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RESEARCH ON THE DEMAND FOR ROAD PUBLIC TRANSPORTATION IN SUBURBAN TRAFFIC

The analysis of existing approaches to estimating transportation demand based on OD matrix modeling has been conducted to identify the most effective methods for suburban and interurban traffic planning. The interval concept is applied by analyzing patterns of trip length distribution within the city and adjacent territories, allowing the definition of intervals within which transportation demand varies in relation to urban centers. This provides a flexible and probabilistic framework for capturing the variability in passenger flows, taking into account daily and seasonal fluctuations as well as differences in travel behavior between urban and suburban areas. To determine the spatial distribution of trips, actual travel distances around the regional center were analyzed, ensuring that the model reflects real-world travel patterns and regional transport infrastructure.

The proposed methodology was applied to evaluate suburban transportation services, demonstrating its capability to generate OD matrices that are consistent with observed demand and operational data. The results confirm that the interval-based approach can enhance planning accuracy, optimize route allocation, and support decision-making in suburban public transport management. Furthermore, this method contributes to the development of more robust models for forecasting transportation demand, offering practical guidance for transport planners and policymakers aiming to improve service efficiency and passenger satisfaction. The study highlights the potential of integrating probabilistic modeling techniques into transportation planning to account for uncertainties and dynamic changes in travel behavior, providing a scientific basis for evidence-based decision-making in the organization of suburban transport systems.

Keywords: demand, suburbanarea, city, commuters, distance, OD matrix.

INTRODUCTION

Under present-day conditions, there is an increasing tendency for some of the inner-city residents to prefer to live outside the city, in the so-called suburbs, that is, in the residential areas that surround the major city. The suburban area is formed under the impact of “suburbanization” that is the process of growth and development of the suburban area of major cities [1], resulting in the formation of urban agglomerations, which are interdependent groups of settlements (primarily urban) united into dynamic systems by different types of ties (labour, production, recreational, infrastructure, etc.). This causes faster development of the suburbs (primarily demographic) compared to the central city [2]. The suburbs are starting to develop at the expense of the central city: a rapid shift of urban residents from the central city areas into the suburbs occurs as well as the relocation of industrial, social and other functional facilities. In turn, the suburban inhabitants are more likely to seek employment and appropriate education in the central city by commuting from home to work or study [3]. That is, there is a continuous interaction between the city and its surroundings, which is realized through their interconnections. One of the important factors of this interaction is population displacement, which involves both centripetal and centrifugal trips.

The suburbanization process is a further stage in the development of the urbanization process, and the development of the transportation system is a prerequisite for both these processes. Special attention should be given to the efficient management of the passenger transportation system, which requires accurate determining the transportation needs of the population. The regularities and conditions for organizing transportation result from fulfilling transportation needs, which are met within the specific transportationsupply, the so-called transportation accessibility [4]. The trip number of suburban inhabitants is one of the main characteristics of the transportation process, which depends on the ways of fulfilling the transportation demand and is influenced by the importance of the city in the system of international, state, regional socio-economic, historical-cultural and other spheres, as well as the nature and content of the system of population distribution and places of work in the sphere of influence of the city including its surroundings.The distribution of the transportation demand in the area surrounding the city determines the regularities of trip length distribution all around the city [4] and can serve as a demand-modelling basis for public transportation services in suburban traffic. Describing the demand pattern of road public transportation is one of the most important tasks of modelling the transportation system of the city with adjacent territories, which is virtually researched in contrast to the methods and approaches within the cities. It lies in determining the most accurate OD matrix, which provides an opportunity to become aware of the quality of public transportation services and to test scenarios of the agglomeration expand.

