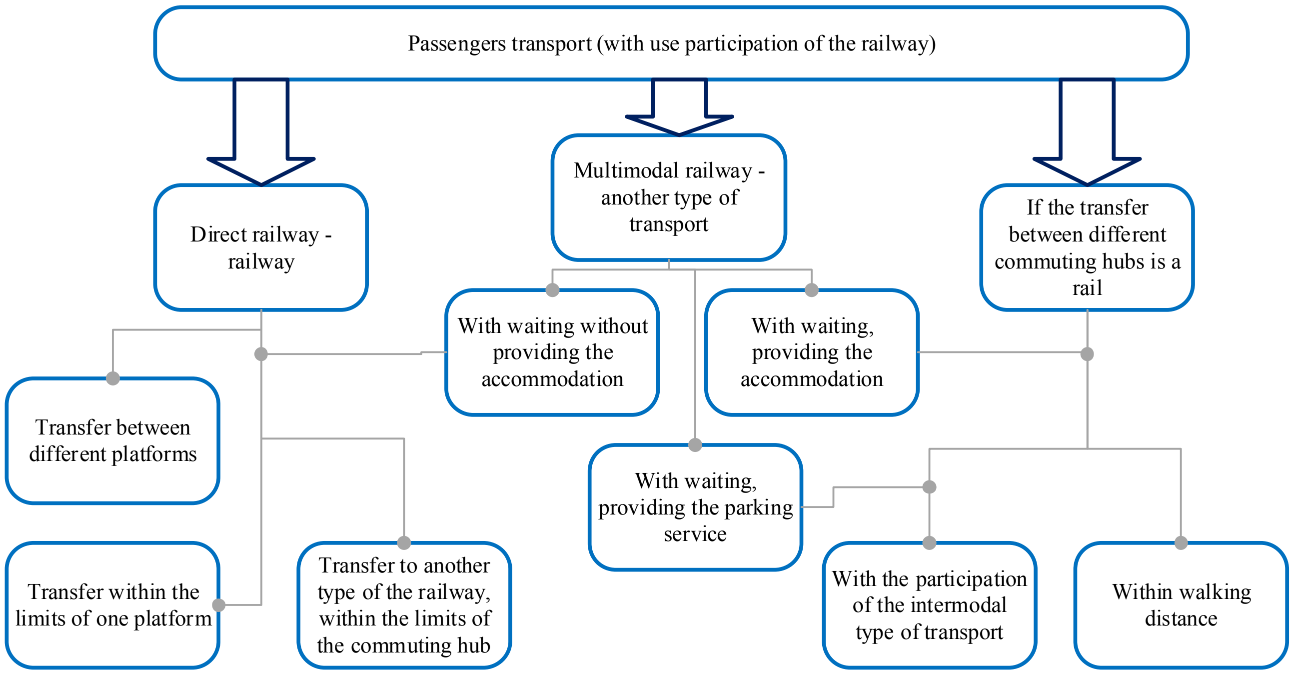


Fig. 1. Main types of passengers transfers in case of the railway transport participation

As the testing area of the research the large settlement – city Dnipro and its railway and bus stations was selected (Fig. 2), it was considered as the commuting hub of the multimodal transportation. The characteristic feature and stable trend for the conditions of the commuting hub Dnipro is the transfer to the other type of transport (long-distance coach) on the other commuting hub without intermediate means of the transfer within the walking distance. It creates the preconditions for the application of the multimodal technologies of the transportation by the «single ticket» by the railway and automobile transport.

