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APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEMS IN TRAFFIC ANALYSES

PHD Supervisors

PROF. DR.ING. PETRE IULIU DRAGOMIR

PROF. DR.ING. ANA-CORNELIA BADEA

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PHD Student

GAVRIŞ (DROJ) GABRIELA

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Introduction

In recent decades, the process of urbanization has swept the world on an extraordinary scale, confronting city and local governments with the task of solving the problems it poses: Infrastructure, transport, risks, disaster prevention, investment planning, etc.

One of the effects of urban development is the intensification of traffic and related problems: congestion, heavy traffic, increasing number of accidents and increasing pollution. As a result, traffic jams in urban areas are now a common phenomenon. In all major cities, the main arteries are congested at peak hours or during avarious events such as traffic accidents, road works, weather, and so on.

Traffic increases day by day, but not all roads are equally predisposed to congestion. Traffic congestion is the cumulative effect of complex factors that can be represented in terms of geospatial data and relationships between them. Incorporating these elements into a geographic information system can improve the ability to analyse and manage traffic at any level. Traffic congestion, however, not only has an undesirable impact on the environment, but also on the regional economy by creating additional costs that increase the cost of living and slow down the local economy.

These congestions make traffic more stressful for participants, increase pollution, or can hinder emergency response efforts. Visualising traffic congestion and automatically rerouting it as traffic patterns change is a sine qua non for GIS -based traffic simulation applications.

In this sense, the research topic proposed in this research report is in line with the development trends of the GIS market, but also with the specific objective of the chosen PhD topic. This thesis consists of three chapters.

The first chapter presented theoretical and practical elements of using cadastral data in traffic analysis, the possibilities of modelling road infrastructure in GIS, and traffic simulation using data collected from participants through crowdsourcing.

The second chapter addresses the applicability of geographic information systems to evaluate public transportation and its impact on congestion. To achieve these objectives, real-time traffic data from various sources were processed and integrated using different analysis techniques to analyse public transport in the Oradea urban area and its impact on regional traffic. In addition, a stochastic mathematical model was used to simulate the travel decisions of residents. Based on the traffic analysis performed and the simulation of the travel choices made in this research, the elements that cause traffic congestion in the region can be easily identified.

Chapter 3 provides an analysis of the applicability of GIS and crowdsourcing technology in traffic analysis and decision support for road infrastructure investment planning.

The last chapter presents the conclusions of the research report.

1. Theoretic support

1.1 Road Informational System

The general cadastre lists all buildings on the entire land area, regardless of their use or destination category: agricultural land, forest land, water land, built-up land, and land for special purposes. Depending on the level of interest, they can be organized into information systems tailored to the specific areas of activity and the detailed data required for their management, operation and maintenance. Information systems can be created for various sectors, such as forestry, water management, real estate, urban development, industry, mining, roads, railroads, sea or river ports, airports, archaeological and historical sites, natural monuments, etc.

The national transportation system includes road, rail, sea, and air transportation networks with all their components: Infrastructure, transportation assets, traffic management systems, positioning and navigation systems.

Road transport is a form of land transport that enables the transportation of people and goods in space by means of motor vehicles. Road transport routes are roads classified according to their importance: local, regional, national and international.

A land information system usually also includes a road/street information system to record and inventory land, buildings, facilities, and the condition of the road/street network. This kind of information system includes all public roads and their components: Bridges, underpasses, tunnels, bike paths, viaducts, sidewalks, etc.

The road elements plotted on a topographic map and included in the Road Information System database are:

- The axis of the road/street represented as the geometric position of the points in the plane at equal distance from the boundaries.

- Road/street geometry;

- 3D geometry of the road/street to represent the cross sections and road/street profile;

- Elements of the street;

- Elements adjacent to the road, such as sidewalks, green areas, bike lanes, sewers, and also road safety measures such as traffic signs and markings.

The geodata contain information on the different modes of transport (car, tram, bus) as well as on traffic-related objects (traffic signs, traffic lights, sidewalks, crosswalks).