LITERATURE REVIEW AND PROBLEM STATEMENT

There are two main approaches to determining the needs for transportation, which are the basis for the OD matrix (ODM) formation. The first one involves surveys aimed at obtaining information on the current rate of demand fulfilment and obtaining information on the regularities and peculiarities of demand formation for mass transit [5]. Conducting field surveys provides information on actual passenger traffic, fill rate of transportation means and the trips' number. Questionnaires and statistical reports provide the idea of population mobility (travel regularities of different population groups, depending on the purpose of the trip), settlement patterns concerning places of work, attendance of cultural-domestic institutions, changing places of work and moving house (changes in settlement patterns) and trip time (possible regularities of passenger travel behaviour). Conducting a full-fledged survey provides enough accurate information, but it is time and labour consuming. Existing transportation reports do not always provide full information on the distribution of trips depending on the purpose of movement.

The second approach that is based on using different demand forecasting models determines the dynamics, trends, and patterns of demand development. This approach is less labour-intensive but does not always provide sufficiently accurate results and in some cases, it simplifies real processes. Using models to calculate the ODM comes with the application of the methods based on the statistical analysis of data on actual trip directions, as well as the methods based on a priori logic hypotheses [6, 7]. Three main approaches to the formation of the ODM can be distinguished, namely statistical, synthetic and probabilistic approaches.

The statistical approach requires field surveys of trips [7] and allows obtaining the most accurate information on the transportation needs of the population. Such total surveys are mostly conducted using a questionnaire and contribute to the formation of the most accurate ODM. This approach also implies the application of statistical methods for calculating the ODM, which allows applying available trips' number values of the current or previously investigated period for the future analysis period. Such methods include the growth factor method, the Detroit method, the Furness method (the Fratar method) and others [5, 7]. However, conducting surveys to obtain the actual matrix is cost-intensive and modelling is performed only for the rates of growth or decay (decline) of trips' number.

A group of methods, which can be distinguished under the latter approach to obtain the ODM, use various synthetic models based on the similarity assumed to exist between processes occurring within the transportation system and physical processes as well as laws of nature [7, 8]. This approach is considerably less labour intensive to form the ODM, but it does not provide sufficiently accurate results. To calculate the trips' number, gravity and entropy models, as well as the intervening opportunities method, are used.

Methods taking into account, to some extent, the credibility of the approach to modelling ODM [8] is based on the assumption that each individual selects a traffic route from a finite number of alternatives considering their socio-economic characteristics and relative attractiveness using discrete choice models, for instance. Multiple correlation models [5, 7] based on identifying factors that specify the emergence of transportation needs and their impact on the formation of passenger flows through the determination of coefficients in the correlation equation that determines the passenger trips' number.

Almost all the methods of obtaining the ODM are characterized by using the unique algorithm for calculating and the point estimate of the matrix. The approach to determining the population demand for public transportation services that provides an opportunity of obtaining the most probable states of the ODM, which are as close to the actual demand state of public transportation service as possible, is presented within the framework of interval concept [7]. This concept assumes that demands for home-based work trips are random and can be described not by a single ODM, but by a set of them. Each matrix from the set represents one of the possible states of the transportation demand. Their fluctuations are within the range corresponding to demand states with the minimum and maximum transportation operation that is performed during the course of the passenger movement process. One of the reasons for such representation of suburban transportation needs is the shift in demand depending on the scope of influence of the city on the magnitude of movements for the specific transportation mode.

A significant impact of human settlements on the intensity of traffic flow on public roads is specified in the work [8]. The models reflecting an increase in traffic intensity on approaching a high-way section located near human settlements have been obtained on the basis of the regression analysis. However, the application of the model gives the possibility of predicting only the magnitude of traffic intensity within the suburban area and does not allow taking into account the probabilistic nature of the shift in demands for transportation depending on the distance of human settlements from the major city.

PURPOSE AND OBJECTIVES OF THE STUDY

Considering the existing problems of determining suburban transportation needs and approaches to the ODM calculation, the relevant objective is to develop the model of suburban transportation needs. The model should be developed using the approach, in which it is reasonable to apply the interval concept to calculate suburban ODM. The application of the interval concept must be based on the patterns of trip distribution within the area surrounding the city. The regularities of the spatial distribution of trips can be determined based on actual distances within the area surrounding the city [4].