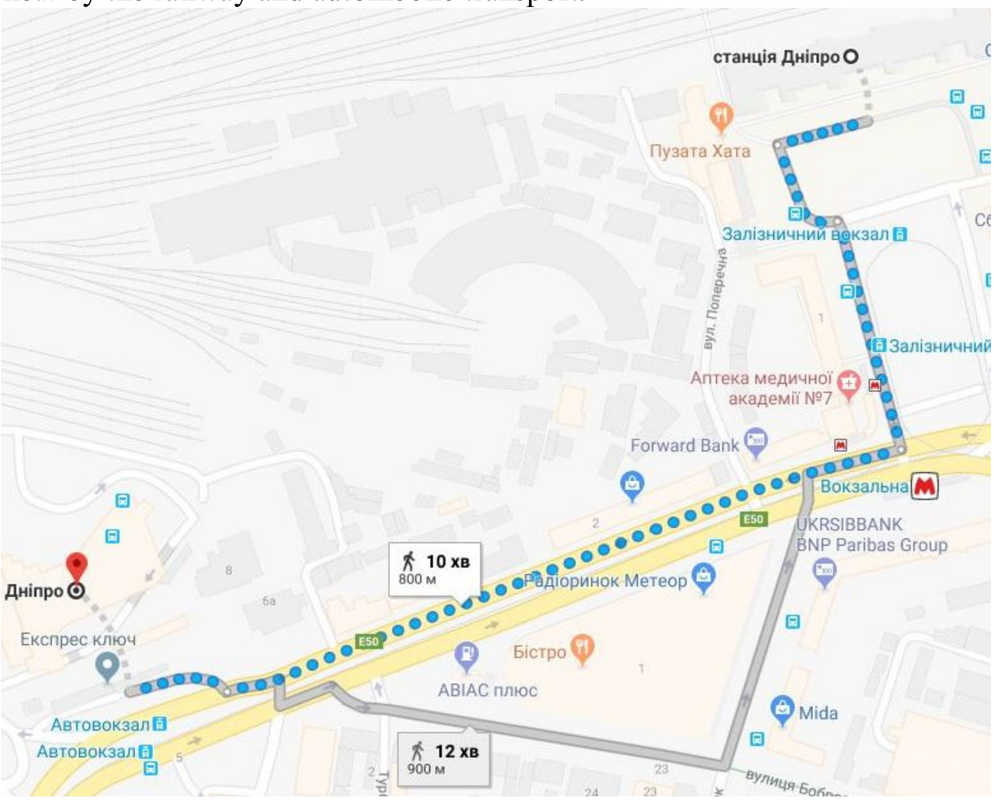


Fig. 2. Scheme of the location of the main railway and bus stations in the commuting hub Dnipro

The realization of the coordinated traffic schedules of the transport facilities, which are the part of the multimodal passenger route, requires taking into consideration the characteristic features of passengers transfer and provides certain technological measures aimed at the reduction of the idle time and improvement of the transfer convenience. Fig. 3 shows structure-logic schemes of the transfer from the railway transport to the buses (Fig. 3a), from the buses to trains (Fig. 3b). Portions of the passenger flow between the separate sections of the transfer are determined by the expert method.