1.2 Transportation Informational System

Transportation is the function of moving (making move) objects (goods or people) in time and space. The transportation system consists of the means and equipment necessary to move goods or people. A transportation management system must enable efficient decision making, process automation, improved services, increased safety, and reduced costs. More and more industries are using geographic information systems, a field that has accepted and integrated technologies from GIS with ease. Geographic information systems are the ideal tool for management and analysis in transportation engineering and play an important role in ensuring transportation capacity, planning and analysis. (Loidl, et al., 2016)

Geographic information systems enable operators to capture, process, and analyse a variety of complex spatial information associated to transportation and traffic, such as: Road geometry, width, number of lanes, road types and categories, capacity of roads and intersections, speed limits, inventory of road signs and their restrictions, temporary or semi-permanent congestion, traffic incidents, so on.

The following image contains the representation of numerous traffic related objects such as: Parking lots, traffic signs, traffic lights and lanes, for the city center of Oradea.

Figure 1 Representation of traffic related information in Oradea (Droj & Droj , 2020)

The use of GIS in transportation is due to the spatial nature of traffic data, but also to its applicability to myriad types of networks, statistical and spatial analysis. In addition, systems based on the technology of GIS enable the integration of socioeconomic information with geographic data of the traffic network for a diversity of specific applications. (Gupta, et al., 2009)

Integrating traffic information into GIS facilitates real-time monitoring of traffic accidents, traffic flows, or congestion, as well as analysis of historical data to identify accident blackspots and congestion patterns and draw conclusions about their possible causes. As a result, more and more urban development and transportation software is being developed that combines traditional transportation research methods with spatial analysis to provide numerous specific applications for both transportation and different transport related activities.

Geographic traffic information systems (abbreviated GIS -T) are an example of combining traffic management information systems based on GIS technology. The blending of different types of geographic and alphanumeric information is the main benefits of GIS -T. The emphasis on the interaction between the traffic system and its background makes GIS the perfect technology for route planning, road design, risk analysis, modelling, and decision making.

Nowadays, GIS -T is increasingly used due to its numerous benefits. The most common applications include roadway design, road maintenance recording and tracking, routing, traffic modelling, accident black spot analysis, and environmental impact assessment. By integrating

GIS -T with complex mathematical modelling, analysis and simulation techniques its applications can be extended to various planning options and management strategies. (Gupta, et al., 2009)

1.1 Modelling road infrastructure in GIS - T

Most systems of GIS operate in the Cartesian system, usually in Euclidean space, where the distance between two objects is determined by the relative positions in space calculated by the Euclidean distance. However, in the case of transportation applications, this distance must be calculated for the predefined paths specified by lines and curves, oriented segments that define graphs. Such trajectories are used not only for modelling roads, but also for infrastructure or hydrography networks. Network modelling is done in the form of graphs.

Definition: *A graph is a system G = (V, A) where V represents the set of all nodes(vertex) and A represents the set of all arcs.*

Definition: *An oriented graph represents a system G = (V, A) where V represents the set of all nodes and A represents a function of type A: V → V. If i∈A and j∈A then there is an arc (i, j) in the graph G.*

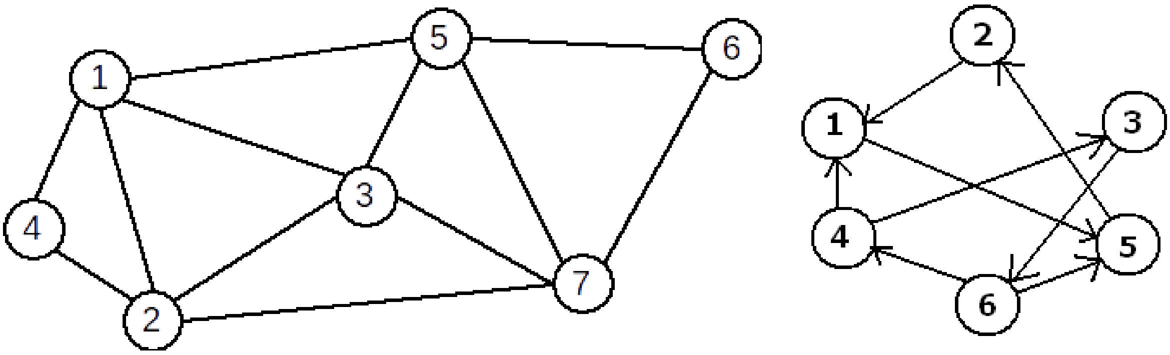


Figure 2 A geometrical representation of a graph and an oriented graph

The geometric representation of graphs is done by assigning the geometric elements in the plane to the elements of the graph, as in the figure above Therefore, the set of roads can be modelled as a non-oriented graph, where road segments become edges and intersections become nodes. However, in traffic simulations, oriented graphs are used, where each roadway represents an oriented arc. (Toadere, 1992)

