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Influence of the Seasonal Factor on the Long-Distance Passenger Correspondence

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Abstract: The process of transportation of passengers on inter-regional routes of general use is investigated in the article. It is established that long-distance passenger transport correspondences have fluctuations that are observed in time. Such variations can be attributed to changes in the volumes or directions of passenger transportation during the day, which are described by many researchers. In addition to the above, it is known that in the system of intercity passenger transport it is possible to observe the existence of processes for the formation of predicted changes when considering the period of transportation during the week. In this case, there is a corresponding change in the characteristics of volumes and directions of passenger correspondence on the days of the week. Similar fluctuations also occur in the consideration of the state of correspondence during the year. Intercity passenger transport systems have as their objective the functioning of a qualitative transport system and safe satisfaction of the needs for the movement of people. The presence of a stable route network scheme can be considered one of the requirements to the quality of passenger service. This leads to the need to take into account the influence of the environment of the functioning of the system in the organization of its functioning, subject to the restrictions.

Keywords: Transport System, Gravity Model, Seasonal Fluctuations of Transport Correspondences, Long-Distance Transportation

1. Introduction

In modern approaches to the organization of the provision of passenger transportation services, priority is given to improving the quality of transport services, making fundamental decisions regarding changes in the elements of the transport system itself. Such elements of long-distance route transportation system include the schedule, the number of vehicles, the type of rolling stock, the cost of transportation and the speed of connection. By changing certain characteristics of the transport process, it is possible to adjust the system of long-distance route passenger transportation.

According to the chosen approach, the following measures will be applied to the system: change in input parameters from the environment of its existence associated with seasonal fluctuations in the population's demand for transport services. This should secure the process of managing the long distance intercity transportation system to ensure the passengers' needs for travel, taking into account fluctuations in their correspondences.

Taking into account seasonal changes in the parameters entering the system from the environment of its functioning, it is determined to change the parameters of the elements of the transport system. This should lead to the provision of an output parameter from the system in such a way that secures the satisfaction requirements, household, production and socio-economic needs of passengers in transit.

Simultaneously, the adoption of managerial decisions on changing the parameters of the system of long-distance transportion affects the effectiveness of the operation of the system itself. Thus, there are limitations on making managerial decisions to ensure the simultaneous satisfaction of the needs of passengers and maintaining a satisfactory level of functioning of the system over time.

2. Object of Study

The object of the study is a modern long-distance passenger transport system in Ukraine. One of the most problematic areas is the study of the actual values of long-distance correspondences, which consists in the receipt of an undefined approach to justifying seasonal changes in the parameters of long-distance passenger transport system elements. The received knowledge gives an opportunity in thorough application of the considered method for the calculations of correspondence between cities in view of characteristic seasonal fluctuations of demand.

3. Purpose and Objectives of the Study

The aim of the work is to simulate the effect of the seasonality factor on long-distance passenger correspondences by formalizing an adequate function of gravity. Formalization of the parameters of the components of the attraction function will lead to the possibility of calculating the corresponding parameters of long-distance passenger correspondences within the investigated system.

To achieve the goal set in the work, the following tasks are supposed to be solved:

1. Set the seasonal parameters of the components of the attraction function for passenger transport correspondence between a set of cities.
2. Compare the theoretical and experimental data obtained.

4. Analysis of Literature Data

The question of calculating transport correspondence between settlements is that until now, the regularities of the parameters of passenger transport systems have not been studied at a sufficient level.

