

DEVELOPMENT OF A METHODOLOGY FOR SELECTING THE LOCATION OF TRANSPORT INTERCHANGE HUBS IN CITIES

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Abstract

In major cities around the world, the leading issues are the correct selection of the location of transport interchanges, determining economic and social efficiency, directing passengers to public transport through the effective organization of coordinated movement of transport modes, and minimizing the total time spent by passengers to reach their destinations while providing reliable transport service. Various mechanisms have been developed by transport scientists around the world to correctly select the location of transport interchanges. As a result of research conducted by world scientists on the correct location of transport interchanges, it was determined that the time spent by passengers on the journey is one of the main criteria, and work was carried out to minimize the total travel time, costs and emissions of environmentally harmful gases from transport vehicles. An algorithm for optimizing the location of transport interchanges (Transport Interchanges) was developed taking into account the initialization of the main parameters, determination of the objective function, verification of boundary conditions, solution of the optimization problem and determination of the results. This article is devoted to the development of a methodology for selecting the location of transport interchanges in cities.

Keywords: Transport links (Transport Interchanges), Euclidean distance, Manhattan distance, travel time, fare costs, ecology, location.

Introduction

The correct choice of the location of transport links in the regions has a positive effect on the optimal distribution of passenger flows between different routes in the city, reducing the time and cost of travel, as well as reducing the harmful impact of transport on the environment. It is important to ensure safe, comfortable and less time-consuming transfer of passengers from one mode of transport to another. The correct placement of such links in the city's transport system



increases the overall efficiency of the existing transport infrastructure and, therefore, has a positive effect on the economic indicators of the region.

In accordance with the Decree of the President of the Republic of Uzbekistan dated February 16, 2023 No. PP-59 "On measures to reform the public transport system", it is envisaged that transport interchanges should be organized in the regions. However, there is no single methodology for organizing, designing and determining the location of transport interchanges in the regions. When developing a methodology for choosing the location of transport interchanges in cities, it is necessary to separately approach the following main criteria: "location determination", "transport integration", "infrastructure", "safety and convenience", "ecology", "development". Increasing the level of reliable transport services for passengers in any conditions through the correct choice of the location of transport interchanges in cities is becoming a priority. Numerous scientific studies are being conducted in this direction by researchers around the world.

1. Literature analysis

At present, it is very important to understand the organization of transport and transit links and determine their locations. In the transport concept being developed in the Republic of Uzbekistan, the organization of transport and transit links and their linkage with modes of transport remains a pressing issue. Vlasov D.N. In the formation of transport and transit links, such indicators as the city's population and its geographical location play a key role. The author recommends combining international and intercity links for medium and small cities into a single TGP, emphasizing the need to form them on the basis of regional (local) urban planning standards. [3]

Ho Thu Phuong, Shcherbina E.V. Analyzed the trajectory of passenger flow at 5 large bus stations and in the Hanoi metro, developed and applied in practice a mathematical expression for the time of transfer of passengers from one mode of transport to another..[4]

Yuwei Yang, Jun Chen, and Zexingjian Du considered the bus and subway system as an important link in the urban multimodal system, redistributing large passenger flows from the suburbs. In the course of the study, the scientists identified six factors that influence combined transportation: personal characteristics of passengers, purpose of travel, mood of passengers, convenience of travel, fare, and flexibility. Other scientists noted that the main reasons are waiting for transport and transfer from one mode of transport to another. [5]

M.V. Fedorova, when developing a three-stage methodology for assessing the locations of transport and transit links, conducted a comprehensive assessment in order to determine the prospects for regional development, identify areas with high transport potential in the present and future, analyze the existing transport infrastructure that provides passenger transportation in the region, and select a promising location for a transport and transit link, as well as in the transport network and regions with high passenger traffic. The need for a subsequent analysis process based on logistic criteria is substantiated. [6]

Moskvichev O.V., Leonova S.V. developed a method for determining the location of a transport transfer based on the criterion of average travel time for a passenger using mathematical modeling. The proposed method consists of three stages: studying the needs of passengers for



transport services, calculating the volume of passenger flows, constructing a matrix of correspondence between intermediate stations, and selecting optimal routes for passengers in the urban public transport system. It is based on selecting "effective" transport and transport transfer hubs that provide transfers from one type of transport to another, and selecting the location of a transport and transport transfer based on an optimal mathematical model based on the criterion of average travel time for a passenger, based on an assessment of the criterion of the size of the passenger flow. [7]

