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Intelligent Decision Support System for Modeling Transport and Passenger Flows in Human-Centric Urban Transport Systems

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Abstract: Engineering human-centric urban transport systems should be carried out using information technology in forecasting traffic and passenger flows. One of the most important objects of urban transport systems' progress is modeling patterns of transport flows and their distribution on the road network. These patterns are determined by the subjective choice of city residents of traffic routes using public and private transport. This study aimed to form a sequence of stages of modeling transport and passenger flows in human-centric urban transport systems and passenger flows in the human-centric urban intelligent transport systems and to determine the patterns of change to the gravity function of employees of municipal services. It was revealed that the trip distribution function of workers of urban service enterprises can be described by the attributes of the structure of the city, socio-economic data, and attributes characterizing the zones and its residents.

Keywords: information technology; transport flows; passenger flows; the trip distribution function; modeling; sustainable management

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1. Introduction

Forecasting is one of the main stages of solving the problems of planning, development, and operation of the transport system [1]. The successful development of contemporary society is inextricably connected with advanced computer technology and information technology [2]. They are currently the main tools through which modernization in the transport sector is carried out [3]. The information approach has long taken a leading position in the planning, organization, and control of transport and passenger flows [4]. The need to improve their management is an urgent problem, the solution of which necessitates the study of information technology in the projects of urban transport systems [5]. The general principles of creation and operation of urban transport systems are analyzed through the prism of the information technologies implemented in them [6]. At the moment, the level of information technology in dynamic planning does not meet the need for reliability, efficiency, and quality. This is due to the lack of methodology for the use of information technology to solve dynamic planning problems [7,8]. Researchers have determined that the demand for relocation of city residents is difficult to predict. As a result, planning, namely forecasting the attributes of trips, is one of the most important and difficult tasks in transport [9].

Simultaneously, less solved problems are the multi-attribute decision-making process of urban residents. Decision making is influenced by a large number of external factors. Recently, the COVID-19 pandemic has had a significant impact on urban travel decisions. It is the result of these decisions that determines the routes of movement that affect the parameters of traffic and passenger flows. The scientific hypothesis of this research is the dependence of decisions by city residents when choosing routes of movement based on their individual characteristics. In the minds of the pandemic, it is important for the authorities to take decisions on how to organize the transport process, while the implementation of the support system will take the decision in the minds of non-insignificance when modeling transport and passenger flows.

Thus, the scientific gap in this area is the lack of existing types of intelligent decision support systems for modeling in the management of urban transport systems, considering the individual characteristics of their inhabitants. In addition, the currently proposed trip distribution functions of urban residents are not differentiated by urban population groups and use only the distance or travel time between these areas as a parameter that describes the difficulty of communication between districts of the city. It would be advisable to expand the type of trip distribution functions for each group of the urban population and identify parameters that affect the difficulty of connecting residents between areas of the city. This will give a more adequate type of trip distribution function. Previous studies have formalized the trip distribution function of employees of city-service enterprises [10]. For other groups of the urban population, the trip distribution function has not yet been estimated. Therefore, in this article, a group of employees of service enterprises and institutions is selected, which perform a significant part of the movement in the city.

The purpose of the study was to develop an algorithm for sustainable management of an intelligent decision support system for modeling transport and passenger flows in human-centric urban transport systems and to determine the patterns of change to the trip distribution function of employees of municipal services.

To achieve the goal, the upcoming tasks were performed:

- Determination of the stages of implementation of an intelligent decision support system for modeling transport and passenger flows in human-centric urban transport systems;
- Mathematical formalization of the change in the trip distribution function of employees of city service enterprises.

2. Literature Review

The development of information technology for forecasting flows should be performed on the basis of patterns established by field surveys of population movements and on the basis of building theoretical models that meet existing conditions [11]. Researchers have paid a lot of attention to determine the patterns of changes in transport and passenger flows. At present, the complexity of transport calculations is such that their implementation requires the use of computer technology. To achieve this goal, researchers undertake the following tasks [12–14]:

1. Analysis of factors affecting the formation and distribution of passenger and traffic flows on urban transport networks;
2. Improvement of the method of calculation of transport and passenger flows considering social and economic factors influencing the distribution of trips and redistribution of flows on urban transport networks;
3. Development of algorithms and programs for calculating flows on urban transport networks;
4. Verification of the developed methodology using the example of existing transport networks;
5. Development of recommendations for the design of urban transport systems using the developed methodology for practical calculations.

Improving the transport services' quality of public transport is impossible without creating a management system with adaptive properties that implement the principle of compliance with the needs of transport, considering external and internal conditions of the urban transport system [15–18]. The constant growth of motorization exacerbates a number of problems, such as creating a rational system of road traffic, parking, ensuring the quality of roads, and environmental protection [8,19–21]. Using an information system for the sustainable management of transport enterprises of the city will allow an increase in productivity and quality of works performed, strengthen control over activities of staff, as well as the use of rolling stock [15]. Due to a single transport model of the city, as scientists claim, it is possible to eliminate the differences between the desired and actual results, as the lack of a quantitative description of transport situations significantly complicates the choice between options for the urban transport system [8,22].

The transport model of the city, used to support sustainable management decisions of strategic transport planning, is the best means for assessing the proposed options for transport network progress and their additional comparison and sound conclusions about the feasibility of investing in transport infrastructure projects [8,16]. According to researchers, transport models based on modern information technologies form the basis of forecasts for the development of the city and are a necessary analytical basis for decision-making on the development of transport infrastructure of the city [8,23].

Improving the efficiency of transport service systems requires the development and implementation of new sustainable management methods using information technology in urban transport [24–27].

There are four levels of transport planning: object, sectoral and integrated transport, which are related to the entire urban transport system, as well as urban, which consists of the connection between the city and transport [28].

The premise of a smart city is that with the right information at the right time, citizens, service providers, and municipalities will be able to make better decisions that will improve the quality of life of inhabitants and the overall urban sustainability [10,27,29–32].