RESEARCH RESULTS

According to the work [4], in considering the trip length outside major city l'_p as a random variable of the trip length in the suburban traffic, it has been found that its distribution must be exponential with the shift parameter, on condition that it is a part of the trip length distribution, which is considered both within the city and beyond the city borders.Determining the regularities of the distribution of l'_p creates the basis for identifying the needs for suburban public transportation, which reflects the distribution of distances of all suburban passenger trips. As previously defined, the form of a demand model between the origin and destination points of transportation traffic is the OD matrix. Taking into account that the values in ODM cells represent the frequency of trips over a certain distance and using the concepts of the statistical probability of an event and exhaustive events, the probability of occurrence of a certain trips' number can be written as follows:

$$p(h_{ij}) = \frac{h_{ij}}{H}, \quad H = \sum_{\substack{i,j=1 \\ i \neq j}}^{m} h_{ij}, \tag{1}$$

where h_{ij} is a trips' number from zone *i* to zone *j*, during time interval considered, pass.;

*H*is the sum of all trips in the matrix, pass.

The empirical probability of moving h_{ij} over a certain distance $l'_{p_{ij}}$ is determined as follows

$$P_{емп}^{(h_{ij})}\left\{l'_{p_{ij}} \in \Delta\right\} = \sum_{\substack{i,j=1 \\ i \neq j}}^{m} \frac{h_{ij}}{H} I_{\left\{l'_{p_{ij}} \in \Delta\right\}}, \tag{2}$$

where $I_{\left\{l'_{p_{ij}} \in \Delta\right\}}$ is the indicator of event, which implies that the travel distance $l'_{p_{ij}}$ from zone *i* to zone *j* is within some interval Δ.

That is, equation (2) is a probabilistic combination of event indicators $I_{\{l_{ij} \in \Delta\}}$. Considering the actual distribution $l'_{p_{ij}}$, which according to [4] has five groups of intervals, if there is a probability of moving over a certain distance, which belongs to the interval Δ and the matrix of distances between transportation zones, according to the interval concept of determining transportation needs it is possible to determine the ODM states that provide support for the exponential distribution of $l'_{p_{ij}}$.This allows taking into account the probabilistic nature of transportation links and eliminating the disadvantages of point estimate of the ODM. The formation of the most probable states of the ODM within the framework of the interval concept based on the actual information on the trips' length $l'_{p_{ij}}$ that the population commits provide an opportunity of determining the percentage ratio of the number of inhabitants, whose travel distances to the city correspond to the defined intervals of trip length. The proportion of inhabitants, whose travel distance $l'_{p_{ij}}$ lies within a certain interval can be determined as the difference of values of the function of exponential distribution at points corresponding to the boundaries of the given interval:

$$P\left\{l_{p_{ij}}^{(\Delta_I)}\right\} = P\left\{l_{p_{ij}} \in \Delta_I\right\} = P\left\{l_{p_{ij}} \in (\Delta_I^н; \Delta_I^в]\right\} = Z(\Delta_I^в) - Z(\Delta_I^н), \tag{3}$$

where $P\left\{l_{p_{ij}}^{(\Delta_I)}\right\} = P\left\{l_{p_{ij}} \in \Delta_I\right\}$ is the probability that the travel distance $l_{p_{ij}}$ is within the interval Δ_I ;

$\Delta_I = (\Delta_I^н; \Delta_I^в)$ is the group interval of travel distances of passengers that is defined by the lower $\Delta_I^н$ and upper $\Delta_I^в$ limits, $I = 1, 2, \ldots, x_{Int}$, x_{Int} is the number of group intervals of travel distances of passengers;

$Z(\Delta_I^{в}), Z(\Delta_I^{н})$ is the value of distribution function $l_{p_{ij}}$ at points $\Delta_I^{в}$ and $\Delta_I^{н}$ respectively, accordingly the total number of movements $H^{(\Delta_I)}$ that must be made at a distance from a certain interval Δ_I can be defined as follows

$$H^{(\Delta_I)} = P\left\{l_{ij}^{(\Delta_I)}\right\} \cdot H , \qquad (4)$$

where H is the total trips' number during time interval considered, pass.