The authors of work [1] Andronov A., & Santalova D. (2009) proposed a model (1) for predicting the passenger flow between different geographical points (cities). Unknown parameters are estimated using aggregated data, when information is provided only about the number of passengers of each city. As an effective evaluation criterion a weighted sum of residual areas is used:

$$H_{\text{в}i,j} = \frac{\left(H_{mi} H_{mj}\right)^{\theta}}{\left(l_{i,j}\right)^{\tau}} \exp\left(a + \left(c(i) + c(j)\right) P_{заг} + g(i,j)\gamma_c + V_{i,j}\right), \quad (1)$$

where: *Нві,j* – the number of departures from the transport area i to the j area for the estimated period of time;

a, Рзаг = (Рзаг 1 Рзаг 2 … Рзаг m) и γс = (γс 1 γс 2 … γс m) – unknown regression parameters;

Рзаг - general mobility of the population;

γс– the average rate of capacity utilization;

c (i) = (ci,j … ci,m) and g (I,l) = (ci,1 cj,1 … ci,m cj,m) – m data sets;

Vi,j – are independent and identically distributed random variables with zero mean and unknown variance σ2;

li,j – distance between areas i and j;

Hmi, Hmj – the number of residents in the areas i and j respectively.

The disadvantage of this method is the neglect of seasonal fluctuations of correspondences. This prevents its use for solving the study objectives.

The authors Baik, H., Trani, A., Hinze, N., Swingle, H., Ashiabor, S., & Seshadri, A. (2008) [2] proposed a model (2) of the analysis of transport systems, which uses the «four-step» simulation process of transport systems for calculating correspondence, allocating travel and selecting a mode of travel for each point of arrival and departure. The model includes a graphical user interface with the ability of usage of geographical information systems. Potential application areas of the model are nationwide studies of the impact of transport policies and transport technologies.

$$H_{ij} = H_{\text{в}\,i} \left[\frac{H_{\text{п}\,j} F_{\text{т}\,ij} F_{ij}}{\sum_j H_{\text{п}\,j} F_{\text{т}\,ij} F_{ij}} \right], \quad (2)$$

where: H_{ij} – number of trips from area *i* to area *j*;

$H_{\text{в}\,i}$ – the number of departures from the transport area *i* for the estimated period of time;

$H_{\text{п}\,j}$ – the number of arrivals in the transport area *j* for the estimated period of time;

$F_{\text{т}\,ij}$ – travel resistance factor;

F_{ij} – factor of socio-economic adaptation for the exchange of *ij*.

In this case, the authors do not take into account the features of the destination and departure points and seasonality of the characteristics of transport correspondence. However, the presence of a socio-economic correspondence between the calculation areas is taken into account.

Ibrahim Seedat in work (2007) [3] proposed to provide calculation of potential departures between cities i and j by means of the dependence (3)

$$H_{ij} = \left[\frac{P_i P_j}{L_{ij}^2} \right], \quad (3)$$

where L_{ij} – the distance between cities *i* and *j*;

P_i and P_j – the number of residents of the cities *i* and *j* respectively.

In this case, the authors do not take into account the features of the destination and departure points.

Similarly with the predecessors, the authors mention the travel resistance factor, but its definition has not been adequately disclosed.

In the work of the authors Terekhov, I., Ghosh, R., & Gollnick, V. (2015) [4], prediction of air passenger flows at the global level is determined using socio-economic aspects of the development of society. The method consists of two stages: forecasting the topology of the initial and final points of the demand network, forecasting the number of passengers on existing and new connections. In work, the attraction between cities is represented through an adapted model of gravity:

$$F_i = \frac{VVP_i * H_{mi} * VVP_j * H_{mj}}{\left(l_{ij} * T_{cepij}\right)^2}, \quad (4)$$

where: F_i – the attractiveness factor of the i- th district for expressing the number of potential passengers, which possibly came to the city i from the city j;

VVP_i, VVP_j – GDP of cities i and j respectively, in the pair x;

H_{mi}, H_{mj} – the number of residents of the cities i and j respectively;

T_{cep} – the average cost of air tickets between city i and city j.

Analogously to the approaches considered in the calculations, the authors Terekhov, I., Ghosh, R., & Gollnick, V. (2015) [4] determined the distance between regions i and j as a factor in reducing the number of potential passengers, which possibly came to city i from city j. At the same time, as an additional factor of resistance to the number of potential passengers, the average cost of air tickets between city i and city j is introduced.