Researchers have found that effective forecasting technology using more accurate methods is important in modern conditions of transport development for economic justification of long-term strategy of transport systems, taking into account the complex realities of modern society [9,33,34].

One of the most important links in the progress of information technology for the design of urban transport systems is information support of transport patterns generation and passenger flows, as well as their distribution on sections of the road network [35,36]. These flows consist of individual movements carried out by road users or users of the transport network [23]. The main factors that determine the number of movements and their distribution in the transport network of the city are:

- *flow-forming factors, i.e., the location of objects that generate movement, such as places of residence, places of employment, cultural and household services, etc.;*
- *characteristics of the transport network, such as the number and quality of streets and roads, parameters of traffic organization, routes and transportation opportunities of public transport, etc.;*
- *behavioural factors, such as population mobility, preferences in choosing ways and routes of movement, etc. [37–42].*

They act as a special physical phenomenon, which have their own patterns and characteristics that cannot be applied to each trip individually [43].

The generation of the transport network load is in the choice of way and means of movement. The process of load modeling: the choice of paths that form the load with the comparison of the different path parameters, which are determined by the capacity. The flows that are actually observed in the network are a certain equilibrium state of this process [44]. The state of flows is generated by the collective movement of urban residents on individual and public transport, which implement the appropriate matrix of correspondence [37,45]. The goal of city dwellers may be to max. reduce travel-related losses, such as travel time and nerve energy expenditure, with zero loss of comfort [46–51]. At the same time, the ways of realizing this goal are significantly influenced by individual characteristics of people [52,53]. However, in the present hour, information technologies for the design of transport systems of the locality do not guard the individual features of the city's citizens, who can be seen as having their temperament.

Demand data, which can be formalized via an O-D matrix [54], are a necessary source for developing Intelligent Transport Systems (ITSs). When estimating transport and passengers' urban trips, researchers use three groups of mathematical models: deterministic, probabilistic, and heuristic, as well as their possible combinations. One of the most common types of deterministic models is the gravity model trip distribution function, which describes the number of trips between transport zones with their known capacity for departures (origins) and arrivals (destinations) [10]. In this case, the probability that a population chooses a transit route between origin–destination nodes (zones) is described by the gravity function, which, according to researchers, also depends on the distance or time of travel between the urban zones.

Residents of urban zones belonging to different socio-demographic population groups have various priorities when choosing destinations [55]. Urban transit is carried out for different purposes, and their number depends on the affiliation of the resident to the relevant group, category of settlement, personal attributes, and other factors. The main groups in the urban population are: employees of city-service enterprises (30–35%); employees of service enterprises and institutions (15–20%); students of higher educational institutions, colleges, secondary vocational schools (5–10%); non-working: children, pensioners, housewives (35–50%) [56]. The hypothesis of this research is the specific trip distribution function of residents, which belong to different socio-demographic groups of the urban population. In addition, the personal qualities of urban residents have a great influence on trip attributes [57,58]. These qualities should also be considered when developing an intelligent transport system.

The trip distribution function may contain parameters that characterize the capacity of the areas of arrival and departure, and also the availability of alternative modes. The main requirement for this function is a monotonous decline with increasing cost of inter-district movement [42]. Many scientists in their work have tried to adequately identify the trip distribution function, representing its hyperbolic dependence on time to move from area to area. It is possible to use exponential models of the trip distribution function [59]. Other researchers based on the data of the questionnaire have concluded that the best approximation of the trip distribution function is the function EVA [14]. A reliable definition of the trip distribution function allows for accurately describing the process of migration of the city's population. At the same time, the formation of population mobility is most significantly affected by the target nature of transit and the social composition of the population [60].

Thus, the gravitational functions proposed by researchers are offered to all urban residents, regardless of their social composition, and the only variable parameter is travel time. This is a shortcoming of previous studies. In fact, people belonging to different populations have different priorities when choosing destinations. As a result, the trip distribution function should be formed separately for each population group within cities: employees of city-forming enterprises; employees of city service enterprises; students of higher-education institutions, colleges, vocational schools. In addition to travel time, it is advisable to take into account other factors that affect the residents' determination of destinations.

3. Sequence of Stages of Modeling Transport and Passenger Flows in Human-Centric Urban Transport Systems

Engineering of the human-centric transport system and making optimal decisions in the field of transport planning are based on sustainable management, effective organization of transport flows, planning of transport infrastructure, and determination of possible scenarios for its growth (Figure 1).

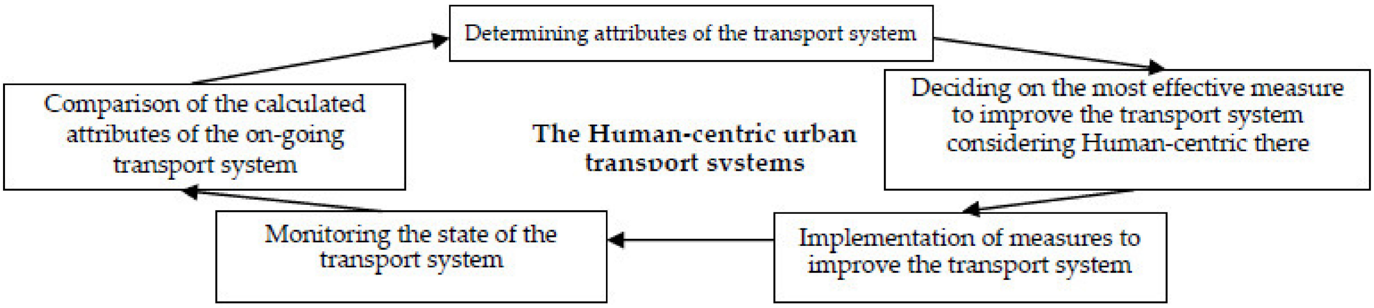

Figure 1. Stages of human-centric urban transport systems.

Deciding on the most effective measure to improve the transport system is possible with the modeling of transport and passenger flows. Its purpose is to produce information on flow attributes for further analysis of management decisions. Components of information technology are a set of models for predicting the attributes of trips. It should be based on the results of a study of the patterns of the influence of attributes on the distribution of flows along the network.

