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MODELING THE INTERDISTRICT CORRESPONDENCE MATRIX

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Abstract: This article analyzes theoretical and practical approaches to modeling the interregional correspondence matrix in the transport sector. The concept of transport demand, the factors that form it, and ways to use it as a means of managing the demand for the transport system in modern urban planning are highlighted. The essence, differences, advantages, and disadvantages of aggregate and disaggregate models used in determining matrix values are considered. Optimized flows from the user and system perspectives are also analyzed based on Wardrop's principles. The need for doset models aimed at identifying potential transport needs, regardless of the network configuration, is substantiated.

Keywords: transport demand, correspondence matrix, aggregate model, disaggregate model, Wardrop principles, user optimization, system optimization, transport flows, transport modeling, doset model.

Introduction. Management and forecasting of traffic flows in urban planning and transport planning is one of the most pressing issues today. Especially for the stable functioning of the transport system in large cities, it is important to analyze data on population movement, to model this movement through interaction in an interregional context. From this point of view, the compilation and modeling of the interregional correspondence matrix is one of the main stages in determining demand in the transport sector and ensuring the effective functioning of the network. In this chapter, the essence of the interregional correspondence matrix, the factors of transport demand formation, the significance of aggregate and disaggregate models used in determining this demand, and the cases of their application are widely covered.

Main Part. Transport demand is a quantitatively determined need for transportation and additional transport services. It can be measured in the number of vehicles, passengers, or cargo per unit of time. The demand for the services of a specific type of transport is determined, in particular, by the development of various types of transport in the region, the degree of their integration, the level of transport tariffs, and the quality of service provided to consumers by various types of transport enterprises and organizations. The demand for freight transportation is largely determined by two factors: the dynamics and structure of changes in production volumes, as well as the solvency of enterprises and organizations in all sectors of the economy [1].

As in the market situation, so-called market equilibrium (balance of supply and demand) operates in the transport services sector. The flow distribution in the transport network is an analogue of the market equilibrium situation, in which traffic participants create a demand for the use of transport system elements, the capabilities of these elements act as a supply, and the price is the costs (time, cost, comfort level) of traffic participants arising from the use of these elements. In the case when demand exceeds the possibilities of supply, a deterioration in the conditions of movement occurs, which leads to an increase in such costs. The total increase in such costs can be used as one of the indicators of the total overload of the transport system. For individual network sections, such growth can serve as an indicator of their insufficient capacity (carrying capacity). In addition, it is known that improved traffic conditions provoke increased traffic - so-called induced demand manifests itself.

It should be noted that in recent years, in the practice of urban planning, transport demand has often been considered not as a predetermined value determining the flow distribution structure, but as a tool for managing the city's transport system. In particular, over the past decades, experience has been accumulated in using a whole range of regulatory measures aimed at reducing the demand for the use of individual transport ports, especially in areas with dense urban development [1].

Modeling the inter-district correspondence matrix is the main stage in calculating transport demand parameters. The problem of distributing movements (correspondences) between pairs of transport areas with known "departure" and "arrival" values, determined at the trip generation stage, has an infinite set of solutions. Figure 1 shows a tabular form of the correspondence matrix, each element of which represents the number of movements between pairs of transport areas - from area i to area j.

	Arrivals				
Shipments	1	2	…	n	sum
1					P1
2		?			P2
…					…
m					Pm
sum	Q1	Q2	…	Qn	

Fig. 1. Correspondence matrix table form

Correspondence matrix values cannot be directly measured, therefore various indirect approaches are used to determine them, such as sociological research or the method of restoring matrix values based on known flow distribution parameters. Within the framework of this training manual, models based on the study of individual preferences of city residents are considered; it is precisely such models that have become widespread in the composition of many well-known software complexes of transport and urban planning modeling.

The models for calculating inter-district correspondence are divided into two large groups: aggregated and disaggregated. Aggregated models are built on averaged values of variables that determine the demand for movement. The number of movements determined by such models is calculated proportionally to the size of the territory generating demand, and the demand is assessed proportionally to the population residing in the transport area. The number of movements attracted to a particular transport area is calculated proportionally to the number of attraction sources located in the considered territory.

However, inter-district correspondence is the aggregate result of individual movements of city residents. Therefore, it is logical to use disaggregated models as a tool sensitive to the individual transport behavior of respondents. Disaggregated models describe an individual's transport behavior, taking into account the impact of socio-economic and urban planning factors on them. Behavioral principles are associated with two possible situations.