Figure 3 - Modeling road axis

Any graph can also be represented in matrix form, where each row and column correspond to a node or arc (edge) of the graph. The adjacency matrix where row and column i corresponds to node i, if $a_{ij} = 0$ there is no arc (i, j), and if the value $a_{ij} \neq 0$ defines there is an arc (i, j) and its cost is a_{ij}. The adjacent matrix is symmetric for an undirected graph. To build the model of roads and urban networks, additional information is usually stored in spatial databases, such as:

- Intersection points between lines and curves-represented as nodes in graph;
- Which graph nodes represent the starting and ending points of lines and curves;
- The localization of lines and curves;
- Specific attributes for start and end node;
- Specific attributes for all polylines;
- In the case of oriented graphs, the direction of movement of the lines or curves.

In contrast to conventional GIS applications, where the road network is usually represented as an unoriented graph in which all nodes are intersections and all edges are segments of a road, traffic applications based on geographic information systems (GIS -T) use oriented graphs that are detailed down to the band level so that all arcs of the graph are represented by traffic lanes. (Droj, 2009)

Converting the non-oriented graph data model to an oriented graph is done by adding additional graph nodes and arcs created by traffic constraints and the number of lanes, where the direction of the arc corresponds to the direction of travel. The following figure shows how to model an intersection in GIS -T.

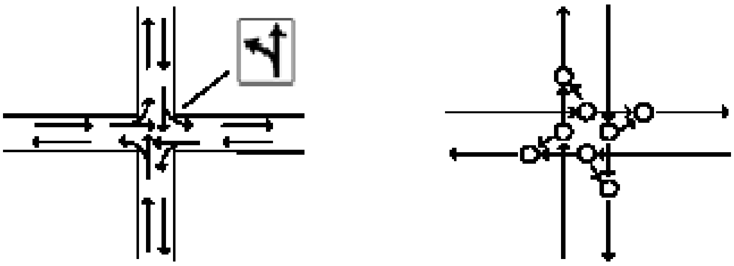


Figure 4 Modelling traffic flow in an intersection (Droj, 2009)

GIS -T applications integrate up-to-date geodatabases about the road network with all traffic information, such as traffic signs, traffic lights, speed limits, traffic restrictions, maximum capacity, points of interest, but also with a variety of real-time information, such as accidents, traffic jams, etc. (Wuest & Mioc , 2007). (Droj & Droj , 2020)

1.2 Routing algorithms

As mentioned earlier, solutions based on geographic information systems are the ideal tools for management and analysis in transportation engineering and also play an important role in ensuring transportation capacity, planning and formulating strategies. In this context, routing algorithms, originally used only in dedicated GIS applications such as Arcgis, have become the most widespread applications based on GIS technology and an indispensable accessory for all modern machines. Finding the most efficient route to your destination is of utmost importance not only for normal users, but also for emergency services.

Determining paths in graphs is one of the oldest and most diverse problems with applications in various fields, such as:

- Design of road investments or urban infrastructures modelled as graphs;
- Determination of optimal route and critical path;
- Flow optimization;
- Network optimization;
- Determination of the optimal path;

- Determination of the path with the lowest cost;
- Reachability analysis.

These path optimization problems are posed for graphs where each arc (or edge) is associated with an attribute. This attribute can have various meanings: the distance between the extremities of the arc, the cost of traversing the arc, the probability of passing through this arc, the capacity of the arc, etc.

1.4.1. Determining the road with the lowest cost

The cost (value) of a road is the sum of the values of the individual arcs in the road. Routing problems are really about determining the optimal route, which can be represented by the road with the lowest or highest cost among all possible roads. Finding the shortest path is a fundamental graph problem that is not only a basic subroutine for many graph algorithms, but also has many real-world applications.