In general, the intelligent decision support system for modeling transport and passenger flows in human-centric urban transport systems is shown in Figure 2.

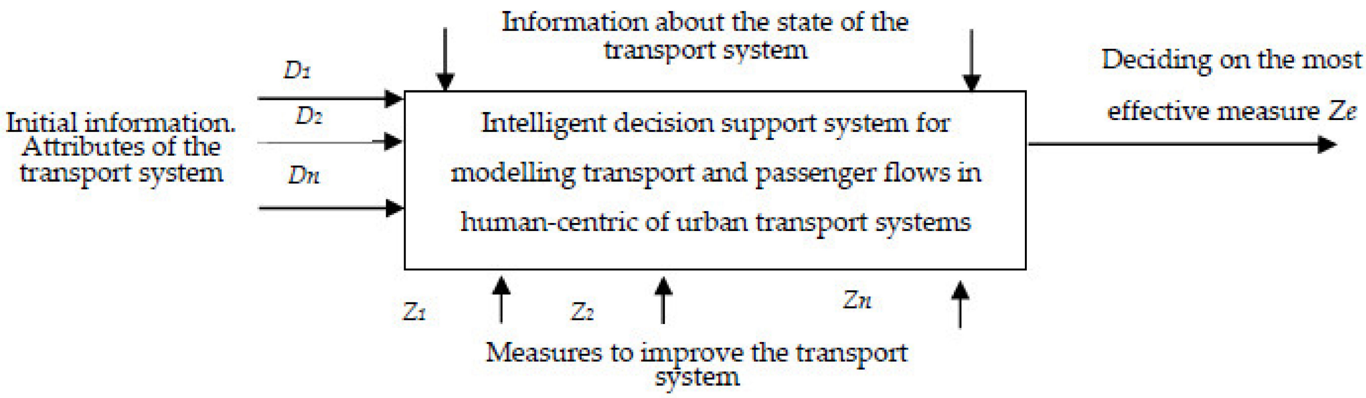

Figure 2. General scheme of intelligent decision support system for modeling passenger and transport flows in human-centric urban transport systems.

The initial information (*D1* ... *Dn*) can be: the urban structure and its zones, socio-economic data of society and the city, attributes of trips on private and public transport, and personal attributes of urban residents. For the latter, it is possible to use gender, age, and type of activity. As information about the state of the transport system, it is possible to use data on the existing parameters of transport and passenger flows in the city. As measures to improve the transport system (*Z1* ... *Zn*), and various options for changing the road network and the route system of urban passenger and freight transport, building new cargo and passenger generating and absorbing points can be used. Using an intelligent decision support system, the modeling of traffic and passenger flows in human-oriented urban transport systems is carried out when implementing certain measures to improve the transport system. It is advisable to carry out the modeling process taking into account various groups of the city's population and the individual characteristics of the inhabitants, which are determined by the type of temperament. Analysis of the simulation results allows the determination of the parameters of the functioning of the transport system during the implementation of each of the possible measures and the decision to be made to use such an event Ze, which allows the maximum efficiency of the transport system to be obtained.

The sequence of stages of modeling transport and passenger flows in human-centric urban transport systems contains a number of stages (Figure 3).