O. Rassolov, N. Popova, V. Naumov considered the issue of assessing the possibility of using transport due to the rational placement of a transport hub. For the city of Kharkov (Ukraine), work was carried out to determine and assess the rational placement of a transport hub by developing a model for changing passenger traffic in the transport hub system using PTV VISUM software. [8]

Egorova Irina Nikolaevna contributed to the development of multimodal passenger transportation in the logistics transport system of the region. At the same time, the researcher paid special attention to the dynamic growth of the socio-economic status of the region's population when determining the required OPM and developed a method for determining the number of required OPM for the region using mathematical analysis. [9]

Nezir Aydin et al. developed a comprehensive and adaptive methodology for selecting mobile hub locations by synergistically combining WASPAS, MCDM and AHP methods. This study offers a new approach to the complex urban planning problem and makes an important contribution to this field. [10]

The analysis of the research showed that many studies have been conducted on the optimization of public transport networks, the assessment of the main options for the location of transport links (TRL) according to various parameters, but studies on obtaining solutions aimed at minimizing the total time of stay of passengers in the TRL location optimization model are insufficient.

2. Research Methodology

In order to optimize the placement of the transport link (TH), develop a model for minimizing the total time of stay of passengers and, on this basis, develop an optimal solution for the provision of passenger transport services, the following model indicators were adopted.

Let (X, Y) be the coordinates of transport and transit links. Optimal coordinates ensure efficient communication of various types of transport with the necessary centers, reduce travel time and increase the convenience of using transport.

The parameters (X_i, Y_i) and the coordinates of the i -th target center, where N is the number of target centers. The coordinates are crucial in determining the distance from the target center to the transport interchange, which directly affects the quality of transport services for passengers.

The transport interchange (TH) location optimization model includes many parameters that influence the choice of its location. Let's consider each of these parameters in detail.

P_i is the number of passengers using the transport system at the i -th destination. The parameter characterizes the intensity of passenger traffic.



V_i — the speed of transport communication on roads in the zone of influence of the center. This parameter allows to estimate the current congestion of roads and the need to improve transport services in this territory.

W_i – i -Average waiting time for transport at the target center. The indicator is important for assessing the quality of transport services and convenience for passengers.

C_i – i - Cost of travel for the future center. Optimization of this parameter allows to reduce financial expenses of passengers on transport services.

E_i – Impact of the i -thrust center on the environment. Including this parameter in the model helps to reduce the negative impact of the transport system on the environment.

D_i – Environmental factors of the i -target center. These factors are important for ensuring the environmental sustainability of the transport system.

G_i – Classification of cities. Belonging of the i -th desired center to (republican, regional or district significance). The parameter allows to take into account differences in the significance and development of different cities. Republican cities may need a more developed transport infrastructure than regional ones.

The objective function of the model is the total time spent by passengers on travel from prospective transport hubs to transit transfer hubs (TH).

Travel time reflects the distance traveled by passengers from their final destination to TH, while waiting time describes the amount of time passengers spend waiting for transport.

Function of the time it takes passengers to travel from the aspiration center to TH

$$L(X, Y) = \sum_{i=1}^N P_i \cdot (d_i(X, Y) + W_i) \quad (1)$$

where $d_i(X, Y)$ is the travel time from the i -th applicant center to TH, which can be determined as follows:

$$d_i(X, Y) = \frac{\sqrt{(X-x_i)^2 + (Y-y_i)^2}}{V_i} \quad (2)$$

Different distance metrics are used to calculate travel time from target centers to a transport hub (TH). In our study, we use the most commonly used Euclidean distance.

The Euclidean distance is the distance in a straight line between two points on a plane, measured along a straight line. It is calculated using the Pythagorean theorem and takes into account situations where movement occurs in a straight line, without taking into account the structure of streets and roads. The formula for calculating the Euclidean distance between the center of gravity and the point TH is as follows:

$$\sqrt{(X - x_i)^2 + (Y - y_i)^2} \quad (4)$$

Euclidean distance is used when the transportation network allows straight-line travel or when streets and roads are organized in a regular grid that minimizes the effects of corners and turns.