The determination of the minimum cost path for graphs that have no negative cost is done by various adaptations of Dijkstra's algorithm. (Dijkstra, 1959) Dijkstra's static algorithm is an iterative algorithm used to find the shortest path from a particular node of the graph, called the source node, to all other nodes of the graph (Dijkstra, 1959). The problem with this basic graph theory algorithm is the long running time required for the pessimistic scenario, namely O (m · n + n ^ 2 · log 〖n)〗 . Given the time required to determine all roads with minimum cost, various ways to optimize and reduce the required computation time have been intensively studied (Demetrescu & Italiano, 2014) (Sunita & Garg, 2018). In the literature, we find variants for optimizing the Dijsktra algorithm. The first method to reduce the computation time was to convert the static Dijsktra algorithm into a dynamic algorithm. The reduction of the required computation time for the dynamic Dijkstra algorithm was achieved by different methods, such as: Decomposition of the roads, algebraic methods or by reducing the number of roads for which the cost is calculated, considering only the fragments of the already calculated roads with minimum cost. (Demetrescu & Italiano, 2014).

The determination of the minimum cost path for graphs containing negative cost arcs is done by the Bellman-Ford algorithm and its adaptations.

1.4.1. Maximum Flow

To develop effective methods for monitoring traffic, traffic modeling is used as a flow network. In traffic flow optimization problems, algorithms based on the Ford-Fulkerson method are used to determine the maximum traffic flow in a graph (in a network), provided that each arc is assigned an additional value to define the maximum capacity of that arch.. (Toadere, 1992). (LÅNGSTRÖM & FRIDSÄLL, 2019) Furthermore, by aggregating the flow through a network node, the input and output capacity must be the same for each node. This method can be used to determine the maximum flow rate, i.e., how many resources can be transported from one node to another. Using the Ford-Fulkerson method, congestion caused by a node input capacity higher than the maximum flow can be identified to optimize traffic.

So we have the following constraints in the graph:

- ***Capacity constraint:*** Let a graph G (V, A), $\forall$ (u, v) $\in$A f (u, v) $\leq$c (u, v) where f (u, v) represents the flow through the arch determined by node u and v and c (u, v) respectively the maximum capacity through that arch.
- ***Symmetry*** $\forall(\mathrm{u},\mathrm{v}) \in \mathrm{A}\ \ \mathrm{f}(\mathrm{u},\mathrm{v}) = -\mathrm{f}(\mathrm{v},\mathrm{u})$
- ***Flow conservation.*** The net flow through a node is zero. $\forall\, u \in \mathrm{V},\ \ \sum_{w\in V} \mathrm{f}(\mathrm{u},\mathrm{w}) = 0$

In the case of traffic modeling, the capacity of a road section is generally expressed by the number of cars that can pass through it in an hour under favorable traffic conditions. Roads in urban localities according to Decree 49/1998 depending on the intensity of traffic and the functions they perform, as follows - category I roads - main roads, - category II roads - connecting roads, - category III roads - collector roads, - category IV roads - of local use.

- Category I roads - main roads - ensure taking over the main traffic flows of the city in the direction of the national road that crosses the city or in the main direction that connects to this road, and have at least 6 lanes, including streetcar lines;
- Category II roads - connecting roads - ensure the main traffic between functional and residential areas, with 4 lanes, including streetcar lines
- Category III roads - collector roads - take over the traffic flows from the functional areas and direct them to the connecting or main roads, with 2 lanes

- Category IV - local use streets - provide access to existing or occasional residences and services in areas with very low traffic levels.

Decree 49/1998 does not define the capacity of roads, because when designing a road, road engineers assume that there are no limits to the use of a road. To estimate the capacity of each road, we used the capacity report prepared by Transport of London for the different roads. Transport of London experts considered the type of road, speed limit, and number of lanes and used these factors to make a valid estimate of capacity, which is measured by the hourly flow of vehicles in each direction. (Force, 2013)

The table below shows the estimated capacity of roads depending on the width of the road. For two-way roads, the total number of lanes per direction is shown, adjusted from Transport of London:

Figure 5 Capacity of roads for two way streets (source Transport of London)

	Total number of lanes					lanes per direction		
Number of lanes	2	2-3		3-4		2	3	4
Width of the road	7	9	10	12	14	7	11	14
Ring road						4000	5600	7200
Cat 1	1320	1590	1860	2010	2550	3600	5200	
Cat 2	1260	1470	1550	1650	1700	3200	4800	
Cat 3	1100	1300	1530	1620		2600	3300	
Cat 4	900	1140	1320	1410				

The following table shows the estimated capacity of one-way streets as a function of the width of the street and the number of lanes per direction, adjusted according to Transport of London:

Figure 6 Capacity of roads for one way streets (source Transport of London)

	1 lane	2 lanes		2 -3 lanes	
Width of the road	5	7	9	10	11
Cat 1		2950	3250	3950	4450
Cat 2		2000	2200	2850	3250
Cat 3	1000	1200	1330		
Cat 4	700	1000	1120		

This capacity estimate can be used in the construction of the traffic flow network for any locality to implicitly identify the nodes that cause traffic congestion and for which the constraints of the graph are not respected: Capacity Constraint, Symmetry, and Flow Conservation.

