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THE USE OF GIS TECHNOLOGIES TO DETERMINE TRANSPORT ACCESSIBILITY IN TOURISM

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Abstract. The article examines the possibilities of using GIS technologies in the tourism sphere. The study focused on the conceptual modeling of tourism and the geoinformation support in planning tourist routes. The subject area of tourism as a conceptual model in terms of database modeling and GIS using UML language was characterized and presented. The method of using the GIS to solve the problem of modeling transport accessibility zones to tourist attractions in shaping transport routes has been proposed. The QGIS was used in tandem with a database management system such as PostgreSQL. GRASS GIS environment was used to perform spatial analysis. The object of this research is the transport network in one of the districts of the Ternopil region. We have tested in practice the proposed technological scheme on the example of the Ternopil district with the use of PostgreSQL database management system, QGIS, and GRAS GIS. We have created a tourist isochrone map of this region with some attractive places. The proposed methodology for determining transport accessibility using spatial analysis tools with the creation of isochrone maps and a flexible system of adjustments in the GIS makes it possible to optimize already existing tourism routes and create new ones.

Keywords: GIS technologies, database, geospatial database, conceptual modeling, GIS modeling, transport accessibility, isochrone map, tourism, tourist route, GRAS GIS.

Introduction

Tourism is intimately linked to spatial objects. The authors Farsari and Prastacos (2004) see tourism as a spatial phenomenon, which, at the very least, concerns the location, the place of destination and the people who move from one place to the other. For them, GIS technologies are the most useful tool for transport planning. They argue that the ability of the GIS to integrate different sets of data (quality and quantity, space and non-space) is particularly important in the context of sustainable tourism, which requires a balance between economic growth, environmental costs and societal benefits (Farsari & Prastacos, 2004). The GIS can be used to carry out transport planning in such a way that there is no excessive pressure on nature conservation areas. This is a mechanism for planning the infrastructure of stable tourism (Boers & Cottrell, 2007).

Tourism planning requires the collection of geospatial information and data processing (Jovanović & Njeguš, 2016). GIS tools for tourism and network analysis help users to ensure optimal planning for tourism. The users save their time by using the GIS (Turk & Gumusay, 2004). Moreover, GIS minimize the difficulties of using maps and graphical tourist guides and is practically a revolution for the public, as it helps to save money and time and is easy to find the most up-to-date information (Shyti & Kushi, 2012). The GIS allows you to search for information about tourist sites. Yang Huanhe proposed software and algorithmic solution for this task on the Visual Studio platform (without online access), which also allows to plan routes (Yang, 2014). The GIS can be used to analyze the tourism attractiveness of regions (Lepetiuk, 2020a), assess the efficiency of the transport network in tourist destinations (Domènech & Gutiérrez, 2017) and analyze the potential of public transport services for the development of tourist journeys (Yahya et al., 2021). Active development of intelligent information systems can now be witnessed, which are designed to assist the tourist personally during his journey (Artemenko et al., 2015) or to form a route plan for the tourist for each day of his or her journey based on a list of designated locations (Gavalas et al., 2012). Also, tourist GIS based on the Internet and mobile devices are actively developing (Afnarius et al., 2020). The GIS with tourist infrastructure information are being developed

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and adapted for further integration into the Web-browser in order to spread this information in the tourist environment for more efficient decision-making on the possible route of journey (Shamim & Muzafar, 2015).

The use of the GIS has made it easier to understand and analyse tourist moving in order to gain a better understanding of tourist behavior and to manage tourist destinations (McKercher & Zoltan, 2014; Więckowski et al., 2014).

Journey models were investigated to demonstrate how a time element can be included in the GIS program to help identify tourist's behavior in a journey (Wu & Carson, 2008).

GIS even allow to develop 3D virtual tours with the effect of the user's presence in three-dimensional virtual scenes (Qiang, 2013).

Despite this wide range of application of GIS technologies in the tourism sphere, tourism mainly uses GIS to determine the suitability of attractions for tourism development. Collaboration between geographers involved in spatial planning, local government representatives and the public sector is still weak. Therefore, the use of the GIS in the management, planning and strategic decision-making process is limited and insignificant. The use of the GIS to manage visitor flows can be particularly important in the routes planning process (Cvetković & Jovanović, 2016). Wei (2012) points out from the case of China that little consideration is given to tourists who travel independently, there is a lack of effective tourism information management for independent travelers. Wei argues the great role of the GIS in tourism management, and suggests introducing the term "Travel Geographic Information System" (TGIS). The ultimate goal of TGIS is to provide timely, accurate and user-friendly services to meet the varied needs of its various users. The development and design of TGIS must be guided by the standards of the tourism industry and meet the research mindset of planners in tourism, who look comprehensively at tourism economics, marketing, natural beauty, stable development, psychology and other aspects in order to meet the demands of a wide range of consumers (Wei, 2012).

Attraction's accessibility is a prerequisite for the development of tourism. Good road connection, together with the proximity to train stations and airports, influences the level of tourism potential of a place (Pareta, 2013).

Accessibility in tourism is considered as the ease of access to the destination and it is one of the most important drivers in the development of a tourist region (Więckowski et al., 2012).

Celata (2007) tried to analyse how transport accessibility influences tourism development. He notes that transport accessibility, when a tourist chooses a destination, correlates with the interchangeability of the destination itself. However, with approximately the same advantages of local attractions, the tourist chooses the destination which has better transport accessibility. To indicate transport accessibility, the author uses the average journey time to the location and signs it on the map by iso-accessibility lines (Celata, 2007). These lines are also called isochrones. The word "isochrone" is Greek and translates as iso – similar, chronos – time. An isochrone is a line drawn on a map joining the dots which indicate the simultaneous occurrence of a phenomenon. This method of representation in cartography allows the map to show the degree of freedom of movement in understandable units of measurement. This unit of measurement is time.

The idea of creating isochrone maps has very old roots. Back in the early 1880s, cartographer Francis Galton tried to create his first isochrone map. He used it to show how long each journey from his home city of London to the vast expanse of the Pacific Ocean would take. After identifying the lines on the map, he decided that he could thus serve the travelers, sailors and those awaiting their mail. The idea was quickly picked up and other cartographers began to implement it, helping map readers to identify their future journeys (Giaimo, 2017).

The territories of transport accessibility (which are sighed between isochrones) can be used very widely in tourism, as they can be used to obtain derivative spatial data. For example, we can find out how many hotels are within walking distance to the attractions. An isochrone map will allow to determine the time interval that a tourist needs to travel to a particular attraction from the location of his accommodation.

Currently, most kinds of tourism activities are carried out through travel agencies to arrange group travel. Most tour operators create sight-seeing tours using Google Maps or other, non-specialized services. Since 2005, Google Maps has improved as a universal and cheap (royalty-free) tool for visualization of maps. It enables the identification of the boundaries between objects and their topology in order to help readers to make effective decisions on the profitability of their investments (Wallace, 2015). But it is not enough for a tour operator to know only the location to understand the future tour and to plan its details.