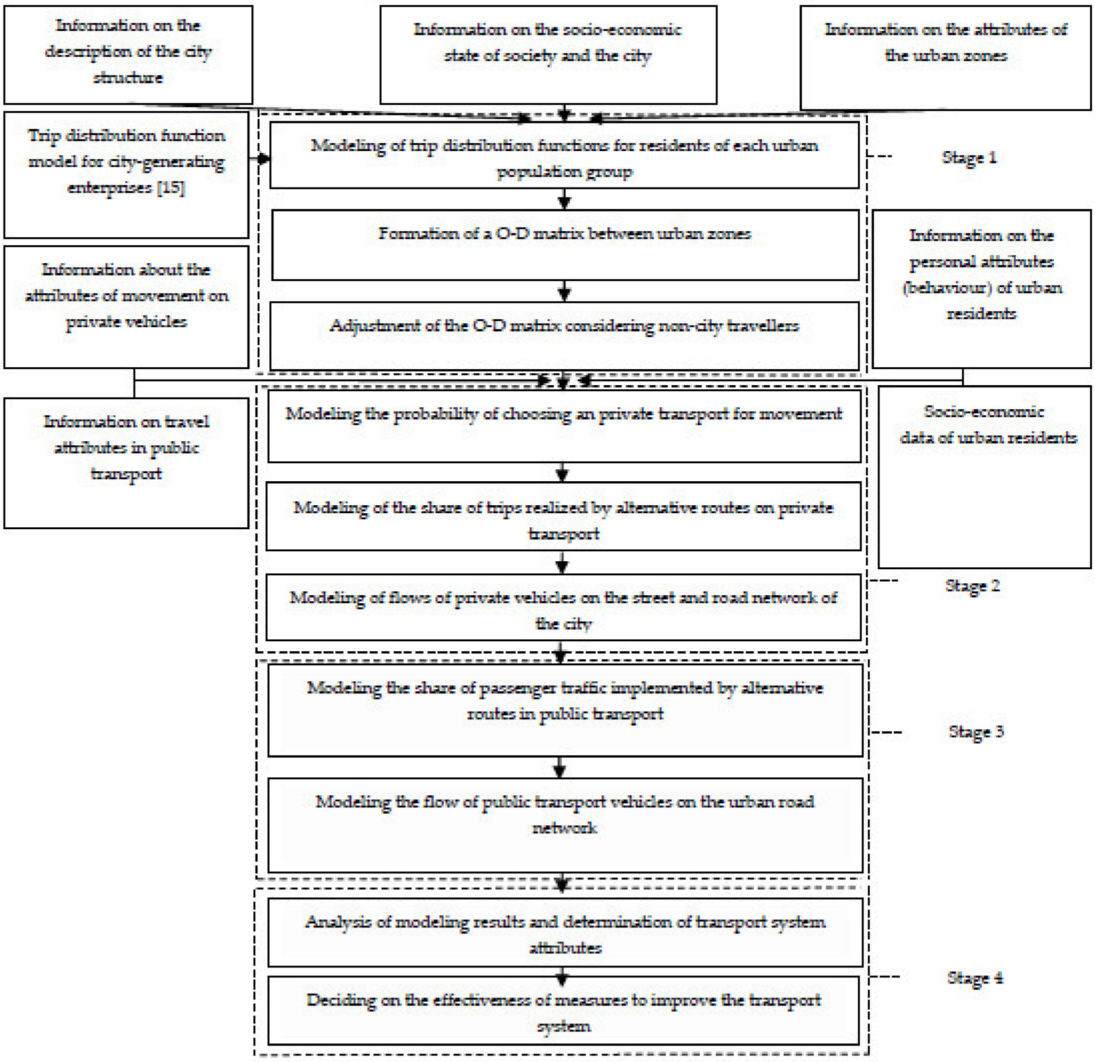

Figure 3. Sequence of stages of modeling transport and passenger flows in human-centric urban transport systems.

Transport generation occurs from meeting the needs of the population in travel and transit flows, ensuring public and private transport in the urban transport system. This affects the urban residents route selection, which determines the trip distribution function between urban zones.

In the first stage, the trip distribution function is modeled for each group of the self-employed person of cities. The use of trip distribution functions will allow an O-D matrix of citizen trips to be obtained. This matrix can be used to model traffic and passenger flows.

In the next stage II, to determine the indicators of transport and passenger flows, modeling the probability of choosing private transport for transit and generating the O-D matrix for it are carried out. To distribute the received trips on the existing urban network, the share of trips is modeled, which is realized by alternative routes of private transport. Considering the street and road network, the flow of private vehicles is modeled.

In the 3rd stage, the modeling of the share of passenger traffic is carried out, which is realized by alternative routes in public transport. Using the obtained data and involving attributes of the urban passenger transport network, the modeling of public transport flows is carried out.

Analysis of the results of modeling and determination of the transport system considering the flows of freight transport are carried out in the 4th stage. This allows the effectiveness of the measure to improve the transport system to be determined.

Thus, the implementation of this algorithm will predict the indicators of transport and passenger flows in the implementation of measures to improve urban transport systems.

4. Estimates of Informativeness of Data Influencing the Choice of Destinations

The choice of the trip distribution function type of residents should be made based on the analysis of attributes influencing the formation of travel needs. A number of factors have a significant influence on the movement of people such as the social structure of society, way of life, development of general production, geographical environment, the character of settlement, communication, technology, budget for leisure, culture, household, and general requests of people.

In the first stage of the study, data influencing the choice of cities of trip distribution were assessed. These attributes were the distance to the place of employment from the place of residence, travel time, distance to the city center from the departure zone, and the average distance of the urban zone from the city center.

The attributes of urban zones characterize the motivation of its residents to move from zones with fewer jobs to other zones where there are more jobs. This is the number of: places of employment in the zone of residence, inhabitants in the zone of residence, places of employment in the zone of employment, and residents in the zone of application.

Socio-economic data characterize the ability of urban residents to spend money on travel and change the zone of residence in relation to the zone of employment. These attributes included the cost of travel, the average salary of city residents, the average monthly income per family member, and the cost of one square meter of housing in residence and employment zones.

The data necessary to determine the trip distribution function of employees of city service enterprises were obtained during field research by questionnaires among employees of the city of Kharkiv. For this, the authors of the article developed a special questionnaire. The questionnaire developed recorded the places of employment and residence of employees, travel route, mode of transport, fare, and average monthly income per family member. When processing the questionnaires, the zones of departure and arrival were determined in accordance with the places of residence and employment of the inhabitants on the basis of a specially developed topological scheme of the city of Kharkov. When developing the scheme, the previously published microzoning rules [16] were used (Figure 4).

In the next stage, the average distance between zones and the geographical center of the city and the average distance to places of interest were determined using GIS. Travel time was defined as the sum of the time to approach the stop, wait for the vehicle, travel, change from one mode of transport to another, and depart from the final stop to the destination point. The average cost of travel was also determined.

To make calculations for each district of the city, the cost of housing and the number of inhabitants and places of employment in the zones of departure and arrival was determined.

The next step was the use of processed and evaluated results for the mathematical formalization of the trip distribution function of employees of urban service enterprises were obtained.

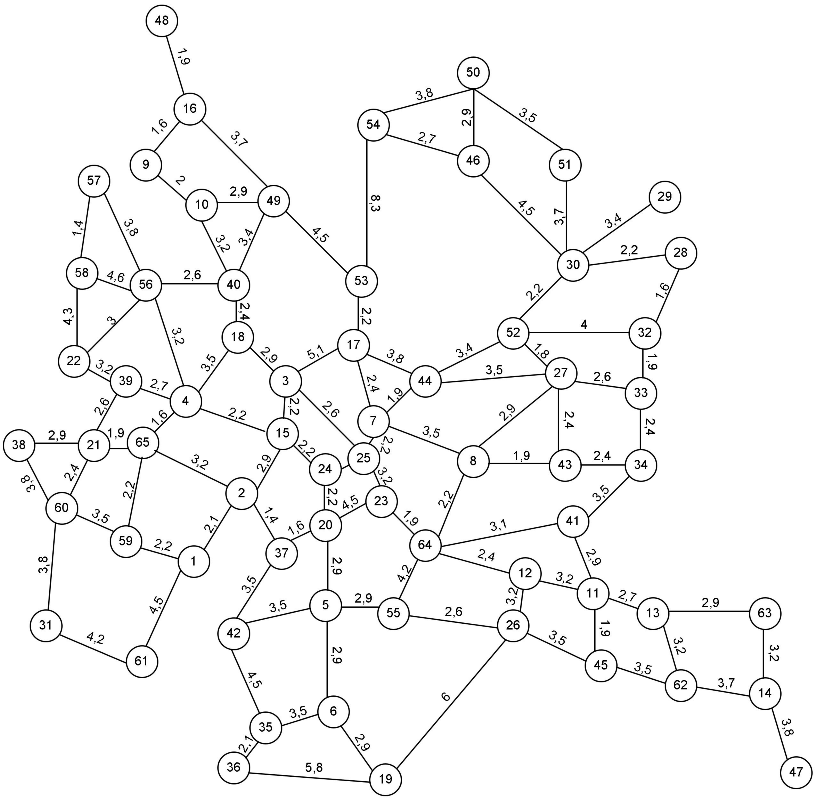

Figure 4. The scheme of zones of Kharkiv city with distances between zones: 31 —attraction of zones (nodes); 4 2,2 15 —links between zones, km.