In the work by Ata M Khan (2007) [5], the author proposed to calculate the passenger correspondence between cities using the classical gravitational model (5):

$$H_{ij} = H_{вi} H_{ni} d_{ij}, \quad (5)$$

where $H_{вi}$ – the number of departures from the city i;

H_{nj} – the number of arrivals in the city j;

d_{ij} – function of attraction from city i to city j.

The disadvantage of this method is accounting, as a factor of correspondence resistance, only the distance between cities i and j.

In the material by the authors Prasolenko A., Lobashov O., Galkin A. (2015) [6] it is proposed to provide surveys of available correspondence to establish the actual values of empirical constants, resistance factors, balancing coefficients and other calibration constants.

It can be noted that the authors of the works Grigorova T., Davidich Yu., Dolya V. (2015), Dolya, C. (2017) [7], [8], [9] proposed carrying out surveys of existing passenger correspondence to establish actual values in the equations proposed by them.

Yves Crozet proposed another method for calculating H_{ij}- potential correspondence between cities, which is given in equation (2009) [10].

$$H_{ij} = S_{ij} d_{ij}, \quad (6)$$

where S_{ij} – potential departure from city i to the city j.

At the same time, the author does not consider the components of the gravity function.

Nokandeh, M. M., Ghosh, I., & Chandra, S. in the work (2015) [11] proposed a relationship for the calculation of potential correspondence between cities i and j, in which it was proposed to consider the correspondence resistance factor as a complex function. The definition or components of this complex attraction function is not suggested. Joseph Schwieterman (2016) [12] prepared the distribution of correspondence between cities for workers and entertainment flows. The proposed approach by the named authors does not disclose the difference between the gravity function from point i to point j and the complex gravity function from point i to point j. The authors of the Borndörfer, R., Reuther, M., Schlechte, T., Waas, K., Weider, S. (2016) [13] and Tao Li (2016) [14], in their works proposed to conduct a survey of available correspondence between cities to calculate the calibration coefficients which they introduced in dependence.

5. Materials and Methods of Research

In order to establish the actual values of passenger traffic between cities in Ukraine, the following method was chosen: it consists in obtaining the relevant quantitative indicators from the records of the transfer services provided to passengers. These documents and materials include information from the system of selling bus and train tickets.

Figure 1 shows the proposed model of the transport network in Ukraine, taking into account connections of interregional significance.