The development of technical means increases the importance of specialists in GIS technologies in the development of the tourism industry, and is one of the potential opportunities for innovative development of tourism. It is GIS technology that can bring different stakeholders together to achieve maximum impact. This can influence to make the best possible decision in the process of tourism development in the area (Cvetković & Jovanović, 2016).

Ukraine connects the Eastern and Western European countries and the Baltic States with the Black Sea region. However, the development of its tourism is significantly hindered by an underdeveloped transport infrastructure. This state of affairs complicates tourist journeys, increases transportation time and reduces the comfort of travel, and thus negatively affects the quality of tourism services.

Ukraine is currently in the process of establishing a national geospatial data infrastructure (NIGD). In June 2020, the Law on National Geospatial Data Infrastructure took effect, and in January 2021 it came into force, so the issue of creating geospatial data as part of the tourism industry (Verkhovna Rada of Ukraine, 2020a) is relevant, because tourism is a component of NIGD. Information on tourist objects and objects of tourist infrastructure refers to profile geospatial data (these include all types of sectoral and thematic geospatial data, which are created on the basis of basic geospatial data) (Lepetiuk, 2020b).

1. Methodology

Conceptual modeling uses a standard approach to systems design, which consists of such basic stages as: description of the subject area, development of conceptual, logical and physical models, which are discussed in more detail later in this article. To describe these models used the Entity-Relationship (ER) approach, a unified modeling language UML (Unified Modeling Language).

For the practical implementation of this study as source data used files from a service that contains open data (OpenStreetMap) and other sources of information available through the use of the Internet. The QGIS geographic information system (GIS) environment was used in tandem with a database management system (DBMS) such as PostgreSQL (works with spatial data using the PostGIS extension). GRASS GIS environment was used to perform spatial analysis.

2. Results of the research

Tourism is a very complex and multifaceted concept. In this study, we consider tourism as an activity, namely the temporary departure of a person from the place of permanent residence for health, educational, professional, business or other purposes without carrying out paid activities in the place of residence (Verkhovna Rada of Ukraine, 2020b).

GIS technologies allow you to design a tour and better balance its plan, specifying the route and the time that will be spent on the trip. To do this, it is advisable to use the possibilities of spatial analysis available in GIS. Determining transport accessibility based on information about the road network is one of the classic tasks of GIS.

The main possibilities of GIS technologies for tour operators in creating tourist routes are the automation of this process and related work, namely:

- convenient search for information on which the creation of tourist routes (points of interest, cost of services, places of service: hotels and others places of accommodation, gas stations, parking lots, campsites, etc.);
- optimization and testing of methods of routes creation;
- calculation of tour terms;
- creation of the special databases;
- guided by the tasks that are solved with the help of GIS technologies, the software for tour operators must:
- be performed in the form of a separate program or Web-service;
- meet the needs of building tourist routes with the optimal number of functions, flexible settings and intuitive interface.

GIS technologies in the field of tourism can be used not only by travel companies when building routes. Different categories of tourists can use GIS technologies (especially those that are freely available) to:

- prepare for travel (information about tourist facilities and tourist infrastructure; existing routes);
- travel planning;
- during the trip (location tracking; distance traveled);
- research of surrounding tourist sites;
- in the end of the trip (results of the trip; system of reviews about certain tourist routes and their rating).

In addition to tourists and tour operators, there are other categories of users who can use GIS technology, and for whom it is important to have information about transport accessibility (including facilities of interest to the tourism industry) – the authorities and businessmen. They can use GIS to plan further construction of tourist and transport infrastructure: gas stations, public transport stops, souvenir shops, parking, hostels, camping etc.

In this study, we focused on the conceptual modeling of tourism and focused in more detail on the geoinformation support of transport accessibility in the formation of tourist routes.

At the present stage, the most optimal when creating GIS models of various subject schemes is the use of object-relational data models. They have a number of advantages, including in terms of providing comprehensive storage of geometric models and attributes of spatial objects in a single environment project-relational DBMS (Maksymova, 2016).

The core of such a GIS model is a database. Under the database means a named set of data that reflect the state of the object, its properties and relationships with other objects, as well as a set of hardware and software for maintaining these databases (Zatserkovnyi et al., 2014).

Traditionally, the process of database development includes such levels of modeling as: description of the subject area (definition of initial data, formation of goals and objectives of the designed database, communication with potential users, etc.), conceptual (infological), logical and physical, which will be considered in more detail further.

In our publication, under the term "database", we will also use the term "geospatial database" (BGD). It is a database that is optimized for the storage of geospatial data (data that have a coordinate reference to the area). Such storage is implemented using a special data type "geometry", which is determined on the basis of the specification Simple Features, developed by the Open Geospatial Consortium (OGC).

We tried to describe the information objects of tourism, or the concept of this subject area, the relationship between them, using the language of database design (Maksymova, 2016). At the external level of presentation of the model is given a description of the subject area (tourism) without taking into account the needs of the user and data processing programs. This is the so-called object or non-process modeling. It makes it possible to objectively and systematically display information in GIS.

The conceptual level of modeling makes it possible to show in more detail the entity of the tourist sphere, to indicate its attributes (characteristics), and to show the connections between them. According to the authors (Zatserkovnyi et al., 2014), this level makes it possible to support every external representation. The task of creating a conceptual model of the database is to determine the object of modeling without focusing on a specific database management system (DBMS). Such a conceptual model is needed to formalize ideas about tourism, to reveal its types and components, as well as to show the main links between the individual components of the tourist sphere. Conceptual model of the database is a visual diagram depicted in the accepted notation, which shows in detail the relationships between objects and their characteristics. A conceptual model is created for further database creation and its transferring, for example, into a relational database. Thus, conceptual modeling is the construction of a semantic model of the subject area, when there is an information model of the highest level of abstraction. Another name of it is infological (information-logical) modeling. The information-logical model does not depend on the type of database management system and determines the set of information objects, their attributes and the relationship between them. This "entity-relationship" model allows us to describe the conceptual scheme using generalized block designs. It is named Entity-Relationship (ER) model or Entity-Relationship diagram (Zatserkovnyi et al., 2014). The basic ER-model consists of three classes: entities, relations (connections) and attributes (Teorey, 1999). This method was proposed in 1976 by Peter Ping Shan Chen. The entities on the diagrams of the conceptual level are depicted by rectangles, attributes – by ellipses, connections – by rhombus. If the subject area is large – it is divided into several local models. The volume of the model of the local subject area is chosen so that it does not include more than 6–8 objects. After creating all local models, they are combined into one large and often complex scheme. Thus, the conceptual model is used to structure the subject area taking into account the information interests of database users; it is not limited to technical and software capabilities, as it does not depend on them.

The next step after describing the conceptual model is logical modeling, which involves building a database schema that does not depend on the specifics of software, but takes into account the specific type of data organization model in GIS and/or database (for example: file, relational or object-oriented model). In our case, the object-relational model of data organization will be used, as we noted earlier.