5. Mathematical Model of Changing the Trip Distribution Function of Urban Service Enterprises' Employees

In the course of the research, a set of factors were identified that most adequately describe the choice of travel by employees of city service enterprises. During the development of the model changes in the trip distribution function, the previously mentioned factors were involved (Section 4).

Using the methods of correlation and regression analysis, the problem of the mathematical description of the change in the trip distribution function of employees of urban service enterprises was solved. Stepwise regression was used to determine significant factors. The regression coefficients were calculated by the method of least squares [17]. The results of calculations for the attributes of the model showing the estimated trip distribution function of city service enterprises' employees are given in Tables 1–3.

Table 1. Limits of measurement of the model of the trip distribution function of employees of city-service enterprises.

Attributes	Designation, Dimension	Measurement Boundaries
Travel time between zones i and j	tn_{ij}, min.	10–110
The ratio of the distance from the departure zone i to the center to the average distance from the zone to the city center	$\frac{Lr_i}{Lrs}$	0.39–2.44
The ratio of the cost of one square meter of housing in the zone of residence i to the cost of one square meter of housing in the work zone j	$\frac{Zz_i}{Zr_j}$	0.78–1.35
The ratio of number of places of application of labor in the zone of work i to the number of places of application of labor in the residence zone j	$\frac{Qr.r_i}{Qr.z_j}$	0.33–46
The ratio of the travel cost between zones i and j to the average income of a resident of zone i	$\frac{S_{ij}}{D_i}$	0.0005–0.0092
Quantity of inhabitants in the zone of residence j	$Qz.z_j$, ppl.	3061–103,794

Table 2. Characteristics of the model of the trip distribution function of employees of city-service enterprises.

Factor	Coefficient	Standard Error	Student's *t*-Test	
			Actual	Calculated
$\frac{1}{tn_{ij}}$	1.351	0.056	24.3	1.98
$1/\left(\frac{Lr_i}{Lrs}\right)$	0.016	0.008	2.1	1.98
$log\left(\frac{Zz_i}{Z}\right)$	−0.068	0.011	−6.28	1.98
$log\left(\frac{Q^o r.r_i}{Q^o r.z_j}\right)$	0.006	0.0009	6.57	1.98
$\sqrt{\left(\frac{S_{ij}}{D_i}\right)}$	−0.652	0.105	−6.2	1.98
$Qz.z_i{}^{0.4}$	0.0003	0.00007	4.19	1.98

Table 3. Confidence intervals of the coefficients of the model.

Factor	Lower Bound	Upper Bound
$\frac{1}{tn_{ij}}$	1.2	1.51
$1/\left(\frac{Lr_i}{Lrs}\right)$	0.0001	0.039
$log\left(\frac{Zz_i}{Z}\right)$	−0.098	−0.038
$log\left(\frac{Q^o r.r_i}{Q^o r.z_j}\right)$	0.003	0.008
$\sqrt{\left(\frac{S_{ij}}{D_i}\right)}$	−0.944	−0.36
$Qz.z_i{}^{0.4}$	0.00009	0.0005

The model has the following form:

$$\begin{aligned} d^o{}_{ij} = 1.351\frac{1}{tn_{ij}} + 0.0164\left(1/\left(\frac{Lr_i}{Lrs}\right)\right) - 0.068\left(log\left(\frac{Zz_i}{Zr_j}\right)\right) + \\ +0.006\left(log\left(\frac{Q^o r.r_i}{Q^o r.z_j}\right)\right) - 0.652\sqrt{\left(\frac{S_{ij}}{D_i}\right)} + 0.00028 Qz.z_i{}^{0.4}, \end{aligned} \quad (1)$$

where $d^o{}_{ij}$ is the trip distribution function of the workers of the city-service enterprises between zones i and j;

tn_{ij}—the travel time between zones i and j;
Lr_i—the distance from the zone of departure i to the city center;
Lrs—the average distance from the zone to the center;
Zz_i—the cost of one square meter of housing in the urban residence i;
Zr_j—the cost of one square meter of housing in the work zone j;
$Q^o r.r_j$—the number of places of employment in the work zone j;
$Q^o r.z_i$—the number of places of application of labor in the zone of residence i;
S_{ij}—the cost of travel between zones i and j;
D_i—the average income of a resident of i zone;
$Qz.z_i$—the number of residents in the zone of residence i;
D_i—the average income of a resident of i district.

After the development of the regression model, its statistical evaluation was carried out. The results of the calculations are given in Table 4.

Table 4. The results of the evaluation of the model of changes in the trip distribution function of the workers of the city-service enterprises.

Indicator	Value
Student's *t*-test: Calculated	1.3
Actual	148.76
Multiple correlation coefficient	0.99
Average approximation error, %	14.3

The results of the study showed that of all the factors studied, ten were significant, which reproduce the relevant connections. These ratios of factors were detected by using the method of stepwise regression. The significance of the model factors is evidenced by the calculated value of the Student's criterion, which is greater than the tabular value. This is also evidenced by the absence of zero in the confidence interval of each coefficient of the model. The information ability of the model was determined by Fisher's test. The estimated value is much larger than the tabular one. This suggests that the estimated model for movement between the transport zones of employees of urban service enterprises describes the results of the experiment better than the simple model, in which for any set of values of variables, the result is a constant equal to the average value.