To obtain the ODM, it is necessary to find a distribution of trips' number that corresponds to the system of limitations

$$\begin{cases} \sum_{i=1}^{m} h_{ij} = HO_i , \ \sum_{j=1}^{m} h_{ij} = HP_j ; \\ \sum_{\substack{i,j \\ i \neq j}} h_{ij}^{(\Delta_I)} = H^{(\Delta_I)}, \ i \neq j, \ I = 1, 2, \ldots, x_{Int} ; \\ \sum_{I=1}^{x_{Int}} H^{(\Delta_I)} = \sum_{i=1}^{m} \sum_{j=1}^{m} h_{ij} = H , \end{cases} \qquad (5)$$

where h_{ij} is the required trips' number between transportation zones *i* and *j*, pass., $h_{ij} \geq 0$;

m is the number of departure and arrival zones, units; HO_j, HP_i is the arrival and departure capacity of each transportation zones, pass.; $h_{ij}^{(\Delta_I)}$ is the trips' number, which are realized at a distance $l_{ij}^{(\Delta_I)}$.

To obtain the OD matrix, which satisfy the limitations (5), the algorithm for calculating suburban transportation needs has been developed. In order to implement the developed methodology for determining the suburban transportation needs in public transportation sector, the following data are required: the arrival and departure capacity of the transportation zones; the matrix of the shortest distances between transportation zones; the probability of movements according to the exponential distribution of the trips' length at points corresponding to the boundaries of the given interval.

The first stage involves checking the balance between the departure and arrival capacity of the transportation zones $\sum_{i=1}^{m} HO_i = \sum_{j=1}^{m} HP_j = H; i,\ldots,m; j,\ldots,m$ and the actual distribution of movements according to the value of the exponential distribution function within the specified intervals of the total number of movements between the transportation zones $\sum_{I=1}^{x_{Int}} H^{(\Delta_I)} = H$

The next step is filling out the OD matrix using a random number generator with a gradual check of each random value in the matrix and the forming of a random state in the ODM is performed.

According to the random ODM and the matrix of the shortest distances, the frequency at which travel distances $h_{ij}^{(\Delta_I)}$ fall within the given interval Δ_I is calculated. After that, the compliance with theactual hit frequencies $l'_{p_{ij}}$ is evaluated and corrected using closed loops. The calculation is carried out until the calculation of the value h_{ij} in the ODM corresponds to the actual distribution $l'_{p_{ij}}$.

The practical implementation of the developed methodology has been carried out by the example of public transport network model of the Kharkiv region. The departure capacity of the transportation zones has been defined as the potential number of inhabitants of human settlements situated in the area surrounding the major city, who move in the direction of the city in accordance with the characteristics of human settlements and the predicted value of traffic intensity of public transit. Last value is determined according to the experimental studies [9] considering other types of public transport links.

$$HO_i = N_{м_i} \cdot \frac{1}{0{,}829 + \dfrac{12{,}59}{L_i} + 0{,}023 \cdot P^{0{,}367}} \cdot k_{з_i} , \qquad (6)$$

where $N_{м_i}$ is the number of inhabitants of human settlement *i*, who commutes in the direction of the city, people.; L_i is the remoteness of human settlement *i*, from the city, km; $k_{з_i}$ is the proportion of trips made using public railway system of human settlement *i*, %; P is the number of inhabitants of the city, in the direction towards which the travel takes place, people.

Experimental verification of the proposed methodology for determining the departure capacity of the transportation zones for human settlements has been carried out based on a sampling survey using the tabular method of passenger flow surveys for different categories of routes in various principal traf-fic directions. The maximum deviation of the calculated data according to the experimental studies is 0.31. The arrival capacity of the transportation zone has been determined to take into account the total number of inhabitants of human settlements who move in the direction of the city and the presence of bus stations and transit trips which ends in the city. The public transport network model and the matrix of the shortest distances between transportation zones have been calculated using the VISUM software.