The transit placement optimization model aims to minimize the total time spent by passengers.

The function using Euclidean distance to calculate travel time is as follows:

$$\min_{X, Y} L(X, Y) = \min_{X, Y} \sum_{i=1}^N P_i \left(\frac{\sqrt{(X - V_i)^2 + (Y - y_i)^2}}{V_i} + W_i \right) \quad (6)$$



The objective function of the optimization model can use different distance measures to calculate travel time. Euclidean distance is used in environments where travel occurs in a straight line.

The optimization model includes a number of boundary conditions that ensure the fulfillment of various requirements and conditions to achieve a balanced solution. Let us consider each boundary condition in more detail.

Fare restrictions. The total fare for all passengers must not exceed the maximum amount allowed.

$$\sum_{i=1}^N C_i \cdot P_i \leq C_{max} \quad (8)$$

C_{max} – the maximum total fare allowed for all passengers.

Boundary conditions are important to ensure the convenience of the transport system. This ensures that the overall transport costs of passengers remain at an acceptable level.

Boundary condition of environmental impact. The boundary limits the overall environmental impact, which should not exceed the maximum permissible value..

$$\sum_{i=1}^N E_i \cdot P_i \leq E_{max} \quad (9)$$

E_{max} – maximum permissible total impact on the environment.

The boundary condition is necessary to ensure the environmental sustainability of the transport system.

Boundary condition of environmental factors. The limit ensures that the sum of environmental factors does not exceed the permissible maximum.

$$\sum_{i=1}^N D_i \cdot P_i \leq D_{max} \quad (10)$$

D_{max} – maximum permissible level of environmental factors.

The boundary condition helps to control and minimize the negative impact of the transport system on the environment.

Boundary condition for uniform distribution of transport-transfer nodes according to city types. This boundary condition ensures an even distribution of transport-transfer nodes based on the significance of border cities.

Cities of republical significance

$$\sum_{i \in \{G_i = 1\}} P_i \geq P_{min}^{repub} \quad (11)$$

$G_i = 1$ – indicator that the i -th destination center is located in a city of national significance.

P_{min}^{repub} – the minimum number of passengers required to locate a transport interchanges (TI) in a city of national significance.

To cities of regional significance:

$$\sum_{i \in \{G_i = 2\}} P_i \geq P_{min}^{reg} \quad (12)$$

$G_i = 2$ – indicator, the i -aspiring center is located in a city of regional significance. P_{min}^{reg} – the minimum number of passengers required to accommodate transport interchanges in a city of regional significance.

To cities of district significance:

$$\sum_{i \in \{G_i = 3\}} P_i \geq P_{min}^{dist} \quad (13)$$



$G_i = 3$ indicator, indicator, i -aspiring center is located in a city of district significance. P_{min}^{dist} – the minimum number of passengers required to accommodate a transport interchange in a city of district significance.

The boundary condition helps to ensure a fair distribution of transport resources between cities of different importance. This guarantees the placement of transport links not only in large and important cities, but also in less important settlements, which contributes to the uniform development of territories and the improvement of transport access for all categories of the population. Taking into account the above objective function and boundary conditions, an algorithm for the placement of transport interchanges (TH) was developed.

The algorithm developed to solve the problem of optimizing the placement of a transport interchanges (TH) includes several main stages, from parameter initialization to displaying the results on a map. Each stage plays an important role in achieving the optimal solution and ensuring a systematic and comprehensive approach to improving transport infrastructure.