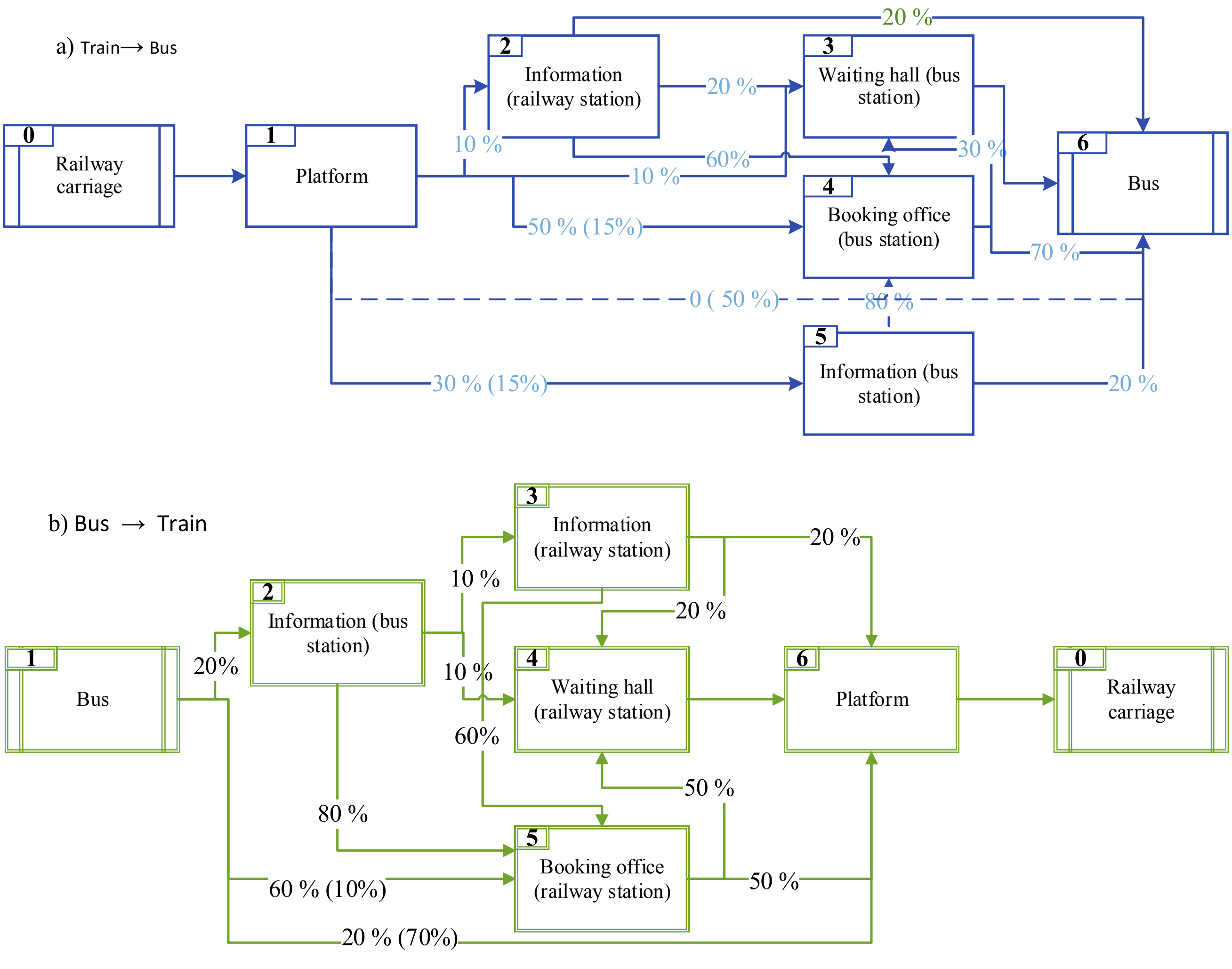


Fig. 3. Structural-logical schemes of the passengers flow distribution m the transfer with the participation of the railway transport and buses

In the conditions of the transport hub Dnipro the traffic of the passengers from the bus station to the railway station and in the reverse direction is complicated, that increases the time for the transfer τ_{trans} – walking route is approximately 800 m (Fig. 1), that contradicts the requirements of the existing regulatory acts and construction norms, which recommend maximum distance of the walking transfer not longer than 400 m.

That is why, at the first stage for the convenience of the orientation it is suggested to install the in formation sings with the indication of the direction on the way, improve the quality of the roadway, stripe the road, create the tactile strips for the weak-sighted people (Fig. 3).For the information of the passengers it is recommended to use audiovisual advertising on both stations and on the screens of the Intercity trains 20, 10 and 5 min before the arrival in the city of Dnipro.

At the second stage it is envisaged to use the city transport with the provision of the free travel between the stations if rail way and bus tickets are available. Now it is the tram of route №

11, work schedule from 5:30 to 23:36 and «floating» interval of motion 2…7 min. during the day. At the same time it suggested to implement the service of the baggage delivery between the stations. Further it is possible to use low floor buses or electrobuses, which are envisaged to be used in the «shuttle-bus» mode.

At the third stage it is planned to create the single commuting hub by means of uniting railway and bus stations, by means of constructing the under ground walkways, equipped with the rolling stairs, lifts for the handicapped people and connected with the subway.

The procedure of «sectorization» of the railway platform with the identification of the zones where it is expedient to perform the transfer provides the reduction of the transfer duration. In case of walking distance the duration of the transfer τ_{trans} must take into account the time for passengers passage and buying tickets, which is typical for the commuting hub of the Dnipro city.With the account of the recommendations [8], the traffic schedule of every transport facility must meet the requirements of the simultaneous arrival at the commuting hub of the involved transport means (train, bus)and characteristic features of the passenger traffic processing if the technology of an “entire ticket” is available.

For the economic assessment of the efficiency of the commuting hub operation with the participation of the railway transport it is suggested to use as the assessment criterion for the solution of the problem of passenger transport requirements the cost of 1 passenger/hr of the complete time expenditures per multimodal travel.

Characteristic features for the conditions of the commuting hub «railway station – bus station» Dnipro are:

- transfer to another long distance train (bus);
- transfer to another short distance train (bus);
- transfer to urban transport and subway;
- transfer to personal motor vehicle;
- motion of the passenger from the train carriage (bus) to the booking offices or to the hotel.

The convenience of the transfer in the commuting hub influences greatly the passenger’s decision-making about the realization of the multimodal travel. The developed structural-logic schemes of passenger traffic distribution while performing the transfer with the participation of the railway transport on the buses (Fig. 3) give the possibility of the quantitative assessment of the multimodal travel attractiveness.