The value of the multiple correlation coefficient used to define the relationship between the variable and the factors, indicates a high degree of close correlation between the values of the path distribution function and the selected factors. The adequacy assessment of the developed model was performed on the attribute of the average approximation error. The value of the average approximation error of trips to the allowable limits.

As a result of the calculations, it is possible to draw a conclusion about the admissibility of use of the received model of the trip distribution function of the city service enterprises' workers at forecasting indicators of transport and passenger flows in projects of urban transport systems.

To analyze the change in the trip distribution function of employees of city service enterprises, graphs of its change depending on the influence of each of the previously identified factors were developed. When constructing graphs, the value of one of the factors changed when the values of other attributes were equal to the average values. The results of the calculations are shown in Figures 5–10.

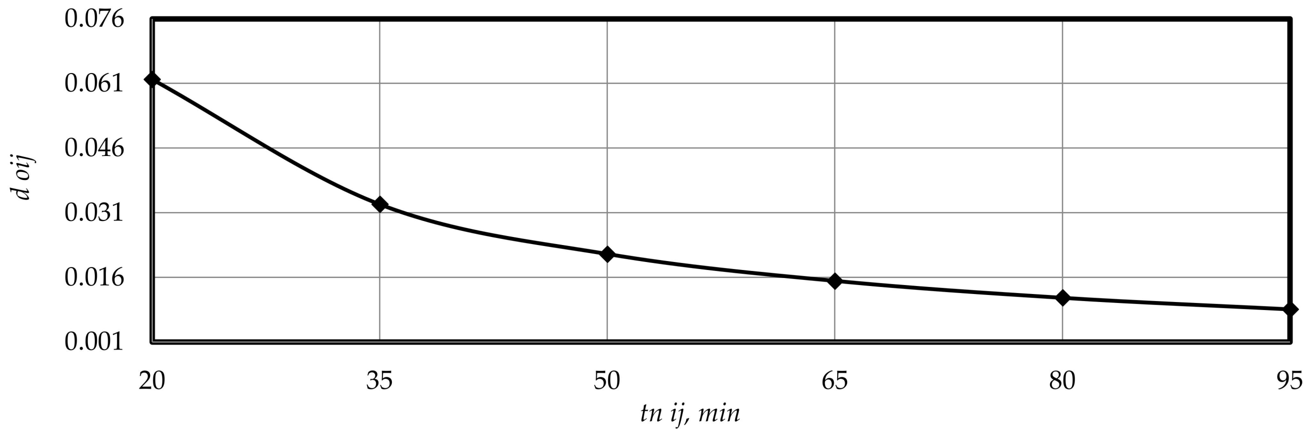

Figure 5. Graph of the change in trip distribution function of urban employers of service enterprises depending on the time of movement between zones.

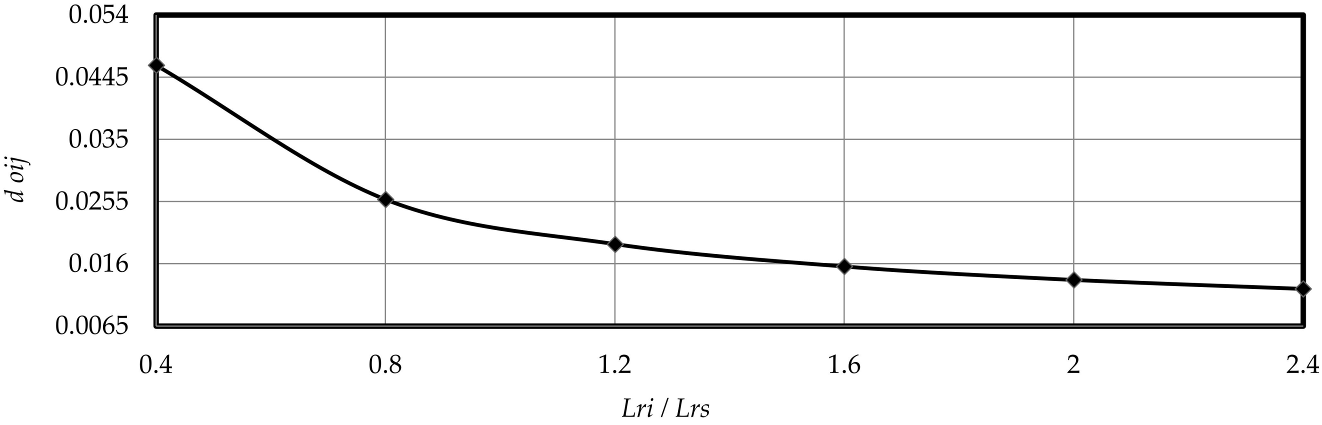

Figure 6. Graph of the change in trip distribution function of urban employers of service enterprises depending on the relation of the distance of the zone of departure to the city center to the average distance of zones of the city from the center.