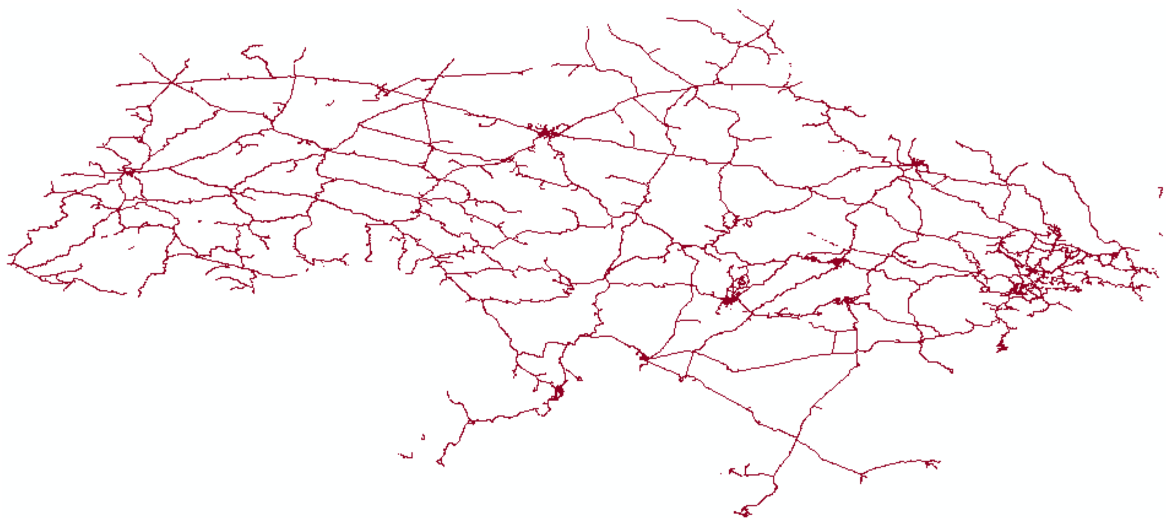

Figure 1. *Model of the transport network of Ukraine.*

Dependence (5) was chosen as a dependence for calculating the correspondence of passengers between cities from point i to point j. In our case, it is proposed to calculate the function of attraction of correspondence between cities by the following relationship:

$$d_{ij} = \frac{a}{L_{ij}^{x}}, \quad (8)$$

where a – empirical constant;

L_{ij} – the distance between cities i and j;

x – calibration coefficient.

Taking into account the dependence (8), equation (5) takes the following form:

$$H_{ij} = H_{\text{в}i} H_{ni} \frac{a}{L_{ij}^{x}}. \quad (9)$$

6. Results of Research of Parameters of Passenger Traffic Between Cities in Summer and Winter Transportation Times

To carry out potential correspondence calculations according to the dependence (7), the following value of the empirical constant was established - a: 1; 5, 35, 65, 95, 125 and 155. The calibration factor x in the calculations took the following quantitative indicators: 0.8; 1, 1.2; 1.4; 1.6; 1.8; 1.9 and 2.5. Potential correspondence between cities i and j has been calculated for all possible combinations between a and x. In accordance with the chosen values of the empirical constant and the calibration factor, potential correspondence between cities i and j was calculated for all possible combinations between a and x.

From the obtained data of actual quantitative indicators of potential correspondence between cities, there were 14 pairs of cities and correspondence between them were investigated. In turn, each of the selected variants of the pairs provided information about the correspondence of passengers between the cities in both directions. As the values of the distance between the cities i and j – L_{ij}, the previously calculated values from the matrix of shortest distances were taken. The obtained calculated values of H_{ij} – potential correspondence between cities i and j are summarized in Table 1.

Table 1. *Estimated and actual values of potential correspondence between the cities H_{ij} (thousand pass.) during summer transportation.*

№ s/n	№ of transport node of the (city) *i*	№ of transport node of the (city) *j*	Actual H_{ij}	H_{ij} for, a=1 x=-0,8	H_{ij} for, a=1 x=1,0	…	H_{ij} for, a=155 x=1,8	H_{ij} for, a=155 x=1,9	H_{ij} for, a=155 x=2,5
1	8	22	18,908	24,23	22,79	...	18,63	17,97	13,66
2	8	15	74,53	79,21	83,86	...	71,34	69,05	53,71
3	13	14	117,16	121,97	131,65	...	114,64	111,27	87,12
4	13	8	38,396	23,97	39,76	...	41,89	41,78	38,92
5	13	15	38,86	26,39	48,17	...	54,45	54,90	55,40
…	…	…	…	…	…	...	…	…	…
26	20	15	3,016	7,22	…	...	2,95	2,59	1,14
27	22	14	161,472	158,83	…	...	160,24	159,96	156,58
28	22	8	7,656	13,96	…	...	6,88	6,20	3,11

The agreement between the values of the calculated potential correspondence H_{ij} between cities i and j to the actual value of the correspondence of passengers (obtained as a result of the carried out research) is carried out according to the dependence (10). The obtained value ε – the deviation of the obtained calculated quantitative index from the actual one in percent makes it possible in the analysis of the quality of use of the combination of the value of the empirical constant – a and the value of the calibration coefficient – x.

$$\varepsilon' = \frac{\left| H_{ij} - H_{ij} \right|}{\mathrm{H_{ij}}}, \quad (10)$$