After describing the conceptual and logical data model at the stage of substantiation of the choice of hardware and software, the scheme of realization of the logical model of the database in the environment of specific software is described, taking into account their properties. This is called the physical database modeling.

In this study, we have described the database "Tourism" in the form of an infographic model. In modern technologies in the design of databases for infological (conceptual) modeling often use a unified modeling language UML (Unified Modeling Language), which is recommended as the main modeling tool in a set of international standards for geographic information or geomatics (ISO/TS 19103:2005. Geographic information: Conceptual schema language).

In our conceptual infographic model of the database "Tourism", we have identified the following main entities: tourism, tourist objects (attractions), tourist events and tourist products as entities of one level. They have a connection with the entity of "tourism" that is called "aggregation" and means the ratio of "part to whole" that is indicated on the diagram by a white rhombus (Figure 1). Thus, the class "tourism" is related to the classes "tourist objects", "tourist products" and "tourist events". Moreover, in this case, aggregation is not a restrictive relationship in the sense that tourism is a whole, and tourist facilities – parts, as individual tourist objects can be considered part of other wholes (for example, sports tourism objects can be simultaneously aggregated with other classes, because we can consider them as part of another whole entity – such as "sport"). Certain tourist objects may conceptually exist on their own or may have links to more than one whole.

For each entity, its main properties (attributes) are defined, which are presented in the diagram. For example, the entity "tourist products" is defined by such a minimum set of attributes as: product code, product name, product type, product category and price. Some of the attributes are defined through a finite list of values (attribute classifier), for example, "Product Type" is defined through a set of values such as: placement service, equipment, tourist products, excursion service, transport service.

To understand the above conceptual model, as well as taking into account the requirements of international standards for describing the structures of geospatial data in the form of catalogues of object classes and application schemes, we have developed a catalogue of objects (Tables 1–3). The catalogue of object classes is a unified classification system that determines the composition of the database (list of entities and their attributes), coding system and/or classification of attributes (classifiers). The creation of such class catalogues is regulated by an international standard ISO 19110 Geographic information — Methodology for feature cataloguing. Because ISO 19110 requires that all entities (classes), their attributes, etc. included in the catalogue be identified by a name that is unique within the directory, each entity, attribute are assigned by a unique name (alias) in English, which is used as their name when implementing the database.

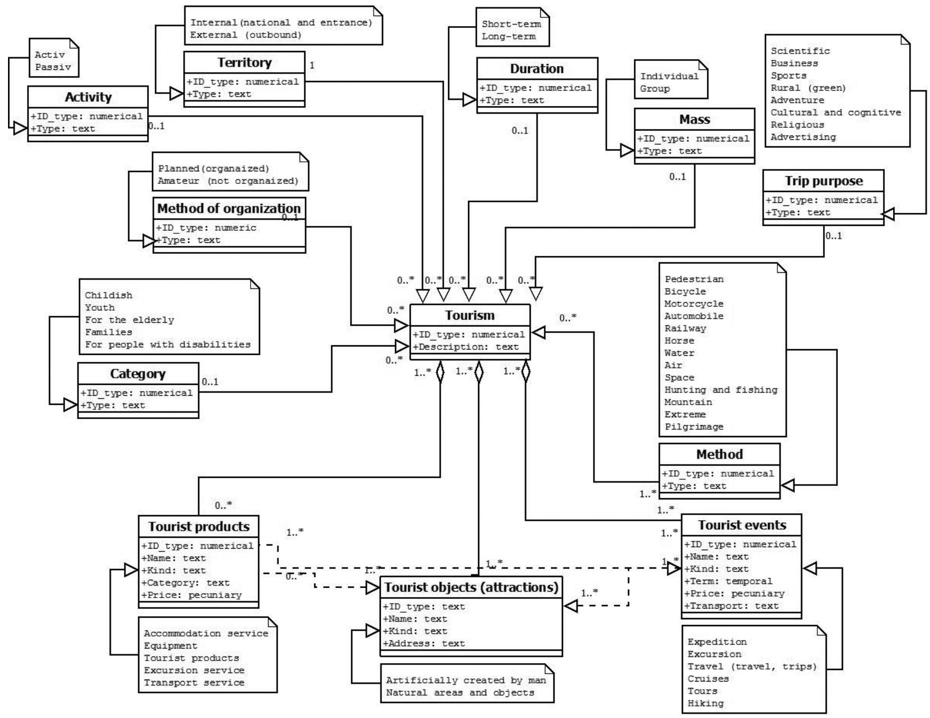

Figure 1. Generalized conceptual infographic model of the database "Tourism"

Table 1. A fragment of the objects catalogue of the database "Tourism". Description of entities (tables)

Entity name	Interpretation
Tourist products	The table is intended to store data about travel products (travel packages, travel services, tours, excursions, routes)
Tourist objects (attractions)	The table is intended to store data about tourist attractions (monuments, parks, museums, theaters, sacred sites, nature reserves, entertainment and sports complexes, conference centers, zoos, etc.)
Tourist events	The table is intended to store data about tourist events and/or events (festivals, exhibitions, fairs, auctions, presentations, historical reconstructions, etc.)

Table 2. A fragment of the objects catalogue of the database "Tourism". Description of entities (tables). Attributes of the entity "Tourist product"

Attribute alias	Definition	Data type	Key field	Classifier presence
ID_type	Product code	Numeric	Yes	
Name	Product name	Text		
Kind	Product type	Text		Yes
Category	Product category	Text		Yes
Price	The product cost	Pecuniary		
Geometry	A field intended to store geospatial data, i.e. the coordinates of objects	Geometry		

Table 3. A fragment of the objects catalogue of the database "Tourism". Classifier "Kind" of the entity "Tourist products"

Value code within the classifier	Name
201	Accommodation service
202	Tourist equipment
203	Tourist products (maps, guides, booklets, flyers)
204	Excursion products (guide, audio, video)
205	Catering service
206	Transport service
207	Additional tourist services
2071	Instructor
2072	SPA procedures

In the diagram (Figure 1) we have presented the classification of tourism by activity, territorial feature, duration of the trip, number of participants, way of organizing the trip, category of tourists and purpose of the trip. We have singled out all these characteristics into the corresponding entities, and they have a connection with the entity of "Tourism", which is called "inheritance". It is indicated on the diagram by a white triangle and is a means of classification. This connection indicates that there are several subclasses that clarify the definition of a superclass "Tourism". Subclass objects inherit all properties and methods of superclasses, and may have their own additional properties. Among the tourist objects there are natural territories and objects (nature protection) and man-made, sports, religious, socio-cultural, recreational, children's and youth tourist objects, tourist objects for family recreation and objects of cultural and historical heritage).