1.3 GIS web services in GIS – T

A large amount of geospatial data about the road network is available online via Web Feature Services (WFS) and Web Map Services (WMS), such as OpenStreetMap. (Droj & Droj, 2019). In the United States, a huge amount of geospatial data is available to the public, such as: Maps of the road network, land use data, census data, and even travel diaries. In the European Union, thanks to the INSPIRE directive, many public institutions publish geospatial data. In the following table are presented the main Romanian geospatial data managers that have published geospatial data essential for traffic simulation:

Figure 7 GIS Data Sources in Romania GIS available for download (November 2020)

Data source	**Warehouse URL**	**Description**	**OGC standards**
CNAIR	http://gis.cestrin.ro/services/rest/services/INSPIRE/TN_Roads/MapServer/exts/InspireView/service? http://gis.cestrin.ro/services/rest/services/INSPIRE/TN_Roads/MapServer/exts/InspireView/service?VERSION=1.3.0&SERVICE=WMS&REQUEST=GetCapabilities%0D%0A&FORMAT=&EXCEPTIONS=&LANG	National Roads,	WMS

	UAGE=&LAYERS=&STYLES=&CRS=&BBOX=&WIDTH=&HEIGHT=&TRANSPARENT=&BGCOLOR=&TIME=&ELEVATION=&f=image		
Romanian Spatial Agency	http://geodata.rosa.ro/arcgis/services/Lccs03/MapServer/WFSServer?SERVICE=WFS&VERSION=1.1.0&REQUEST=GetCapabilities http://194.116.136.107/arcgis/services/icpa/sigstar/MapServer/WMSServer?REQUEST=GetCapabilities&SERVICE=WMS&VERSION=1.3.0	Lands use	WFS
National Agency for Cadastre and Land Registration (ANCPI)	http://geoportal.gov.ro	Administrative limits Cities	Download
Statistical National Institute	http://www.efgs.info/wp-content/uploads/Data/GRID/Grid_ETRS89_LAEA_RO_1K.zip.	Census 2011	Download
City Hall of Oradea	www.oradea.ro	Streets City Limits	Download

One of the biggest challenges for today's computer systems is concurrent access to large amounts of distributed data. Mapping and navigation systems are among the most popular and widely used applications that simultaneously pose challenges for accessing massive amounts of data because they require real-time access to both static (e.g., road maps) and dynamic (e.g., traffic data) geospatial data. These types of applications are becoming increasingly popular, but are also expanding into related areas as the power of computing devices continues to increase, wireless networks become ubiquitous, and users are willing to contribute to data collection through excessive phone use. smart and social media applications. In this context, access to online maps is mainly through proprietary and thematically limited geographic information services, such as Google Maps. A more interesting alternative for mobile applications is the use of sources from spatial data infrastructures based on the standardized web services of the Open Geospatial Consortium, such as the Web Map Service (WMS). Nevertheless, WMS requires high communication and power consumption for the mobile device and has limited querying potential. This research presents a proposal for the development of different application for spatial analyses in which some of these challenges can be adequately addressed based on geospatial and crowdsource data.

1.4 „People as sensor" - crowdsourcing in GIS – T

In recent years, citizen participation has been increasingly used in various software applications such as advertising and marketing, disaster response, transportation, and management, taking advantage of new universal and ubiquitous technologies. In 2007, M. Goodchild introduced the name Voluntary Geographic Information (VGI), a term that has come to define citizen geospatial data. (Goodchild, 2007).