The transfer process from the railway transport to the buses will be considered to be the Markov process, that is why, this technology of the commuting hub operation (Fig. 3a) can be written in the form of the system of Kolmogorov differential equations:

$$\begin{cases} \frac{dp_2(t)}{dt} = -(\lambda_{23} + \lambda_{24} + \lambda_{26})p_2(t) + \lambda_{12}p_1(t) \\ \frac{dp_3(t)}{dt} = -\lambda_{36}p_3(t) + \lambda_{13}p_1(t) + \lambda_{23}p_2(t) + \lambda_{43}p_4(t) \\ \frac{dp_4(t)}{dt} = -(\lambda_{43}+\lambda_{46})p_4(t) + \lambda_{14}p_1(t) + \lambda_{24}p_2(t) + \lambda_{54}p_5(t) \\ \frac{dp_5(t)}{dt} = -(\lambda_{54} + \lambda_{56})p_5(t) + \lambda_{15}p_1(t) \\ \frac{dp_6(t)}{dt} = -p_6(t) + \lambda_{26}p_2(t) + \lambda_{36}p_3(t) + \lambda_{46}p_6(t) + \lambda_{56}p_5(t) \\ p_1 + p_2 + p_3 + p_4 + p_5 + p_6 = 1 \end{cases}, \quad (1)$$

where λ_{ab} – is the intensity of the passenger traffic from a^{th} technological operation to the operation b; $p_i(t)$ – is the probability function of the system occurrence in the i^{th} state.

Characteristic feature of the passenger traffic study is that for the system (1) total intensities of the flows, arriving from each state of the technological element, equal the total flow (in relative units equal 1). That is why, for the technological scheme (Fig. 3a) in the conditions of the commuting hub Dnipro the system (1) will have the form:

$$\begin{cases} \frac{dp_2(t)}{dt} = -p_2(t) + 0.2p_1(t) \\ \frac{dp_3(t)}{dt} = -p_3(t) + 0.1p_1(t) + 0.2p_2(t) + 0.6p_4(t) \\ \frac{dp_4(t)}{dt} = -p_4(t) + 0.5p_1(t) + 0.6p_2(t) + 0.8p_5(t) \\ \frac{dp_5(t)}{dt} = -p_5(t) + 0.3p_1(t) \\ \frac{dp_6(t)}{dt} = -p_6(t) + 0.2p_2(t) + p_3(t) + 0.7p_6(t) + 0.2p_5(t) \\ p_1 + p_2 + p_3 + p_4 + p_5 + p_6 = 1 \end{cases} . \quad (2)$$

For the search of the final state probabilities the system of equations (2) is converted into the system of equations in the matrix form:

$$\begin{bmatrix} -0.2p_1 + p_2 + 0p_3 + 0p_4 + 0p_5 + 0p_6 \\ -0.1p_1 - 0.2p_2 + p_3 + 0.6p_4 + 0p_5 + 0p_6 \\ -0.5p_1 - 0.6p_2 + 0p_3 + p_4 - 0.8p_5 + 0p_6 \\ -0.3p_1 + 0p_2 + 0p_3 + 0p_4 + p_5 + 0p_6 \\ 0p_1 - 0.2p_2 - p_3 - 0.7p_4 - 0.2p_5 + p_6 \\ p_1 + p_2 + p_3 + p_4 + p_5 + p_6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}. \quad (3)$$

Final probabilities for the existing conditions of the application of the technological scheme of the transfer from the railway transport to the buses will be equal $\bar{p}_1 = 0.281, \bar{p}_2 = 0.028, \bar{p}_3 = 0.101, \bar{p}_4 = 0.225, \bar{p}_5 = 0.084, \bar{p}_6 = 0.281$. The assessment of the necessary hourly processing capacity B_i of each technological element of the transfer is evaluated as the product $\bar{p}_i\eta i$, where ηi is quantitative evaluation of the passenger flow during one hour in «rush-hour» period.

In order to study the demand and determination of the rational technology of the organization of multimodal passenger transportations in the conditions of the commuting hub Dnipro general passenger traffic and its main directions are investigated (Fig. 4). The analysis, carried out, shows that the main direction in the long distance traffic is Kyiv, and in all the directions only small difference between the number of arriving and departing passengers during the year is observed. This is proved by the data of the routes of the rapid trains of the Intercity type (Fig. 5).