There is a connection between the classes of tourist products, events and tourist objects, which belongs to the type of "subordination". This is a weak form of use relationship in which changes in the specification of one entail changes in the other. And the reverse effect is optional. It occurs, for example, when a specific tourist product (certain equipment, gear or transport, etc.) is prepared for a certain type of tourist event. Therefore, the tourist product is in the form of a parameter or local variable of the tourist event. This type of connection is shown in the conceptual model by a dotted arrow that goes from the dependent element to the one on which it depends.

2.1. Designing a database of tourist routes

The given scheme of tourism is rather generalized, and its detailing is impossible within one publication. So we will consider in more detail the database intended for tourist routes. To describe it, we first needed to define such concepts as "tour" and "tourist route".

By a tour in this study, we mean a set of different types of tourist services, combined on the basis of the main purpose of travel, provided along the route in a certain time to meet the needs of tourists. A tourist route is a preplanned route for tourists to travel for a certain period of time in order to provide them with services provided by the service program.

The construction of the tourist route is influenced by some of the following factors:

- characteristics of tour users: age, category, personal preferences, opportunities;
- way to travel during the tour;
- topics of the tour or excursion;
- objects involved in the tour or excursion.

These factors aren't exhaustive but they affect the timing and price of a tour. It is desirable for tourists to build a route that would pass through the maximum possible number of points of interest and meet user requests. These requests relate to the time of overcoming the route; the topic and the potential price; the availability and level of available amenities; the complexity of the tour.

A tourist product can be a separate tour, tourist and excursion services on a separate route, in a tourist cluster or in a certain area.

We have created a conceptual model of the database "Tour", which defines the main entities, their characteristics and relationships, shown in Figure 2. This model is presented in the form of a conceptual model of the subject area "Entity-Relationship".

The key entity in the scheme is the "Tour", which includes the "Purchase DB" and the "Tourist route DB". The main entity of the "Tourist route DB" is the tourist routes themselves, which are organized by the entity of "Travel company". In turn, the "Purchase DB" contains the main entity of "Purchase", which performs the entity of "Tourist".

2.2. Object catalogue and logical model of tourist routes database

Structural and conceptual model of tourist routes database is presented in Figure 3. This model has been created using UML language and it reflects the basic entities needed to describe tourist routes, their characteristics and relationships between them.

According to the given model the "TouristRoute" is classified by the organizational form (the "TravelType" entity), by the activity ("Activity"), by the territorial form ("Territorially"), by the duration of trip ("TripLenght"), by the quantity of participants ("ParticipantsNumber"), by the organization ("Organization"), by the category of participants ("TravelerCategory"), by the purpose travel (TravelPurpose). In the diagram, this is reflected in the form of a connection named "generalization".

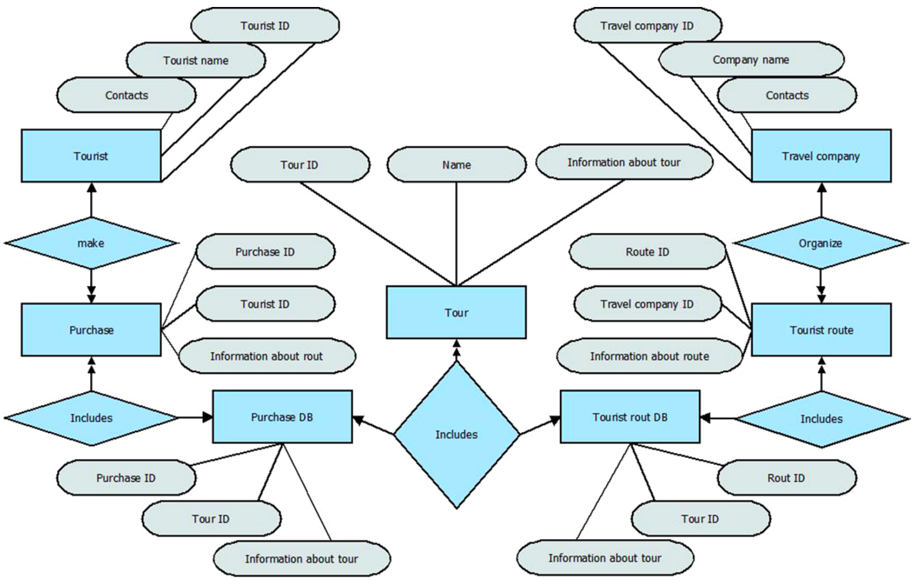

Figure 2. Conceptual model of the database named "Tour"

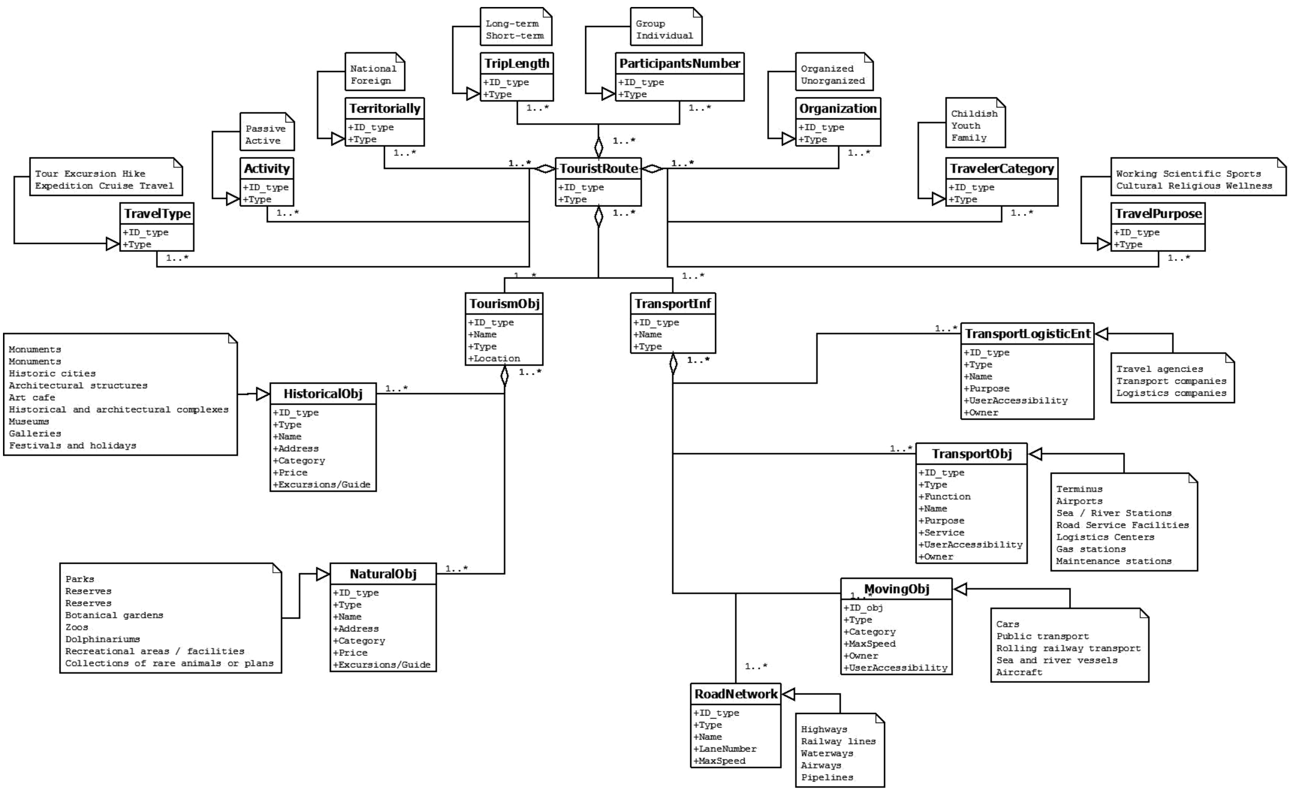

Figure 3. Structural and logical model of the database of geospatial data of tourist routes