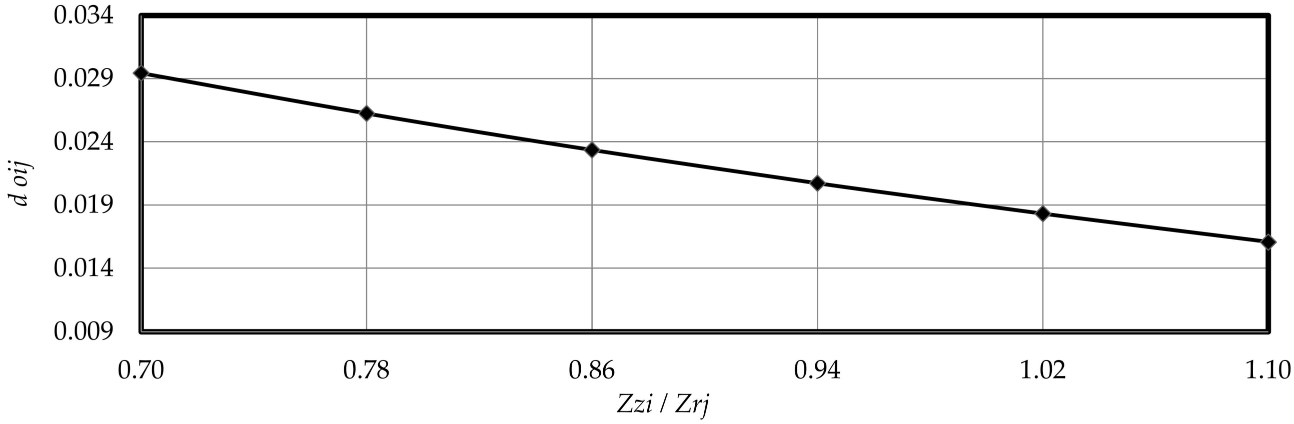

Figure 7. Graph of the change in trip distribution function of urban employers of service enterprises depending on the ratio of one square meter cost of housing in the zone of residence to the cost of one square meter of housing in the zone of application of labor.

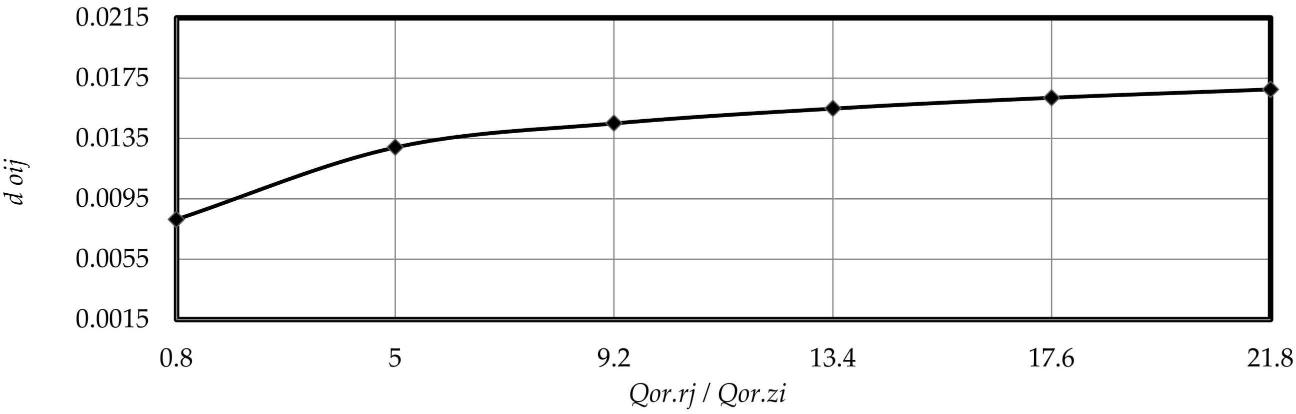

Figure 8. Graph of the change in trip distribution function of urban employers of service enterprises depending on the ratio of quantity of places of application of work in the zone of application of work to the quantity of places of application of labor in the zone of residence.

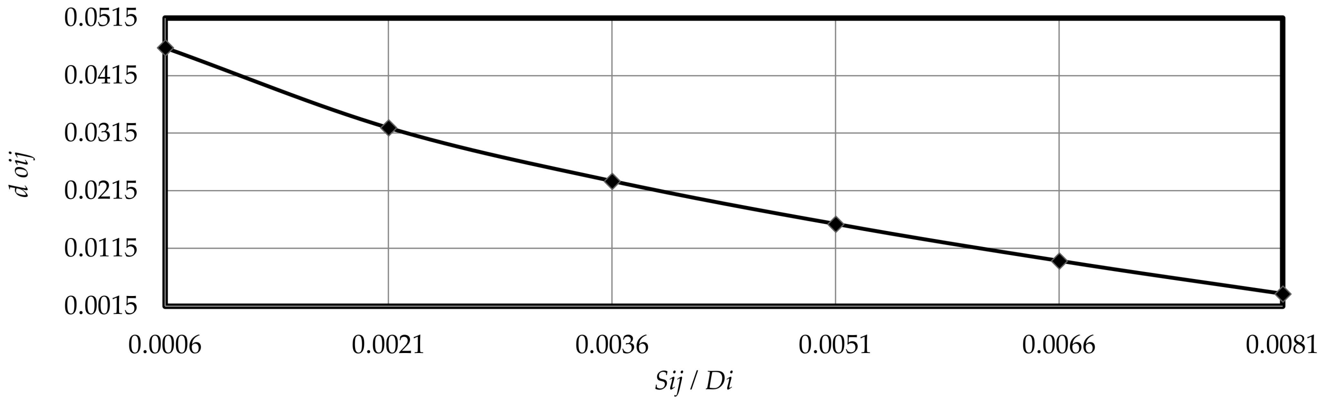

Figure 9. Graph of the change in trip distribution function of employees of the city service enterprises depending on the relation of the cost of travel to the average income of the zone of residence.