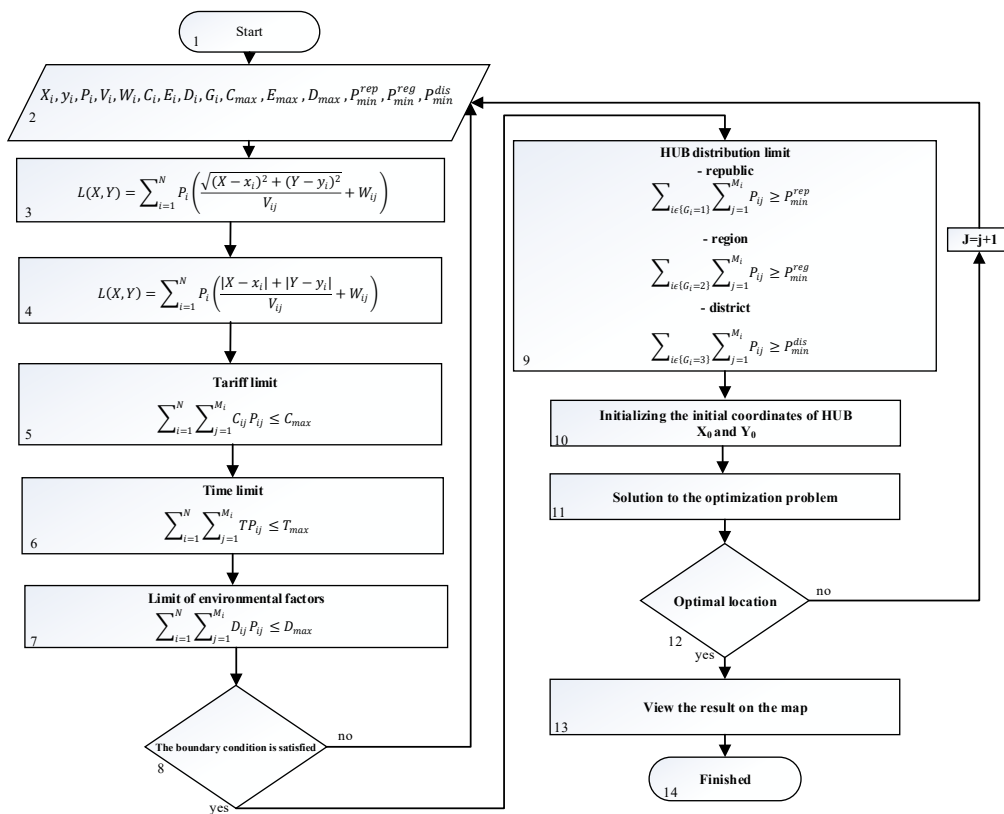


Fig. 1. Optimization Algorithm for Placing transport interchanges (TH).

The algorithm for optimizing the placement of transport links includes initializing the parameters, determining the objective function, checking the boundary conditions, solving the optimization problem and outputting the results.



3. Research results

A field study was conducted to select the location of transport interchanges (TH), and the research was analyzed. The study was carried out over 7 days (work and rest days) during the morning peak hours. It primarily focused on determining passenger travel times, daily traffic flow arriving at the transport interchanges, passenger transportation costs, and the amount of harmful exhaust gases emitted by transport vehicles into the environment.

The determined indicator for the passenger's arrival time at the destination, based on the boundary condition $T_{max}=1\text{watch}<C_{max}=1,20$ showed that the calculated result for the transport interchange (TH) location exceeded the required range by 20%.

The set boundary is $C_{max} = 2476 \text{ UZS}$, and $C_{total} = 4062 \text{ UZS}$. According to the calculations, the transport interchange (TH) location exceeds the established road toll requirements by 40%.

According to the results of the above method, it was determined that, during peak time intervals, an average of 1289 vehicles of various brands moved in the area, belonging to classes 3-4 (Euro) and emitting harmful exhaust gases. The emission rate for a 0.3 km distance was calculated to be 3.5 kg. Based on the results from the PTV-VISSIM software, the ecological impact of the vehicles on the street network was recorded by the F indicator. It was determined that the established boundary conditions regarding the environmental impact were at a critical level (the lowest) according to the service level (LOS) criteria

Conclusion

The article presents a methodology for selecting optimal locations for transport interchange hubs (TH) in urban areas, focusing on minimizing passenger travel time, costs, and environmental impact while enhancing transport efficiency. The proposed model incorporates key parameters such as passenger flow, travel speed, waiting times, fare costs, and ecological factors. Using Euclidean distance and optimization algorithms, the methodology evaluates TH placement based on objective functions and boundary conditions like fare limits and environmental sustainability. A field study conducted over seven days during peak hours revealed that the selected TH locations exceeded acceptable travel time and cost thresholds by 20% and 40%, respectively, with significant environmental emissions. The study underscores the need for a balanced approach to TH placement to improve urban transport systems, ensuring accessibility, safety, and sustainability across cities of varying significance.

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