The entity "TouristRoute" includes the entity of transport infrastructure ("TransportInf") and tourist objects ("TourismObj"). In turn, the entity of transport infrastructure ("TransportInf") includes transport and logistics enterprises ("TransportLogisticEnt"), transport objects ("TransportObj"), moving objects ("MovingObj"), road network ("RoadNetwork"). The entity of tourist objects ("TourismObj") includes historical objects ("HistoricalObj") and natural objects ("NaturalObj"). Each entity is characterized by its own set of characteristics (attributes), the main of which are presented in the diagram.

A catalogue of object classes has been developed for the "Tourist routes DB" according to the scheme described in this article above, on the example of the database "Tourism".

Transport is one of the important industries that influence the formation of tourism in any country, region. Therefore, it is necessary to investigate the structure and composition of transport resources of the study area in any analysis of the tourism industry. For a deeper understanding of the conceptions of the studied sphere and the relationships between objects, we have also developed a structural model of BGD transport infrastructure (Figure 4), which identifies the key elements and their relationships. Thus, the transport infrastructure includes both the network itself and the objects of transport infrastructure, such as stations, service stations, gas stations, etc., objects that move within the network and objects that set the rules of operation of transport infrastructure (transport and logistics enterprises).

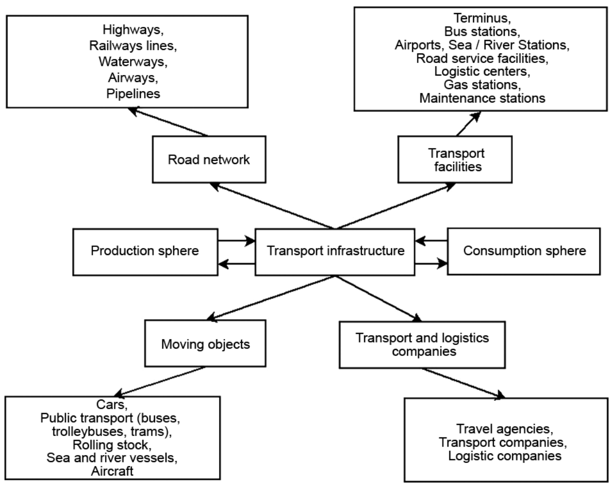

Figure 4. Structural model of BGD of transport infrastructure

In this study, we propose to break down the process of geoinformation modeling of transport accessibility into stages and identify 2 main stages (pre-project stage and project) – Figure 5. The key stage of work in the given scheme, in our opinion, is the creation and filling of a database of geospatial data related to tourism activities.

2.3. Implementation of GIS modeling in the formation of tourist routes on the example of the Ternopil district

In this study, we chose the Ternopil region of Ukraine to perform the practical part of our study due to the following features:

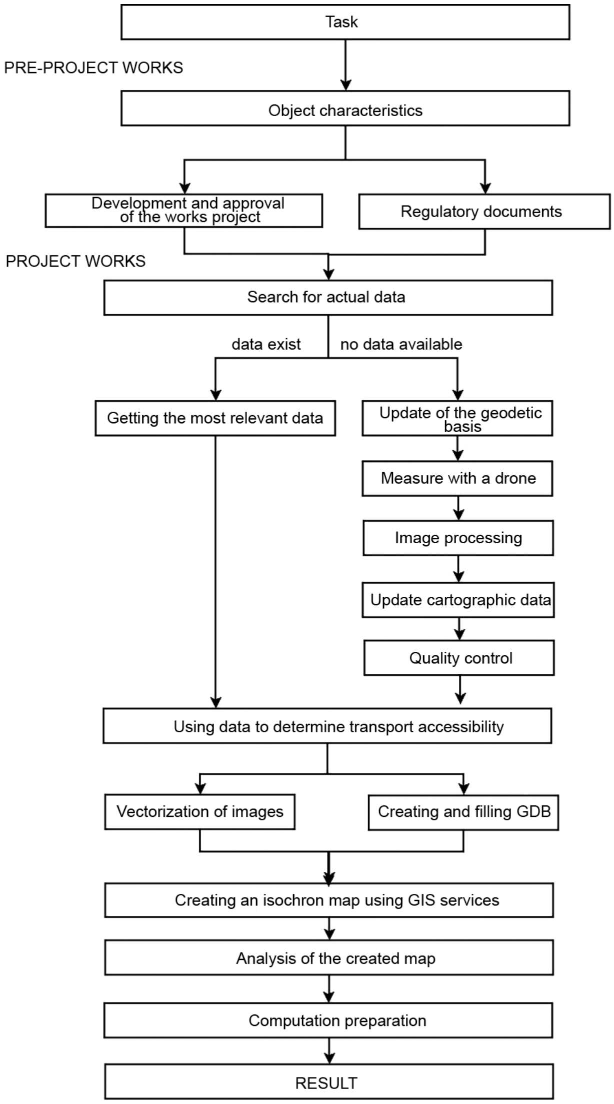

Figure 5. General technological scheme for determining transport accessibility in the formation of tourist routes using GIS technologies

– a large number of points of interest: from historical and cultural monuments to botanical gardens and parks;
– inhomogeneous relief over the entire area of the region, which is better suited for the visual perception of the isochrone map;
– availability of different modes of transport.

Through the Ternopil region pass the following routes of European significance: E50 and E85, international routes: M-09, M-12, M-19, route of national importance – H02; and regional significance: R-39, R-41. There is a railway connection in the area, which is represented by stations Birky-Velyki, Hlybochok-Velyky, Berezovytsia-Ostrov, and Kurnyky. The length of railway tracks in the region is 777.3 km (of which 634.3 km are operational and 139 km are electrified). The density of the railway network is 45.9 km per 1,000, which is much higher than the average in Ukraine (37.6 km per 1,000).

Bus routes cover the entire district and region, which runs about 2.5 thousand buses and minibuses and are 680 bus routes. In Ternopil there is a city electric transport – trolleybuses (there are 9 routes in the city). This greatly simplifies travel around the city to tourist destinations.