Table 2. *Deviation of calculated values of potential correspondence between cities in the summer time from the actual obtained one as a result of the conducted study in percent.*

№ s/n	№ of transport node of the (city) *i*	№ of transport node of the (city) *j*	έ for, a=1 та x=-0,8	έ for, a=1 x=1,0	…	έ for, a=155 x=1,6	έ for, a=155 x=1,8	έ for, a=155 x=1,9	έ for, a=155 x=2,5
1	8	22	0,28	0,21	…	0,05	0,01	0,05	0,28
2	8	15	0,06	0,13	…	0,01	0,04	0,07	0,28
3	13	14	0,04	0,12	…	0,03	0,02	0,05	0,26
4	13	8	0,38	0,04	…	0,09	0,09	0,09	0,01
5	13	15	0,32	0,24	…	0,37	0,40	0,41	0,43
…	…	…	…	…	…	…	…	…	…
26	20	15	5,40	1,39	…	0,25	0,02	0,14	0,62
27	22	14	0,32	0,02	…	0,01	0,01	0,01	0,03
28	22	8	2,29	0,82	…	0,10	0,10	0,19	0,59
$έ_{cep}$			2,14	0,59	…	0,11	0,09	0,15	0,41

The obtained value makes it possible to estimate the deviation of the calculated quantitative indices from the actual ones in percent when applying a certain combination of values of the empirical constant – a and the value of the calibration coefficient – x. The obtained calculation results provided an opportunity to establish empirically the parameters of the attraction function for passenger correspondence between cities during summer and winter periods, at which the calculated values of potential correspondence are close to the actual ones.

With the quantitative indices available in each calculation a, x and $\acute{\varepsilon}_{cep}$ we obtain the possibility of constructing the surface of the dependence of $\acute{\varepsilon}_{cep}$ for the variables a and x. The resulting surface is shown in Figure 2.

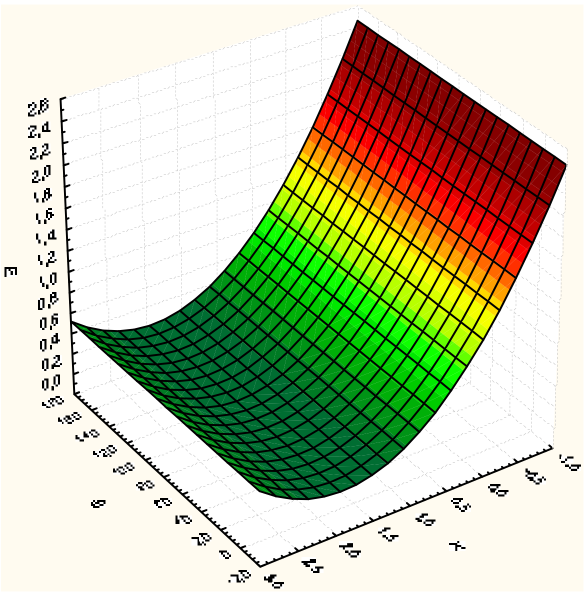

Figure 2. *The surfaces of the dependence* $\acute{\varepsilon}_{cep}$ *in the summer period of transportation for the variables a and x.*

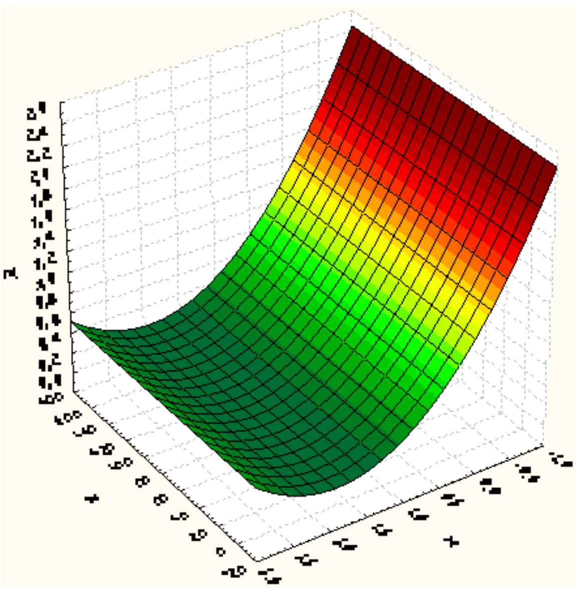

Figure 3. *The surfaces of the dependence* $\acute{\varepsilon}_{cep}$ *in the summer period of transportation for the variables a and x.*