Crowdsourcing approaches are supported by a set of highly mediated software platforms that rely on information from people to gather data from the field in real time. This approach is widely accepted by social media. A Twitter user can be considered a sensor, and a tweet created by a user represents sensory information. Humans as social sensors transmit information full of "noise" compared to physical sensors (such as heat sensors, kinetic sensors, light sensors).(Chaves, et al., 2019)

The increasing use of humans as sensors has led to the definition of a new way of collecting data through participatory sensing, known in English as social sensing. This new method of remote sensing based on human sensors is defined as a set of paradigms for detecting and collecting data where data is collected by people or devices on their behalf. (Wang, et al., 2016)

In the figure below, we present the degree of brightness of the Earth, the night through the processing of tele detection images made by NASA in 2017 and the degree of "illumination" through tweets 2017 from July 1 to June 30, 2018. (Li, 2021)

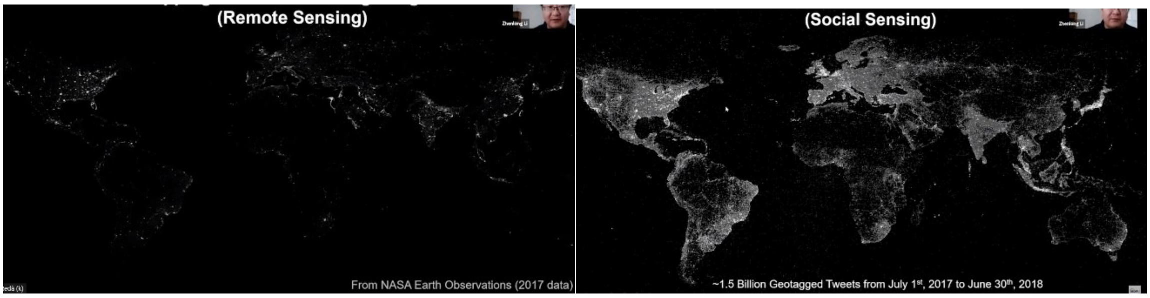


Figure 8 The brightness of the earth (NASA in 2017) vs. the degree of "enlightenment" through tweets 2017 (Li, 2021)

Nowadays, in the age of information abundance, traditional methods of traffic monitoring and control face great challenges. Therefore, several researches on traffic monitoring with wireless sensor networks have been conducted in the last decade. Most of them focused on tracking and detection of mobile vehicles equipped with sensors and mobile acquisition devices (Zhang, et al., 2012). In 2008, the University of Berkeley launched a pilot traffic monitoring project called Mobile Century. The successor of this project is called Mobile Millennium, and it was developed to collect traffic data based on the sensor embedded in cell phones GPS. After the implementation of this project, it was found that only 2-5% of the points provided by sensors in mobile devices were sufficient to provide the information needed for traffic monitoring and control (Herrera, et al., 2010) (Zhang, et al. , 2012). In this context, more and more studies have addressed the use of crowdsourcing technologies to provide the geospatial data needed for traffic monitoring. It is important to note that most platforms have been classified as open-source applications, with a focus on providing volunteer geospatial data, mobile crowdsourcing, and participatory discovery

So it turns out that geospatial data volunteered through crowdsourcing can be used for congestion avoidance and traffic planning. Crowdsourcing data collection allows for the asynchronous building and storage of diverse knowledge through active participation in the recording process. (Herrera, et al., 2010) (Li, 2021) (Goodchild, 2007). (Chaves, et al., 2019).

Whereas in the past it was necessary to install sensors to detect and count vehicles, today, with the help of crowdsourcing in GIS -based applications, any user can represent a vehicle or pedestrian and voluntarily contribute to traffic analysis. (Droj & Droj , 2020)

As long as social sensing application platforms are designed to motivate the public to participate, this approach to collecting real-time traffic data offers many advantages over traditional models. (Chaves, et al., 2019)

All crowdsourcing applications rely on the voluntary participation of road users in addition to automatically downloaded information. Routing applications such as Waze, Traffic, or Google Maps are successful because they provide real-time maps, routing solutions, and traffic updates, but at the same time encourage road users to report traffic events, accidents, road works, or other situations. that may cause traffic problems. In addition to information voluntarily shared by users, the app collects the location of all users, with traffic participants being able to interpret and update the GPS locations of vehicles in real time and update the actual speed for each lane.. (Droj & Droj , 2020)

Processing and interpreting geospatial data from a large number of participants is another challenge for the widespread use of crowdsourcing systems. (Chaves, et al., 2019)

1.5 The influence of public transport on traffic

Given the increase in traffic, it is noticeable that some streets are prone to congestion. Undoubtedly, both congestion and urban traffic are caused by numerous factors characterised by complex spatial data and the relationships between them. Locating all these factors helps to optimise the methods of traffic analysis and management, as well as the planning, implementation and monitoring of investments in local, regional and interregional road infrastructure. (Yuan, et al., 2014) Public transport is perhaps the most important factor that can have a lasting impact on traffic.