Air transport is the fastest, most comfortable, and safest mode of transport. Its development in the region has a strong impact on the tourism industry. There is a Ternopil airport in the Ternopil region, which is now almost non-functioning, although its renovation can significantly increase the attendance of the district and region, and thus lead to the development of the tourism industry.

In the Ternopil region, there is river transport that runs on the Dniester River but is used more for the transportation of construction materials than passengers, and there is a small river transport for passengers in Ternopil and in the Ternopil region.

2.4. Determination of transport accessibility in the formation of tourist routes

Modern GIS programs are quite expensive, which makes some restrictions on their use in tourism. Therefore, we turned our attention to open source software, namely QGIS, GRASS GIS, and PostgreSQL/PostGIS. The advantages of such GIS technologies are the free license and the flexibility to adapt these programs to the user's needs to solve diverse application problems (Françoso et al., 2013). QGIS and GRASS GIS are GIS designed for geomodeling, spatial data management, and computer graphics, satellite imaging, mapping, spatial modeling and visualization.

The procedure for determining the transport accessibility can be as follows (Tretiak & Lepetiuk, 2021):

1. Preparatory stage (implementation of the designed database in PostgreSQL/Postgis environment).
2. Obtaining and preparing data on the road network, transport infrastructure objects and tourist objects.
   2.1. Unloading data from OpenStreetMap (OSM) and trimming them by administrative boundaries.
   2.2. Sampling of geospatial data on the suitability of roads for car traffic in PostgreSQL/Postgis.
   2.3. Assignment of attributive characteristics to objects of a road network (necessary for modeling of accessibility).
3. Modeling of the surface of transport accessibility.
   3.1. Project preparation and data processing in GRASS GIS.
   3.2. Construction of isochrones.
4. Graphical representation of results.

Consider the above stages of determining transport accessibility in more details.

The designed database was created in the PostgreSQL/Postgis database. The Postgis extension allows to store and process geospatial data, which is important for our task. For convenience of work with the given DBMS we used the graphical interface PgAdmin which allows creating a database, using both SQL language (Structured Query

Language), and elements of the graphical interface familiar to the user. At the preparatory stage, the created database was connected to the QGIS GIS environment using the standard QGIS module "Data Source Manager".

Obtaining and preparing data. Data can be obtained from a variety of sources. To do this, open data sources are used, paper maps, atlases or orthophotos of the area are vectorized, or specialized vector data is purchased from a supplier. Data collection was performed from the following sources listed in Table 4.

Table 4. Data sources

Sources	Data type
OpenStreetMap	Road network
	Administrative boundaries of the district
Internet sources	Points of interest for tourists (attractions)

For our research, we used OpenStreetMap data due to their sufficient accuracy and the possibility of free receive. Data preparation is one of the key stages of our study, as it depends on the quality and reliability of the results. OpenStreetMap service (connected to GIS QGIS using the OpenLayers plugin) allowed downloading data about the road network and administrative boundaries of the Ternopil region in the format of shp-files. Points of interest were those objects that may be of interest to tourists for one reason or another. They were uploaded to PgAdmin from the Geoportal of the urban cadaster of the Ternopil region. We chose a car as the target mode of transport.

After uploading the OSM data to QGIS, the roads were first trimmed, as the shp-files of the road network contained objects all over Ukraine. Therefore, only roads within the Ternopil region were cut from shp-files. To do this, we used the standard operation in QGIS – Clipe.

After the required data was cut, it was loaded into the created database in PostgreSQL via the QGIS interface using the standard DataBaseManager module. A table of points of interest was also created in the database and was filled by the attributes (Figure 6).

The next step was to filter the roads taking into account the requirements for transport modeling. This step is the first in the narrowed data (only those roads that are suitable for road transport are selected). That is, types of roads which will be involved in modeling transport accessibility were chosen by method of movement. For example, all types of roads will be taken into account for modeling pedestrian traffic; cars cannot drive on pedestrian roads, so they should be excluded from analyze, etc.

Because the data was taken from OpenStreetMap, the differences between objects can only be seen at the level of the tags contained in the attribute table, the Highway field. We can see the following data types in this field: path, step, footway, residential, primary, service, unclassified, secondary, road, track, construction, tertiary, raceway tertiary_link, trunk, secondary_link, proposed, pedestrian,

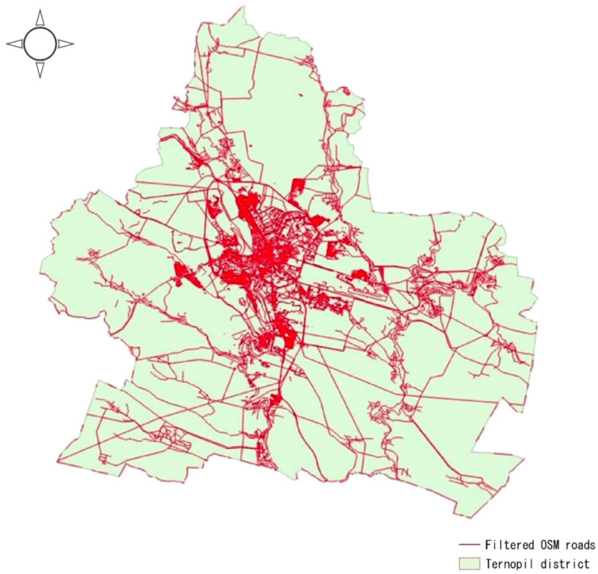

Figure 7. The filtered road network inside the administrative boundaries of the Ternopil district

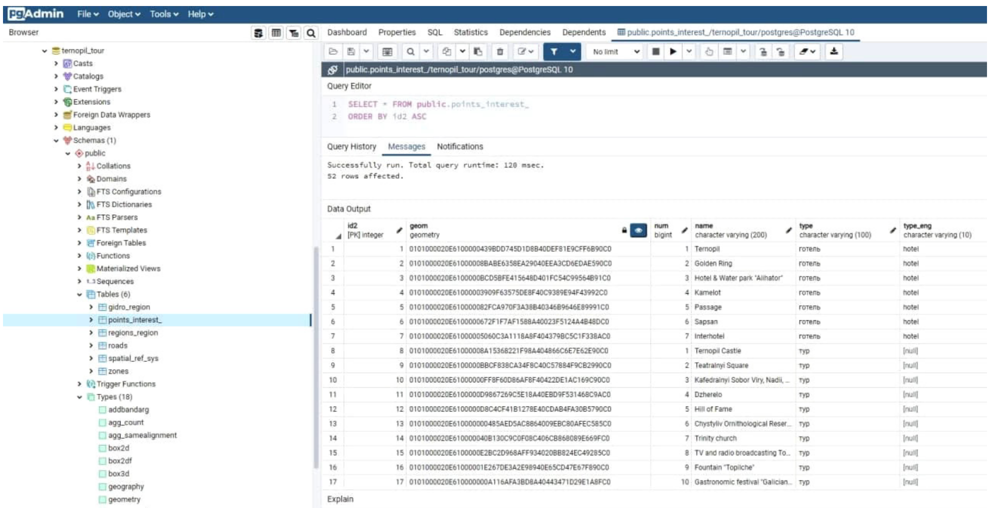

Figure 6. A table "points_interest_" in database "ternopil_tour" in PgAdmin

bridleway, primary_link, living_street, trunk_link. More information about tags can be found on the OpenStreetMap (Wikipedia, 2021) – a Web-resource about OSM. We have excluded such objects on which the car can't move: path, steps, footway, construction, proposed, pedestrian, bridleway. To do this, a query was generated that selects the roads of these data types. After editing, the result presented in Figure 7 was obtained.

