Application of geoinformation systems to ensure sustainable development of the city transport system

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Abstract. Population increase and urbanization of cities in all countries in recent decades, therefore, ensuring the development of the urban environment has become an important and relevant issue. The article considers the possibility of using a geographic information system (GIS) to ensure the functioning of the city’s transport systems and the selected basic tools of spatial analysis: transport accessibility of the area, air pollution (emissions), noise pollution, energy consumption, route and transport network, traffic and transport network infrastructure. The main components of GIS in the field of transport are analyzed. In addition, it uses methods for collecting, researching, synthesizing, analyzing, evaluating and presenting data on the transport environment of the city. The development of the urban environment is associated with the creation of transport systems that require large costs for movement and economic feasibility.

1. Introduction
Transport plays an important role in the implementation of human activities; therefore, attention must be paid to supporting the sustainability of its development as an industry. An increase in the population and urbanization of cities has been observed in all countries of the world over the past decades, therefore, ensuring sustainable urban development is becoming an important and relevant issue. The growth of the urban population is directly proportional to the increased need for mobility, both by public and individual transport. In this regard, there is a need to evaluate (measure) the effectiveness of functioning of transport system [1-3].

The following analytical methods are distinguished for assessing the relationship between urban and transport environments: descriptive statistics (research and graphical methods), spatial statistics, spatial mapping, travel preference functions, regression analysis [4]. However, the article discusses the use of a geographic information system (GIS) as a tool for analyzing the effectiveness of a city’s transport system.

2. Concept of geoinformation system
To wide extent, a geoinformation system is an information system specializing in the input, management, analysis and presentation of geographic (spatially related) information [5]. The main advantages of the system are the ability to store large amounts of data, analyze them and visualize the obtained cartographic results. Among the wide range of opportunities for which GIS can be used, much attention is paid to transport issues. This specific area, designated as GIS-T, is one of the first application areas of the geoinformation system.
The use of GIS in transport is quite widespread, the main areas of application include traffic modeling, analysis of traffic accidents, planning of public transport routes and environmental assessment of the urban environment. The main requirement for vehicles is the availability of a structured network of streets. There are problems connected with technology of control GIS. They are database maintenance and management; selection and updating of hardware and software; the use of technology to solve problems; creation of transport networks and providing user access. Standard GIS functions include thematic mapping, statistics, scheduling, matrix manipulation, a decision support system, modeling and algorithms, as well as support for simultaneous access to multiple databases.

3. GIS-T components

There are four main components of GIS-T: coding, management, analysis and reporting (Figure 1) [5].

![Figure 1. Components of GIS-T [5]](image)

3.1. Coding

This component of the system is designed to represent (visualize) the transport system and its spatial components. For the use in GIS, the transport network must be correctly encoded, which implies a functional topology consisting of nodes and links. All the elements related to transport network, namely qualitative and quantitative data, must be also encoded and associated with their corresponding spatial elements. For example, an encoded section of a road network is characterized by width, number of lanes, and driving direction.

3.2. Management

Encoded information is often stored in a database and can be organized by spatial (regions, cities, countries), thematic (city street, express road) or time periods (year, month, week). It is important to design a GIS database that organizes a large number of heterogeneous data in an integrated environment so that they can be easily accessed for the operation of transport applications.

3.3. Analysis

It is possible to use a wide range of methodologies and tools available to solve transport problems. They can range from a simple query on an element of the transport system to a complex model that explores the relationship between its elements.
3.4. Reporting
A geographic information system would not be complete without its ability to visualize and present data. This component is especially important because it offers interactive tools for conveying complex information in a visual format. Thus, GIS-T is becoming a useful tool for informing the public about the transport situation in the city.

Geographic information technologies are designed to automate many time-consuming operations that previously required a lot of time, energy, psychological and other costs from a person. However, the various stages of the technological chain lend themselves to greater or lesser automation, which to a large extent may depend on the correct formulation of the initial tasks.

Information in the GIS is stored and presented in the form of layers, which are a set of geographical objects associated with their characteristics. In the above figure, the transport system is presented in the form of three levels associated with the urban environment, by flows (spatial interactions) and network. Each has its own characteristics, related data and can be used independently or in conjunction with other layers.