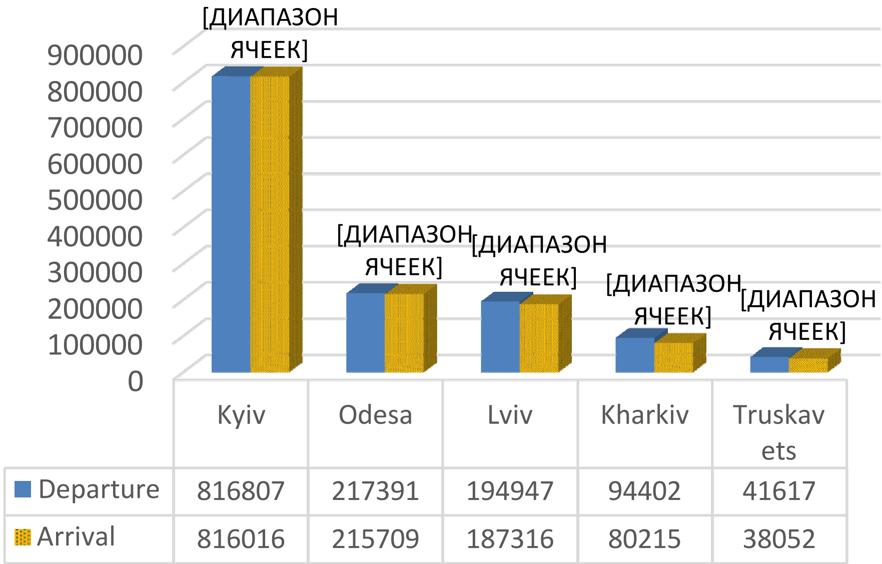


Fig. 4. Main directions of the passenger traffic in the commuting hub of the railway station Dnipro (data, presented by the joint-stock company «Ukrrailway»), passengers /year

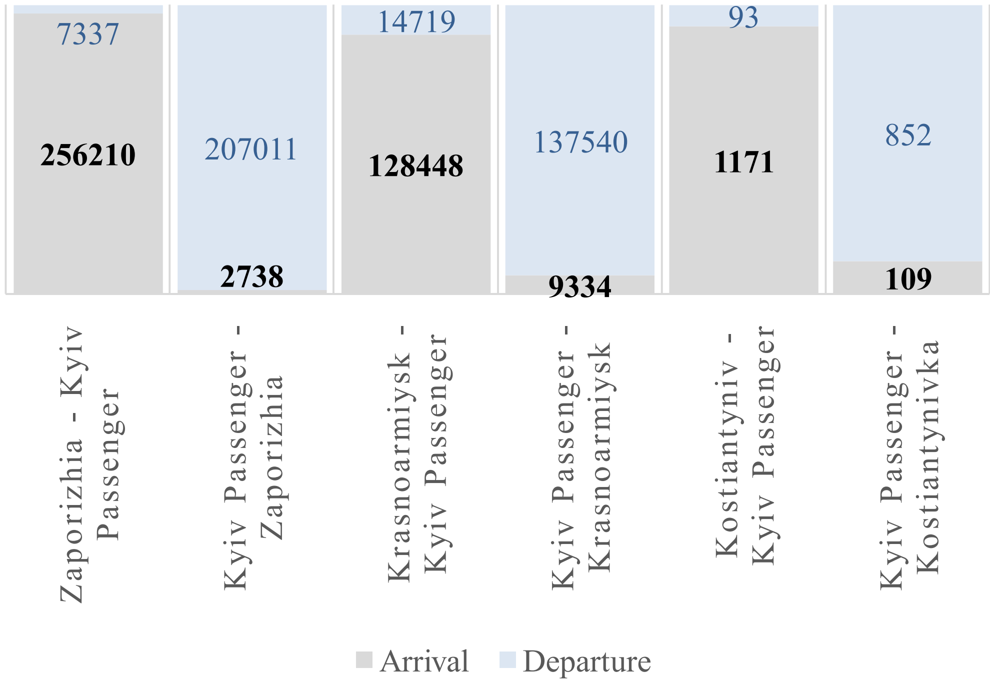


Fig. 5. Main directions of passenger traffic at the commuting hub of the train station Dnipro on the routes of the Intercity trains in 2018, passengers /year

The formation of the adjusted schedule is carried out, taking into account the hourly day irregularity of the passenger traffic. The results of the study of the hourly variation of the long distance passenger traffic in the community hub Dnipro, given in Fig. 6, showed the considerable irregularity in the distribution of the index in time. The character of the irregularity is close to the irregularity in suburban trains ([8] and Fig. 8) and in the bus station of the commuting hub Dnipro (Fig. 7) with the availability of morning (on arrival) and evening (on departure) peak periods. The comparison of the results of the passenger traffic distribution on the commuting hub Dnipro enabled to determine that the highest probability of the demand for multimodal service on the side of the passengers will be observed from 06 o'clock a. m. to 10 a. m.: in this period the arrival of the passengers is up to 45 % of the daily volume by the railway and up to 33% – by buses. Thus, the analysis proves the necessity of mode organization of the multimodal passenger traffic in the first half of the day (from 06 a. m. till 10 a. m.) with the prevailing orientation on the arriving passengers and in the second half of the day (from 19 p. m. till 22 p. m.) – on the departing passengers.