The next step in data preparation was to add attributes to the geospatial data of the road network needed to model transport accessibility. Each class of road must have information about the average speed of our chosen vehicle (a car). The classes of roads we selected after filtering, their description, and speed are shown in Table 5.

Table 5. Characteristics of roads

Class name	Description	Speed of movement, km/h
trunk	the most important and largest roads	90
primary	big highway, next level after the trunk	90
secondary	relatively large roads, the next level after the primary	60
tertiary	ordinary highways between small settlements	60
living_ street	residential areas where pedestrians have a clear advantage in the right of movement	15
residential	highways in residential areas	40
service	service entrances etc.	30
road	highway of unknown type	60
track	dirt roads (usually for agricultural machinery)	30
raceway	roads for motor sports	90
tertiary_ link	junctions between tertiary among ourselves or with roads of other types	40
secondary_ link	junctions between secondary among ourselves or with roads of other types	40
primary_ link	junctions between primary among ourselves or with roads of other types	40
trunk_link	junctions between trunk among ourselves or with roads of other types	40
unclassified	roads without a tag	40

The values accepted by us (Table 5) are rather conditional and averaged as there is no possibility of exact measurement of the speed of movement of cars for each class of road.

To assign the "speed" attribute for each road class in the "road network" table, we used the Field Calculator tool in QGIS. After creating the SPEED attribute, each road class has a certain speed at which the car can move on it.

In the next step, we calculated the time it will take to overcome each section of the road network based on the ratio of parameters such as speed, time and distance. To do this, we pre-calculated the length of each section of the road network using the Field Calculator tool in QGIS and creating a new LENGTH attribute.

Modeling of the surface of transport accessibility

Project preparation and data processing in GRASS GIS. After preparing the data and filling it with the necessary attributes, we proceeded to their processing and loading into GRASS GIS. In this GIS, geospatial data is stored in the form of subdirectories, a set of which is referred to as "location". They, in turn, are divided into sets of maps (mapset). Preparing data to work with them in GRASS GIS is expressed in setting up the GRASS GIS environment and transferring pre-prepared data from QGIS.

Initially, the initial settings were made: a new "location" was created (it is a new file with the selected coordinate system); a new "mapset" was created; the main plug-in (v.isochrones) was connected. All actions in GRASS GIS can be performed both through the visual interface and the console. The next step was to transfer the previously prepared data from QGIS to GRASS GIS. For this purpose, the function of import of vector data – v.in.ogr was used.

The most obvious, simple, and therefore popular way to determine transport accessibility, is the building of an isochrone map. An isochrone is a line drawn on a map that connects points that show the simultaneous occurrence of a phenomenon. In this case, these are lines of equal time to overcome the distance to the specified points of interest along the lines of the road network. Building and using an isochrone map is the next step towards creating a more convenient tool for building and organizing tourist routes. Next, we connected a pre-formed point layer POI.shp, which contains information about the location of attractions for which isochrones will be calculated.

The loaded layer of roads must be converted into a network data set (a set of points and lines). The linear data set is converted to a network data set using the v.net tool (Figure 8). This action is necessary because we perform

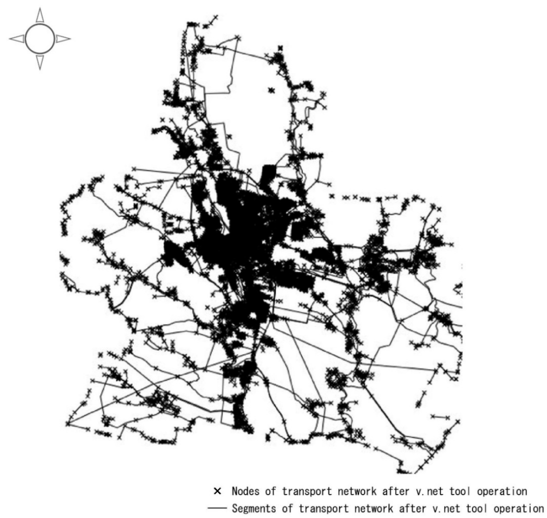

Figure 8. The result of the v.net tool

network analysis, and this analysis in GRASS GIS software is impossible without it.

The last step in data preparation in GRASS GIS is to specify the region and modeling resolution using the g.region module.

Construction of isochrones

The next step is to directly create an isochrone map using the v.isochrones module. The module works in two modes. This article gives an example of the use of continuous isochrones. As a result of using the v.isochrones module, two files are created (vector isochrone layer isochrones_rcost – Figure 9, and raster layer of the time surface timemap_rcost). After their creation, vector and raster files are exported using the tools v.out.ogr and r.out.gdal in standard GIS formats – shp-file and GeoTIFF, respectively.

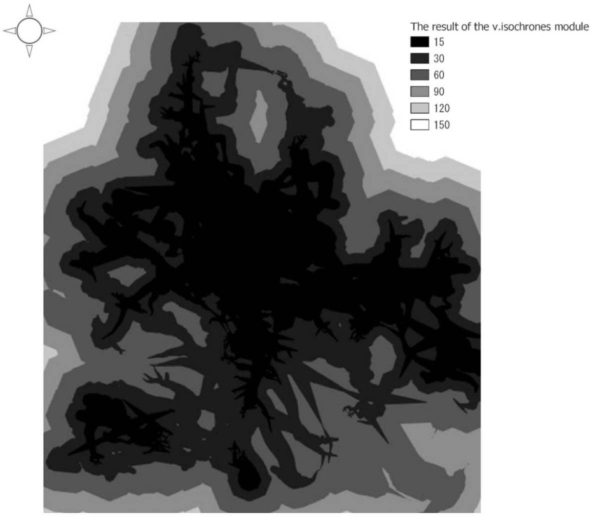

Figure 9. The result of the v.isochrones module. Vector isochrone layer

Graphical representation of results

The last step in creating an isochrone map is its design, for this, we returned to QGIS and added the exported files.

Raster image – the surface of the time spent. Using the plugin Value Tool gave us to obtain the result: hovering over a certain point of the raster allows us to have the time spent to this point, which is expressed in minutes (Figure 10), and therefore operate on numerical data.