Let us carry out analogous calculations for the investigated system on condition of considering winter long-distance passenger transportations and reflect the constructed corresponding surface of the dependence $\acute{\varepsilon}_{cep}$ for the variables a and x in Figure 3.

From the obtained results of calculations, it is established that $\acute{\varepsilon}_{cep}$ does not significantly depend on the change of a.

The applied approaches to the modeling of long-distance passenger transport correspondences indicate the possibility of their application to the studied system. At the same time, they mostly rely on the gravitational analogy, they have common interpretations and are based on arrays of the number of departures and arrivals of passengers in cities i and j with the definition of the attraction function between them. At the same time, the adequacy of models as a whole depends on the accuracy of determining these arrays and the invention of quantitative indicators of their calibration coefficients.

The formalization of the value of the calibration factor – x in dependence (9) for the considered model was achieved using the applied above method, taking into account the seasonal fluctuations of correspondence between cities during the winter and summer periods.

By using the method, the calibration factor – x was attained in the dependence (9) for the model in question, taking into account the seasonal fluctuations in correspondence between cities during the winter and summer periods.

The attraction function between cities i and j depends on the distances between pairs of cities L_{ij} in the degree of 1,6 for summer correspondences and 1,8 for winter correspondences. That is, in this case, the relative deviation $\acute{\varepsilon}_{cep}$ of the calculated parameter H_{ij} from the actual indicator is from 9% to 11%. Such accuracy of passenger transport correspondence H_{ij} can satisfy the needs of science and practice for modeling the parameters of the functioning of passenger transport systems for long-distance communication.

The indicator of the deviation of the calculated values of potential correspondence between the cities from the actual obtained from the results of the conducted study provided an opportunity to assess the possibility of using the calibration coefficient x for winter and summer correspondences.

The results of the statistical evaluation indicate that the obtained model has a sufficiently high informational consistency, as evidenced by the calculated value of the Fisher index of 207,71. The degree of correlation is 0,954. The average error of approximation is 7,62%. The obtained regularity testifies that an increase in the optimal carrying capacity of a vehicle with an increase in the volume of delivery occurs on a nonlinear dependence.

The presented results are valid for the specific parameters of the tasks for delivery, which are considered in the article. However, the analysis of other schemes for the transportation of package goods and piece goods in cities indicates the maintenance of the general patterns of growth of optimum carrying capacity of vehicles, depending on the volume of transportation. In this case, the coefficients of equation (6) have different meanings depending on the specific conditions of the task for transportation.

7. Conclusions

1. The analysis of modern scientific approaches to the calculation of passenger transport correspondence found that this issue is not sufficiently studied. There is a need to conduct experimental studies of the parameters of the functioning of the experimental system and further establishment of the corrective coefficients of the known dependencies of predicting passenger correspondence in the system. The gravitational modeling of passenger transport correspondence is chosen as acceptable for the studied system.
2. The results of establishing a correction factor for the investigated system of long-distance passenger traffic in Ukraine are obtained. From the obtained values of the calibration coefficient – x in the dependence (9) the values 1.6 for summer and 1.8 for winter correspondences can be taken. The obtained information on the parameters of the investigated correspondences supplemented the known scientific approaches to predicting the parameters of the functioning of the process of transporting passengers with the determination of the peculiarities of seasonal fluctuations in demand for transportation, which provides an opportunity for forecasting the correspondence of passengers in the studied system using gravitational modeling.

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