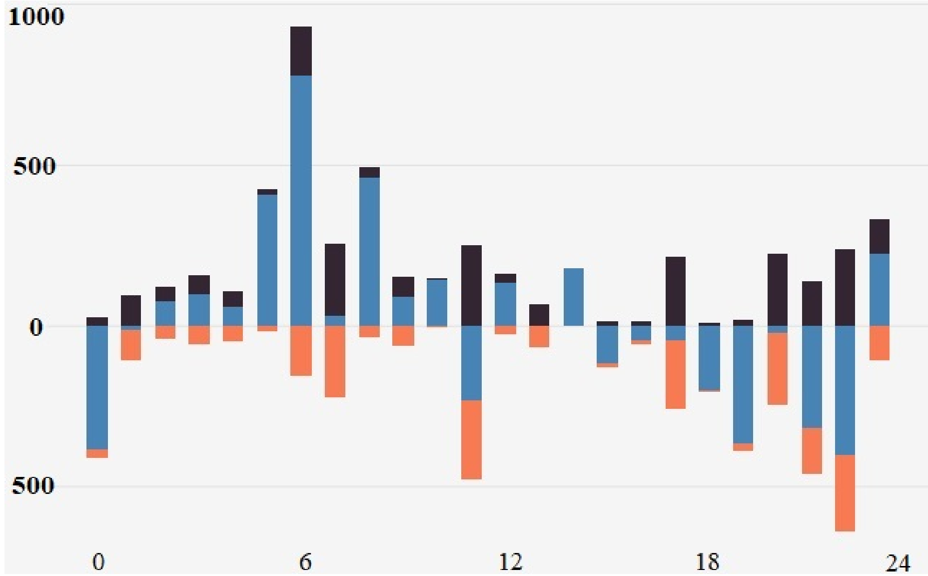


Fig. 6. Irregularity of the long distance passenger traffic in the commuting hub of Dnipro, passengers/hr. (data of the Ukrainian railroads)