1) network users independently choose the route route corresponding to their minimum transportation costs (time, money);

2) Network users choose travel routes based on minimizing total transport costs in the network.

These behavioral principles were called Wardrop's first and second principles, respectively. In the first case, everyone strives to reach the final destination of their journey as efficiently as possible for themselves and chooses the route that will incur minimal travel expenses (time, financial, moral, etc.). Therefore, this principle is also called custom optimization.

Wardrop's second principle assumes centralized control of movement in the network. The corresponding distribution of transport flows is called the system optimum, and the principle itself is called system optimization. An example of users moving according to the second principle is the drivers of route transport [2].

In the classical (network) demand calculation scheme, it is assumed that correspondents choose arrival districts based on the capabilities of the transport network, i.e., the time spent traveling between districts is calculated taking into account the possible travel speeds. When developing projects for the future, even when it comes to established cities, such an approach is not always acceptable. For example, nearby districts, separated by a water barrier and therefore practically inaccessible to each other through the network, can be mutually attractive for residents during the construction of a bridge crossing.

When calculating the correspondence matrix in the network model, it turns out that the costs for such movement are high, and, as a result, the number of correspondents between these districts will be small, from which it can be concluded that it is not advisable to build crossings for the connections of these districts. Speaking about the 20-30-year perspective, for which many projects are being developed, one cannot focus on network configuration, as its construction is one of the main goals of developing such projects. Thus, there is a need to develop pre-network models for forming inter-district correspondence that would take into account the overall level of transport services, network speed parameters, but would be less susceptible to the influence of geometric features and network limitations. Such models will allow for more adequate identification of potential demand for inter-district movements.

The determining factor in modeling the distribution of correspondences at the pre-network level is the relative location of settlement areas and labor application areas, i.e., such factors as the parameters of the city territory configuration, the density of population and labor application areas, as well as the relative location of functional zones come to the forefront (Table. 1). Pre-network models provide the designer with information about the directions of transport network development under the given location of functional zones. Modeling the distribution of correspondence at the pre-network level allows for calculating the situation of the most complete disclosure of the territory's potential by proposing a rational structure of attraction, which can be supported by network solutions.

Table 1

Comparison of matrix calculation approaches

Method for calculating inter-district movement matrices	Network method (network level model)	Pre-network method (pre-network level model)
Approach to determining time expenditures between departure and arrival points	Taking into account the speed parameters of the transport network elements	Based on the average level of transport services
Method for calculating inter-district movement matrices	Network method (network level model)	Pre-network method (pre-network level model)
Factors influencing the distribution of correspondence	Mutual arrangement of flow-forming and flow-absorbing centers Transport network configuration and parameters Behavioral factors (attractive function)	Mutual arrangement of flow-forming and flow-absorbing centers Behavioral factors (attractive function)

The gravitational model is based on the following statement: the correspondence from area i to area j is proportional to the total volume of departure from center i, the total volume of arrival at center j, and some function dependent on the transportation distance between centers i and j. Transport distance reflects the degree of proximity of districts, taking into account the speed and convenience of movement provided by the transport network. The method of determining this quantity may differ in different model variants. In essence, the gravitational model is based on the analogy between the mutual attraction of two masses and the attraction of those leaving the i region to the arrival points in the j region [3], i.e., it is assumed that

$$x_{ij} = \frac{kP_iQ_i}{c_{ij}^2}$$

where $\mathbf{x_{ij}}$ - the volume of correspondence between districts i and j, thousand people;

P_i - volume of shipments from the i-th district, thousand people;

Q_j - volume of arrivals to the j-th district, thousand people;

c_{ij} - generalized cost of travel between districts i and j (distance analogy);

k- is some constant.

Conclusion. Modeling the matrix of interregional correspondences plays a key role in the planning of transport systems, and in this process, the correct assessment and forecasting of transport demand occupies a central place. Due to the difficulty of directly determining matrix values, various fuzzy but practically useful models are used. Aggregate and disaggregate models have their own peculiarities, and disaggregate approaches are relevant because they reflect the individual characteristics of transport users' movement. Optimization approaches based on the Vardrop principle are an important tool for regulating traffic flows. The use of existing non-network-based doset models allows for a more accurate assessment of potential needs in the formation of long-term transport strategies.

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