Geographic information systems, in conjunction with global positioning systems (GPS), change the methods of collecting, researching, synthesizing, analyzing, evaluating and presenting data on the transport environment of the city [6]. The use of GIS for the analysis and planning of the transport system is reduced to the creation of digital maps of the city, dynamic modeling of traffic flows and the integration of spatial data. The development of the urban environment is associated with the creation of transport systems that contribute to sustainability in terms of increasing social interaction of the population, reducing time spent on travel and economic feasibility [3, 7].

GIS has several spatial analysis tools that can be used to assess the effectiveness of the sustainable development of the city’s transport system: transport accessibility of the area, air pollution (emissions), noise pollution, energy consumption, route and transport networks, traffic and transport infrastructure.

Spatial analysis tools allow determining the transport need of the city’s districts based on an analysis of various factors: the level of motorization, population density and the location of attraction centers. It is convenient to perform such an analysis on the basis of a digital map and regionalization prepared in a GIS.

Network analysis tools allow building optimal routes on a real street-road network with its capabilities and limitations (street capacity, permitted traffic directions, turns). A database of passenger transport routes with an integral geographical component is the basis for preparing traditional transport maps and creating interactive information systems for the population. In addition, the analysis tools available in the GIS allow not only laying routes on existing network of streets, but also planning the development of this network, calculating its bottlenecks, that is, evaluating the effectiveness of its functioning.

4. GIS-T and transport modeling
The authors consider the relationship between GIS and transport models in order to plan the organization of the urban environment more detailed. As it is noted in the works earlier [1, 2, 4, 8], GIS has all the capabilities to support the analysis of spatial processes and improve spatial modeling, in the same turn, these capabilities are simple tools for development and visualization.

GIS is mainly data driven, and transport models are theory-based. Thus, the GIS data are detailed, while the data for transport modeling contain as much information as is needed to execute a particular algorithm (Figure 2).

The upper part of the figure represents the GIS approach to the zonal and network system; the road network is reflected taking into account its configuration and position in space with respect to fixed objects (buildings, structures). The bottom of Figure 2 is a display of the source data for the transport model. The presentation of the transport model in the corresponding software consists of intermediate nodes, while the GIS can consist of hundreds of coordinates. This feature can be attributed to the fundamental difference between GIS and modeling.
Fig. 2. Differences in the representation of space in GIS and transport modeling

Most GISs are not intended for a specific application or for one purpose, but have a stable foundation in a spatial perspective. The lack of theoretical guidance that would characterize the operation of GIS often leads to excessive data collection. By having a theoretical foundation in terms of modeling, unnecessary data collection can be avoided. In transport modeling, spatial perspective is replaced by network connectivity. This can be seen as a fundamental theoretical and conceptual difference between the two systems [8].

Even the simplest processing of time, the path from one system state to another is poorly represented in GIS. Time processing in transport models is also criticized, but they allow predicting simple transitions from one state of the system to another. Transport models are designed to find out what happens as a result of changes in transport infrastructure. In GIS, most of the “what if” questions will remain unanswered. Zonal characteristics in GIS are indicators such as the number of residents, jobs, and the area of attraction.

GIS is ideal for describing, presenting and sketching current and future land use and will be used for storing, retrieving and managing geographic features to visually reflect the future use of the urban environment.

This can be seen as tracking town planning at different points in time, now and in the future. Figure 3 shows the process of predicting the state of a system in GIS.

Fig. 3. Process of predicting state system in GIS
At time $t$, the system is provided with geographic data: zones, networks, environmental data, facilities and planning restrictions, etc. These objects are associated with data, for example, population, employment, income and type of housing, etc. for each type of object. A detailed geographic database is the main planning tool; it is also possible to make changes to the characteristics of a particular zone to achieve various planning goals, and to obtain information based on combinations in space and on various variables. Based on the zonal data, it is possible to calculate transport-related indicators, such as potential values of object availability, using simple analytical tools available in GIS.

GIS can also be used as a tool for analyzing research data. On the basis of thematic maps, which can be improved with the help of graphs associated with maps, one can get an idea of complex spatial processes. The visualization of these processes can be obtained using analytical tools built into the GIS, which in most cases are sufficient for transport analysis.

Such time slices can be made over several periods, the process of which is illustrated in Figure 3. GIS does not provide any connection between different time periods, in connection with this there is a lack of random and theoretical relationships between previous states of the system.