The point objects that define the spatial position of the intersections – “nodes”, which are also the starting points or respectively endpoints of the segments are placed on the loaded “background”. For more accurate refining of “nodes” real coordinates of their location are assigned. The next step of modeling is the allocation of “segments” that are directed edges, which characterize the forward and reverse directions and are independent objects of the network. The segments connect the nodes and thus describe the structure of the road network. After that, the objects that describe the state of attractors in the network, namely zones are entered into the supply model. The points of attraction of passengers, which are human settlements, are assigned as zones. The zones in the transport model are entry points and the purpose of the transport movement. The centre of the transportation zone is defined in specific human settlements according to the main directions of passenger traffic with approximately the same area of service. They are connected to the network by a “junction”. The junctions connect the “zones” with the road network. For each specific transportation system, they correspond to the ending and starting pedestrian crossways between the zone centre and the junction. The next step of the design process is to plot the stopping points on the map of the object under consideration and register regular suburban and regional traffic routes.

Table 1 General description of the model

Parameter		Value
Number of stopping points, units		689
Number of transportation zones, units		199
Number of human settlements in the region, units		218
Number of inhabitants of human settlements, people.	minimum	16
	maximum	56 655
The total population, thousand people		878.485
The area of a human settlement, km^2	minimum	0.06
	maximum	56.026
Number of human settlements with railroad transportation service, units		36
Population density, people per sq. km	minimum	5.3
	maximum	3694

The application of the developed algorithm has allowed for the formation of the ODM that corresponds to (3) and (4) and satisfies the limitations (5). In compliance with the actual distribution of travel distances within the Kharkiv region, the fluctuations have been calculated within the given group intervals. According to the calculations, the maximum fluctuation $\sum_{\substack{i,j \\ i\neq j}} h_{ij}^{(\Delta_l)}$ in compliance with the proposed methodology of ODM calculation is 8.5 %.

It should be pointed out that the maximum distinguishes is observed at a distance of more than 60 km. This can be explained by the fact that the influence of the city tends to decrease significantly with the distance of human settlements (points of attraction) from the city and restricts suburban transportation service.

DISCUSSION OF RESEARCH RESULTS

The use of the proposed methodology in suburban traffic has advantages compared to previously proposed ones. For example, the study of the spatial distribution of displacements in suburban traffic in [4] is based on the process of rural population dispersal relative to the regional center. But in the study of settlement patterns, settlements are united depending on the remoteness of their regional center. The procedure for calculating the ODM is based on the gravity model and does not take into account the random nature of the trip directions formation.

Table 2 Estimation of ODM calculation

Group interval	Lower limit, km.	Upper limit, km.	Probability of movement	Number of movements, units			
				according to probability	according to model	distinguishes	%
1	0	20	0.309	41374	41958	-584	1.4
2	20	40	0.199	26645	27531	-886	3.3
3	40	60	0.153	20486	20324	162	0.8
4	60	80	0.099	13256	14386	1130	8.5
5	80	100	0.240	32135	29697	2438	7.6
TOTAL			1	133896	133896	5200	-

The use of a probabilistic approach in the framework of the interval concept is presented in [7] for the urban territories with a different population based on the distribution function. In this case, the author considers the process of the emergence of new attractors at the city border and the suburban zone. Using this approach served as the basis for the study of the trip length distribution. Confirmation of patterns in the distribution of trip length was presented in [4] in the suburban traffic. Therefore, the proposed methodology was the next step in the study of a suburban land-use.