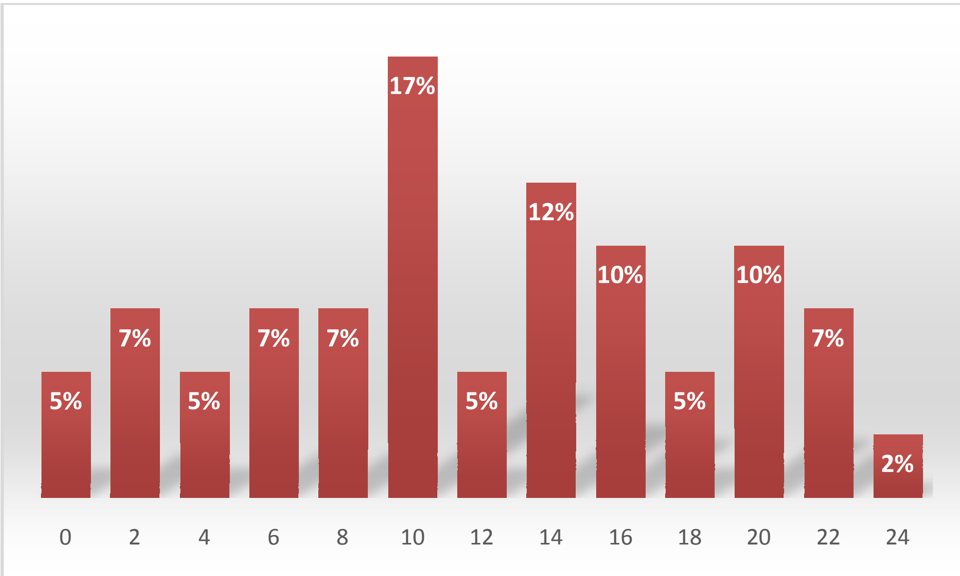


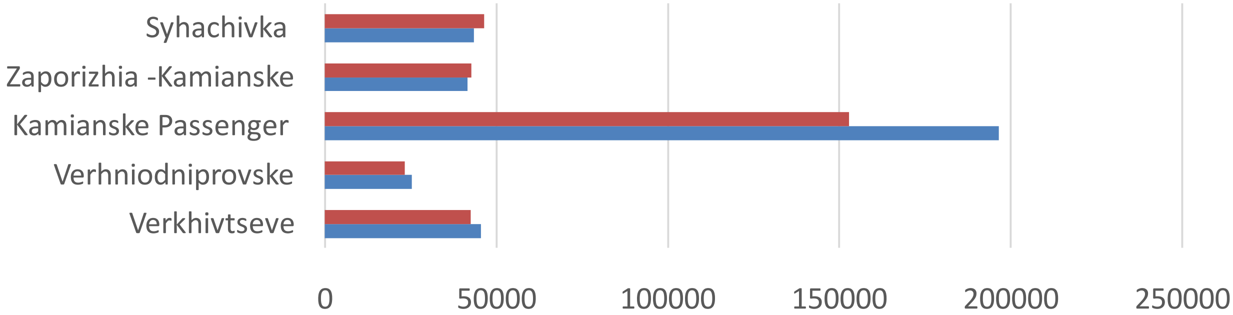
Fig. 7. Irregularityofthepassenger traffic(departure) at the bus station of the community hub Dnipro ,passengers/hr. (dataofPJSC "DOPAS")

Further studies of the possibilities of involving the part of the local passengers into the multimodal transfer is carried out on the example of the most important direction of the local passenger traffic in the commuting hub Dnipro in the morning rush hour interval 6…10 a. m., it is the most complex interval from the point of view of the schedule coordination (Fig. 8). As a result of the week irregularity of the long distance and suburban passenger traffic specific part of the working day (the day off) should be taken into account, separately for summer and winter period of the year, and availability of the inter year irregularity. Mathematical expectation of the average dayly amount of passengers at the commuting hub Dnipro in long distance communication was N_{ld}=4244 passenger./day, in the suburban communication –N_{sub}=11170 passenger./day, in bus communication – N_{bus}= 2050 passenger./day variation coefficients were ν_{ld}=0.033, ν_{sub}=0.027 and ν_{bus}=0.138.

The assessment of the passenger traffic during an hour in «rush hour» period is carried out as:

$$\eta_{\mathrm{i}} = \frac{1}{24} N_i (1 + \nu_i). \tag{4}$$

Thus, the most probable intensity of the passenger traffic in the commuting hub Dnipro in long distance communication was η_{ld}=182.7 passenger./hr, in suburban communication – η_{sub}=478.0 passenger./hr, bus communication – η_{bus} = 97.2 passenger./hr.



	Verkhivtseve	Verhniodniprovske	Kamianske Passenger	Zaporizhia - Kamianske	Syhachivka
2018	42519	23337	152754	42675	46529
2017	45527	25420	196470	41658	43498

Fig. 8. Distribution of the most important urban passenger traffic in the commuting hub Dnipro, passenger/year

There exists characteristic feature which greatly increases the time, needed for the transfer: during the transfer «train → bus» practically there is no passenger traffic, directed to the bus. During the transfer «bus → train» the traffic directly to the train platform exists but it is not considerable. This characteristic feature is selected as one of the directions, aimed at the improvement of the passengers transfer technology in the process of the organization of multimodal communication in the commuting hub Dnipro, applying electronic facilities for the automatic selling of the tickets (payment-information self-service terminals).

Taking into account the intensity of η_{ld} in the conditions of the commuting hub Dnipro, to provide the transfer between the railway station and bus station the hourly estimated capacity is needed, the results are presented in Table 1.

The transfer technology, improved with the account of the above-mentioned measures during of multimodal traffic will lead to the changes in the system of equations (2) for the intensity and directions of the passenger traffic: $\lambda_{14} = 0.25, \lambda_{15} = 0.15, \lambda_{16} = 0.5$ .Similarly the final probabilities and the required processing capacity of the elements of the commuting hub Dnipro are shown in Table 1.

Table 1

Characteristics of the technological elements of the transfer scheme from the railway transport to the buses (conditions of the commuting hub Dnipro)

Technological index	Information service of the railway	Waiting room of the bus station	Booking office of the bus station	Information service of the bus station	Total
Existing technology					
Final probabilityp̅i	0.028	0.101	0.225	0.084	-
Required estimated capacity Bi, passenger/hour.	5.12	18.45	41.11	15.35	80.03
Multimodal technology					
Final probabilityp̅i	0.033	0.082	0.142	0.05	-
Required estimated capacity Bi, passenger./hour.	6.03	15.0	25.94	9.14	56.11
Changes of the estimated capacity	+17.8%	-17.6%	-36.9%	-40.5%	-30% (23.92 passenger/hour)

Similarly, according to the structural-logic scheme of the transfer from the buses to the trains (Fig. 3b) the indices of the technological elements of the transfer scheme are calculated in the conditions of the commuting hub Dnipro (Table 2). In general, in the conditions of the commuting hub Dnipro due to the introduction of the multimodal scheme of the passenger transportation general needed processing capacity of the hub decreases by ΔB_i = 40.24 passenger/hour (by 14.4% from the existing).