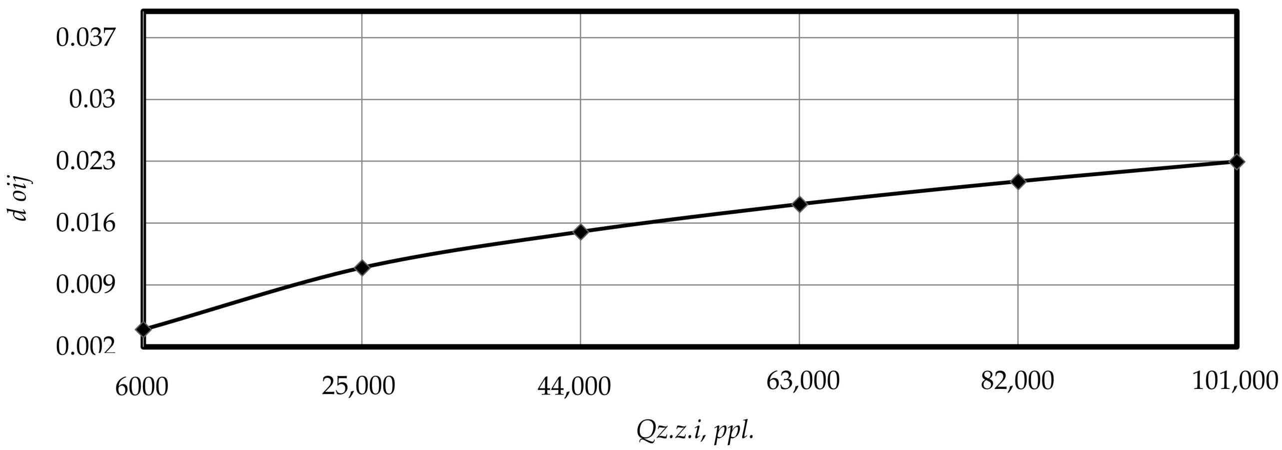

Figure 10. Graph of the change in trip distribution function of urban employers of city service enterprises depending on the number of inhabitants in the zone of residence.

Relevant conclusions can be drawn from the analysis.

As the travel time between departure and destination zones increases, the value of the trip distribution function decreases. It is also due to the fact that employees of city service companies usually choose a place of work as close as possible to the place of residence to keep travel time to a minimum.

As the ratio of fare to average wage increases, the value of the trip distribution function decreases. This is due to the fact that employees of city service companies will not use very expensive transport, such as taxis.

With an increase in the ratio of the distance of the departure zone to the city center to the average distance of the urban zones from the center, the value of the trip distribution function decreases. This is due to the fact that as the distance increases, the travel time and the cost of travel increase.

With an increase in the ratio of the cost of one square meter of housing in the zone of residence to the cost of one square meter of housing in the zone of labor application, the value of the trip distribution function decreases. Simultaneously, with the increase in the number of places of employment in the zone of employment to the number of places of employment in the zone of residence, the value of the trip distribution function increases. This is due to the fact that there are vacancies in other zones.

6. Discussion

People's satisfaction with their trips to work can affect their subjective well-being and overall quality of life [55]. Recently, the COVID-19 pandemic has had a significant impact on urban travel decisions. The duty of a modern city is to fully meet the needs and expectations of its inhabitants, while offering a wide range of opportunities. City management involves taking the necessary measures in accordance with the idea of a smart city. To implement these measures, it is necessary to use widely available tools, which are defined as intelligent solutions [61]. In a pandemic, it is important for decision-makers to organize the transport process and the implementation of the decision support system under conditions of uncertainty in the modeling of transport and passenger flows.

The information technology proposed in this work forms the stages of decision-making in the sustainable management of urban transport systems using intelligent transport systems. Its peculiarity is taking into account the individual characteristics of urban residents, determined by the type of person's temperament. This will take into account the needs and expectations of the urban population.

Predicting the migration of people as accurately as possible is important in city-building, international trade, the spread of infectious diseases, conservation planning, and public policy development [61]. Human movement models can help reduce road congestion and pollution, and can be used to determine land use policies and development options [62]. The scientific basis of these studies is the study of the multifaceted decision-making process of urban residents [54]. In their work, scientists use a passenger-centric approach. This passenger-centered approach places the individual at the center of future decisions, where their growing demand and values are used by sustainable management as a way to enhance the existing core functionality service [46]. The trip distribution function of city service enterprises employees given in this work is obtained on the basis of the results of field surveys, taking into account the individual decision-making of city residents when choosing places of employment. Their use will consider the peculiarities of the choice of trip distribution places by city service enterprises employees.

According to researchers, traditional models of human mobility, such as gravitational models, predict flows of human mobility based only on population and distance functions [62]. Gravitational modeling is currently used in solving various transport problems: planning a new transport service (or a new road); defining the boundaries of retail purchases; understanding the impact of migration on consumption patterns; analysis of admission to universities; determining the optimal location of infrastructure. One of the disadvantages of these models is that they have a fixed shape and are, therefore, unable to capture the more complex dynamics of migration [63]. Researchers have determined that there is no limit to the number of variables that can be used to describe a particular attribute; in addition, including more than one variable for any or all of the attributes will not change the general discussion. The trip distribution function of city service enterprises' employees proposed in the article, in addition to distance, considers the parameters of the socio-economic factors, city structure, and parameters that characterize the areas of residence and employment. Its use allows a wider range of factors to be taken into account and a more adequate matrix of correspondence of city service enterprises employees to be obtained.

7. Conclusions

The development of urban transport systems should be aimed at building comfortable living conditions for the population. The successful creation and functioning of projects for the development of urban transport systems can be carried out only with the consistent implementation of the information technology, which makes it possible to improve engineering methods in urban transit in a new way. The purpose of ITS is to produce information for further analysis of sustainable management decisions. Existing research and methods for forecasting the traffic and passenger flows do not include personal attributes of urban residents. Personal attributes of zone's residents constantly influence all their decisions, including those related to transport. Therefore, it is important to understand how residents will behave under the influence of the conditions of transport systems' functioning. The offered intelligent decision support system for modeling transport and passenger flows in human-centric urban transport systems allows the information on forecast values of attributes of flows of vehicles to be received, considering the personal attributes of residents at decision-making on movement. This is the first result of the study. The novelty of the proposed information technology is considering the age and temperament of urban residents when modeling their travel path. Components of intelligent decision support systems are a set of models for predicting the attributes of movement of urban residents.

The proposed trip distribution function of employees of urban service enterprises is based on the attributes of its structure: socio-economic data and attributes of urban zones. It should be noted that the range of measurements of the model factors trips to the initial data for the city of Kharkiv. The proposed trip distribution function, which is the second result of the study, makes it possible to form an O-D matrix for local service providers to predict the transport and passenger flows for improving the transport system of cities, as well as the construction of new residential zones. This is its technological focus for improving the transport service of urban residents. In future research, it is planned to develop a model of the attraction function for students of higher education and colleges. Demand modeling in transportation planning will provide information for the economic justification of a long-term strategy for the development of transport systems, taking into account the complex realities of modern society.

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