The complexity of transport modeling increases with the number of functional limitations. Taking into account only one restriction on the registration of departure and arrival points on the transport network, it is quite difficult to model in practice the real values of the duration of the movement and the route.

In this regard, the transport accessibility of the object of gravity at location $k$ can be determined at time $t$ taking into account one restriction of the point of departure $i$ and one destination $j$ with a fixed time of departure and arrival. By adding information about the travel time $t_i$ between the set points, we can determine the potential route ($PR$) defined in equation (1) [8]. $PR$ takes into account individual time limits and duration of movement.

$$PR = \{(k, t) \mid t_i + t_k \leq t \leq t_j - t_k\},$$

where $t_i$ – latest departure time from point $i$, $t_j$ – earliest start time for arrival at point $j$, $t_k$ – travel time from $i$ to $k$, $t_j$ – travel time from $k$ to $j$.

Based on the simulation, we can illustrate the prism of space-time and its projection onto the map: the area of the potential route ($PRA$). $PRA$ gives us the maximum time that can be spent in every place $k$. Obviously, for the region $k$, which should be in the $PRA$, $t$ must be greater than 0. In this structure, it is assumed that the $PR$ is fixed taking into account restrictions on points of departure and arrival.

Based on the potential route, it is possible to determine a number of characteristics of transport accessibility: the maximum residence time $t_k$, the number (or amount) of possible routes, the sum of the possible routes, taking into account the definition of the distance function. When determining the functional relationship “space-time” it is necessary to take into account the additional travel time, taking into account the duration of the approach to the departure / arrival points. This aspect is an important point in modeling, which is not taken into account by other types of accessibility. Additional travel time is determined by equation (2):

$$t_{kj} = (t_k + t_j) - t_i,$$

$i$ may be equal to $j$, which means no movement. If $i = j$ and $k$ are objects of gravity with points of arrival and departure from $i$ to $j$, the extra travel time is 0.

The final step is to take into account the time spent $t_i$ in each place $k$. Total time will be equal $t_{kj} + t_i$. If $t_i$ is impossible (or difficult) to estimate, then a functional constraint on the desired parameter can be imposed. Equation (1) does not take into account the human factor, except for time limits.

Time constraints are not necessarily human-related; rather, most restrictions are consequences of environmental influences. They do not say anything about the individual preferences of the population, that is, the usefulness of any object of gravity is the same in space if it is in the zone of a potential route. In addition, equation (1) is closely related to cumulative indicators of transport accessibility, in this case the difference is that the amount is limited by $PRA$, taking into account the necessary presence at fixed points on the route.
5. Conclusion

The main functional purpose of GIS in transport planning is the collection, management and display of model input and output data. Nevertheless, in research a new direction, in which the analytical advantages of GIS are used, is being actively developed. An example is the design of the zonal distribution of traffic flows based on special solutions and analysis of the model output using spatial statistics.

The use of GIS in modeling of transport requires high quality data, which leads to a lengthy process of preparation and collection of data. If the transport problem should be solved only once and subsequently the database will not be used, it is advisable to consider a different modeling environment in view of the initial costs.

The most optimal solution is to use one commercial software with the modification of all additional programs to ensure smooth integration with GIS. The software environment used can also be modified to increase functionality. One of the advantages of working with GIS is an open database provided by systems that analyzes and presents the results in a simple and convenient way for the user.

General geographic data management procedures in GIS have the ability to process any type of data that may be of interest for modeling purposes. Since GIS is an information management system, productivity with respect to any type of data processing is high. Data visualization is an important step in the modeling process, errors are detected and hypotheses are generated. The lack of GIS in this situation is observed when going beyond the scope of simple query and visualization tools, in this case there is a need for additional programming and integration with GIS.

Thus, to ensure the stable functioning of the city’s transport system, it is necessary to approach from two different, but complementary, directions of the development of geographic information systems. Some GIS-T studies focus on further developing and improving the system to meet the needs of transport applications, while other studies focus on how GIS can be used to facilitate and improve transport surveys. In general, topics related to GIS-T research can be divided into three categories: data presentation (how various components of transport systems can be represented in a geographic information system); analysis and modeling of the transport network (use of transport methodologies); selection of application types suitable for GIS-T.

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