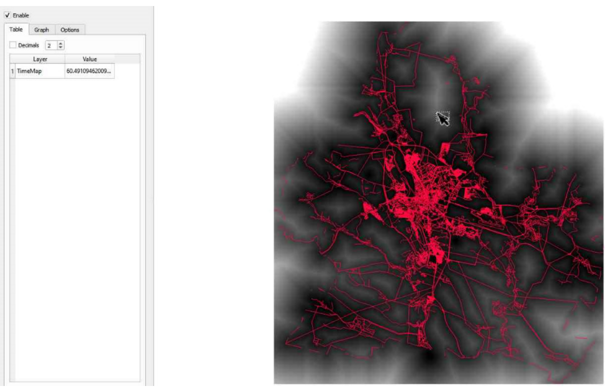

Figure 10. Demonstration of the possibilities of a raster image of the surface of time

The next figure visualizes the isochrones (Figure 11). Note that there is no starting point of reference in this isochrone map.

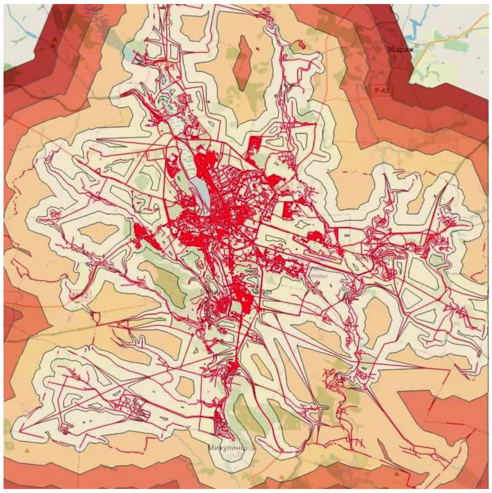

Figure 11. An isochrone map as the image of the surface of time

Figure 11 visualizes isochrones. The surface of the time spent actually shows the overall speed of movement or how long does it take to move between points of interest in a given area. We can assume that the larger the road (this is expressed in the maximum speed of movement along it), the more likely it is you get to the point of interest faster, which is shown by this isochrone map.

However, the proposed method does not take into account possible traffic jams that will affect the movement of

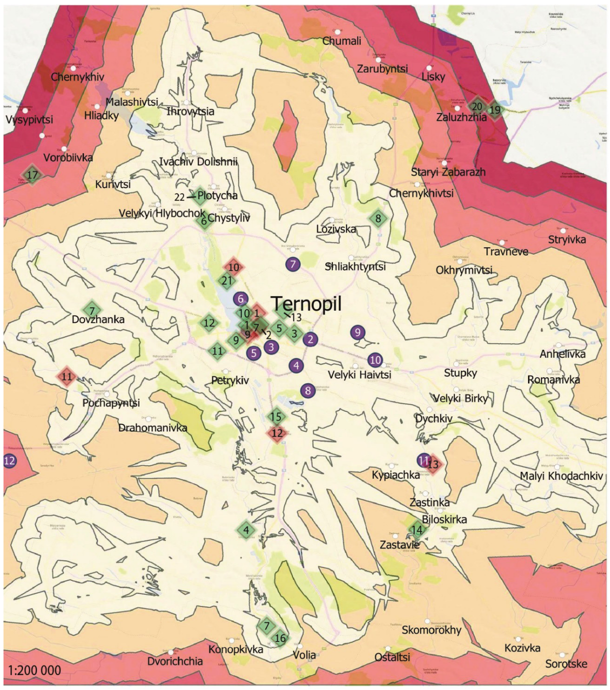

Figure 12. Fragment of the map of the Ternopil district with some attractive places and with a surface of time (color calibration is based on marks in minutes)

Figure 13. The legend to the map of Figure 12

each individual tourist traveling by car. This method will only be useful for pre-planning a tour, not for real-time travel.

In Figures 12–13 we have added the location of some tourist attractions, monuments, and hotels together with time information to this isochrone map. It will be easier for the authorities or the tour operators to use this isochrone map as guidance in tourism planning and management.

3. Interpretation of the results obtained

The obtained isochrone color map helps to determine transport accessibility and build time-balanced transport routes. Tourist routes are often limited in time, which is why with the help of isochrone map analysis we can select points of interest within the appropriate transport accessibility and plan the route.

When using better source data, the result can be more accurate and it will help to create an idea of transport accessibility to certain tourist attractions. This can be achieved by using data from specialized sources (which are paid), or by self-monitoring and collecting more detailed information in the study area.

The proposed method may be useful for tour operators and for tourists themselves, who prefer to independently plan routes and travel on them. This solution to the problem of determining transport accessibility in the formation of tourist routes is also suitable for other types of movement: walking, cycling, rail, etc.

GIS tools also allow you to build a so-called "distance matrix". This matrix will help to calculate travel cost (it includes expenses for transportation) from one starting point or group of points (for example, location - location of the tourist) to another point or group of points (for example, places of rest, tourist attractions). In fact, such a matrix calculates travel time, distance to popular routes from the point (points) of departure to destinations. Depending on the task, such an analysis can be supplemented in GIS by tools for finding the shortest routes, which make it possible to search for optimal distances by distance or time, taking into account speed, direction, and obstacles.

Conclusions

GIS is one of the most promising information systems for solving analytical problems (in this case, they are related to the tourism industry), especially in connection with the use of new technologies. To successfully solve the problem of determining the transport accessibility of the GIS engineer requires a clear understanding of the subject area in general and the transport infrastructure in particular, which will maximize the quality of the results.

The database models developed by us help to visualize and determine the structure of the database, to imagine how the data will be stored, processed, and organized in the database. Creating a database is a complex process that is not static; it can be repeatedly refined during modeling. Starting from the conceptual scheme of the database, the process of creation develops and grows into a logical model, and then the physical model – the final stage of preparation for the creation of the database of tourist routes.

During this study, a method of constructing an isochrone map based on OpenStreetMap data using PostgreSQL/Postgis, QGIS and GRASS GIS software was chosen. The PostgreSQL/Postgis database is used as a geospatial data storage environment. QGIS prepared data and visualized results, while GRASS GIS simulated results.

The method of using GIS in the formation of tourist routes allows tour operators to design and create more balanced routes. This helps them to more accurately determine transportation prices and create more comfortable travel conditions for tourists, saving time. Creating an isochrone map with a flexible system of settings (using the spatial analysis tools) helps to optimize existing tourist routes, create new ones. Thus, the spatial analysis showed that with the help of GIS it is possible to more optimally determine transport accessibility in the formation of tourist routes. The creation and further use of a Web-site or software for personal computers and mobile phones and tablets will be in demand in travel agencies that do not cooperate with GIS specialists. The obtained data can be used for many other industries that use logistics.

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Author contributions

Viktoriia Lepetiuk came up with the idea to create this publication and she led the process of scientific research. Also, she was responsible for the analysis and interpretation of the result, for the translation of this article. Vladislav Tretyak developed databases, processed data, and created isochron maps. He was responsible for data collection, analysis. Yuliia Maksymova was responsible for the design and development of the data analysis.

Disclosure statement

No potential conflict of interest was reported by the authors.

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