ODM is certainly an integral part of the public transport model of the suburban transport system for road transport. Without ODM, it is practically impossible to assess the effectiveness of the route network for any kind of trip, both from the passengers' and the carriers' point of view. That is why obtaining the most likely states of the ODM that best reflect the mobility needs of the commuter population is the goal of transport planning and modeling experts. To assess the probabilistic nature of the demand is still a task that requires new solutions and the use of new approaches. The innovation of the developed methodology for determining demand in suburban traffic primarily lies in the possibility of its use in assessing changes in the transport system of the city and its surroundings. When forming the initial information for calculating ODM, separate the most common relationships between the city and the suburban area, determine the real border of the suburban area for towns of regional and district significance.

The results of the calculations by the proposed methodology can represent a methodological basis that can provide a solution to the problems of improving the organization of passenger transportation in suburban traffic both for transport enterprises and for organizations that participate in the management of various types of activities related to the public transport system. For the above-mentioned stakeholders in the transport process, work efficiency can be considered both from a social point of view (meeting demand) and from the economic side - increasing the level of profit and profitability of enterprises.

Risks associated with the inaccuracy in determining the demand in suburban traffic according to the developed algorithm can primarily be associated with the lack of actual data on the distribution of distance of movement across territories in the suburban traffic, in the wrong methodology for conducting a passenger flow survey, in inaccurate information provided by transport enterprises (trips without issued tickets). The elimination of these risks depends on administrative organizations interested in obtaining accurate and reliable information to assess the satisfaction of demand and improve the efficiency of the functioning of the public transport system in suburban traffic.

Uncertainty of the results of calculations may pose increased risks for the population as a result of not being in a timely manner at the final destination, which may include both the place of work and any institution in which there are strict restrictions on the time of arrival. The developed algorithm for determining the OD matrix allows reducing risks for the population due to the inefficient operation of public transport in suburban traffic.

CONCLUSIONS

The proposed methodology of calculating the ODM allows us to take fully into account the probabilistic nature of the demand and to obtain such distribution between the cells of the ODM, which ensures the formation of the actual distribution of travel distance in suburban traffic. Be-sides, the developed methodology is fully consistent with the interval concept of modeling transportation needs and contributes to its application in suburban transportation service. At that, it is also possible to develop ODM alternatives that may correspond to the minimum deviation from the actual distribution of movements around the city. The obtained OD matrices can make possible the interval estimation of any parameters related to the realization of transportation needs and, accordingly, the quality of public transportation services.

The application of the developed methodology within the framework of interval concept can significantly reduce a range of possible states of passenger correspondencematrix and allows defining the so-called boundaries of the zones of influence of the city in suburban traffic.

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***А. Кочина.* Дослідження попиту на автомобільні перевезення громадським транспортом в приміському сполученні**

Було проведено аналіз існуючих підходів до оцінки транспортного попиту на основі моделювання матриці пасажирських кореспонденцій з метою визначення найефективніших методів планування приміського та міжміського руху. Інтервальна концепція застосовується шляхом аналізу моделей розподілу довжини поїздок у межах міста та прилеглих територій, що дозволяє визначити інтервали, в межах яких транспортний попит варіюється у відношенні до міських центрів. Це забезпечує гнучку та імовірнісну основу для відображення пасажиропотоків, а також відмінностей у поведінці пасажирів між міськими та приміськими районами. Для визначення просторового розподілу поїздок було проаналізовано фактичні відстані поїздок навколо регіонального центру, що забезпечило відображення в моделі реальних моделей поїздок та регіональної транспортної інфраструктури.

Запропоновано методику визначення попиту на пересування в приміському сполученні на основі інтервальної концепції розрахунку матриці МПК, яка дозволяє отримати найбільш ймовірнісні стани МПК, котрі максимально наближені до реального стану попиту. Застосування інтервальної концепції основане на закономірностях розподілу пересування на території, що оточує місто та надає можливість визначити інтервали в межах яких змінюється попит на пересування відносно міста. При визначенні закономірностей просторового розподілу пересувань були використані фактичні відстані пересувань навколо обласного центру та здійснено оцінка запропонованого підходу визначення попиту на пересування в приміському сполученні.

Ключові слова: попит, приміська зона, місто, пасажири, відстань, матриця пасажирських кореспонденцій

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