Table2

Characteristic of the technological elements of the transfer scheme from the buses to railway transport (conditions of the commuting hub Dnipro)

Technological index	Information service of the bus station	Information service of the railway	Waiting room of the railway station	Booking office of the railway	Total
Existing technology					
Final probabilityp̅i	0.059	0.006	0.120	0.227	-
Required processing capacity, Bi, passenger./hour	5.73	0.58	11.66	22.06	40.03
Multimodal technology					
Final probability p̅i	0.075	0.007	0.060	0.102	-
Required processing capacity passenger /hour	7.29	0.68	5.83	9.91	23.71
Changes of the required capacity	+27.2%	+17.2%	-50.0%	-55.1%	-40.8% (16.32 pas/senger/hour)

The efficiency index of the multimodal passenger transportation can be expressed by the total expenses of the passenger, taking into account the total time of the travel T:

$$\mathrm{T} = 2\, t_{\text{пк}} + \sum_{i,j}\left(\frac{60\, L_{ij}}{v_{\text{м}i}} + \tau_{ij} + \frac{1}{2}\left[I_{\text{р}} + \frac{\sigma_{I\text{р}}^{2}}{I_{\text{р}}}\right]\right) \quad (5)$$

where $t_{\text{пк}}$ – is the time, that characterizes the accessibility of the commuting hub at the beginning of the travel and at its completion.

The experience of the developed countries shows that the commuting hub has satisfactory accessibility if from 75 % of the points in a large city it is possible to reach the commuting hub during $t_{пк} \leq 45$ min.
Lij – is the distance of the passenger travel by each kind of transport of the i^{th} and j^{th} routes, km. For the determination of the average distance of the travel Lij for the commuting hub Dnipro it is possible to use the statistic data of the joint-stock company «Ukrainian railway roads» (Fig. 4); $v_{мij}$ – route speed of the transportation by the i^{th} transport in the given direction, km/hrs. τij – target duration of the passengers transfer operation in the hub between the transport facilities, min. I_m– average traffic interval between the transport facilities, min; σ^2_{Ip}– dispersion of the transport traffic interval.

The transition to the agreed schedule of the railway and bus transport will provide the equilibrium in the usage of the seats in all transport means in case of multimodal transportation according to the forecast passenger traffic. This enables to use rationally the capacity of the rapid trains, electric trains, buses and reduce the passengers waiting time in the commuting hub up to 30%. According to [8] the analysis of the traffic intervals between the local trains at the main commuting hubs of the domestic railway transport showed that the schedules with traffic interval of I_p 8, 24 and 40 min between the trains are typical. That is why, when developing the coordinated traffic schedule of the multimodal passenger traffic maximal duration is assumed to be the duration connected with the arrival of the next transport facility T_{maxi} not more than 40 min. By the same value maximal interval of the possible correction of the local traffic schedule is assumed. Decision making regarding the development of the agreed schedule of the passenger traffic of the several kinds of transport and its assessment is carried out according to the specially developed procedure. Information, necessary for the analysis of the variants of the processing of the trains of different categories and buses can be obtained from the automated control system of passenger traffic of Ukrainian Railway and the dispatching center of the bus terminal, which is suggested to use for the connection with the railway transport. The availability of such data enables to prepare in time for the processing of the transport means, rationally use transport infrastructure, rapidly correct the traffic schedule, inform clients about the possibility of traveling with the transfer and in perspective – about the buy of a single ticket.

Conclusion. The technology of the multimodal railway passenger traffic with the participation of automobile transport, based on the agreed traffic schedule of all kinds of transport is suggested. The coordination of the schedule is realized in the conditions of the commuting hub, applying passenger traffic modeling in the process of the interaction of different kinds of transport. This will enable to optimize the capacity of the trains and buses, reduce by 30% the waiting time of the passengers in the transfer points, reduce the demands to carrying capacity of the commuting hub elements. The calculations, carried out for the conditions of the commuting hub of Dnipro it became possible to reduce the load on the transport infrastructure by 14.4%

It is determined that for the planning and optimization of the routes of the complex passenger traffic it is necessary to organize systematic collection of the information, regarding the passenger traffic by means of using of modern computing facilities, communication means and satellite navigation. This will allow to create multimodal technology of functioning the network of the passenger traffic at local and intercity routes, with the participation of railway transport and automobile transport. In its turn, this technology must be based on the concept of the «entire ticket» and comprehensive responsibility for the observing of the conditions of passenger transportation. This will promote the creation of the operators of multimodal passenger transportation and attractiveness of the transport branch for the investors.

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