Improving public transportation has become an important environmental and socioeconomic issue in recent years. In fact, the difficulty of the problem lies in the interaction between the choice of means of transport for passengers and the changes in urban traffic. When choosing a means of travel, people primarily consider geographic elements such as origin and destination, but also aspects such as frequency, duration of the travel, traffic congestion, and service quality.

Based on the urban economic model defined by Fujita and Ogawa, the population generally chooses accommodation, place of work and type of communication to minimize costs. (Masahisa & Hideaki , 1982). Mathematicians Vincent Verbavatz and Marc Barthelemy adapted this model to analyse the aspects that affect traffic by creating a simple model that showed the basic relationships between traffic flow and public transport. The objectives of their study were to determine the essential relationship between the main variables - first, the population that prefers to drive rather than use public transportation, and second, the residents who have access to and therefore choose to use public transportation.(Verbavatz & Barthelemy, 2019).

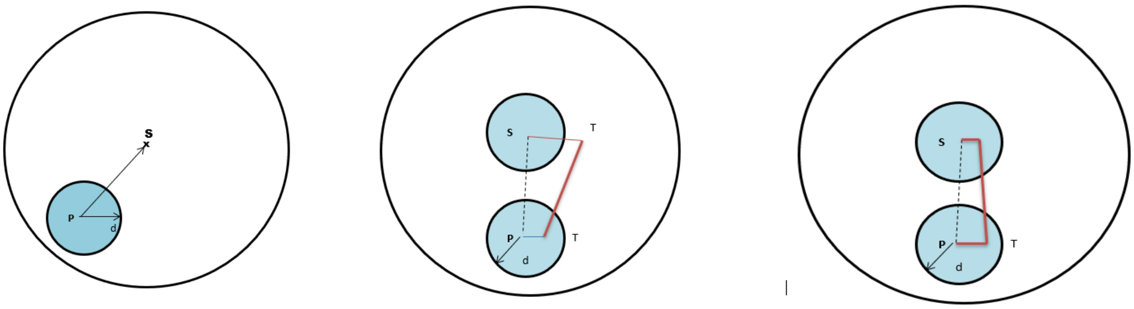
The total number of inhabitants of the area near to public transportation is called Pa, the total population is P, and T is the proportion of people who prefer to use cars rather than public transportation. The model developed by Vincent Verbavatz and Marc Barthelemy provides an amazingly simple estimation: $\frac{T}{P} = 1 - p_a$ where,

T represents the proportion of people who prefer to use cars rather than public transportation

P_a represents the total number of inhabitants living "near" public transportation

P is the total population of the region

The model proposed by Vincent Verbavatz and Marc Barthelemy assumes that in the center of localities all possible destinations are easily accessible by public transport, but in historic cities this is not always the case. Therefore, we modified this model as shown in the following figure. The first situation shown in Figure 3 (1) includes the cases where both the departure and destination points are too far from public transportation. Figure 3 (2) includes the cases where the departure point is easily accessible by public transportation but the destination is far from a station or vice versa, and Figure 3 (3) includes the cases where both the departure point and the destination are accessible by public transportation.



1) **2)** **3)**

Figure 9 choice of public transport (adaptation (Verbavatz & Barthelemy, 2019))

In this case, our proposed model considers the substitution of Pa by Pc, where Pc <Pa and Pc stands for the total number of inhabitants for whom both departure and the destination point are located accessible to public transport station:

$$.\frac{T}{P} = 1 - p_c$$

One of the most important principles in choosing a means of transportation is the shortest travel time from the point of departure p to the destination s.

The travel time from point p to point s when driving by own car can be calculated with the following formula:

$$t_m = \frac{dist(s,p)}{v_m} \text{ where,}$$

t_m – travel time by own car,

dist (s,p) – stand for the distance from *p* to *s*

v_m – average speed of travel

Since the average speed of a route depends on the degree of congestion, the time estimate should be modified by taking into account a congestion-dependent coefficient, which is calculated using the traffic index. Therefore, t_i was estimated as the ratio between the total number of vehicles in traffic and the capacity of the roads, increased by the power μ, which represents the traffic sensitivity., $t_i = \left(\frac{T}{c}\right)^{\mu}$. The traffic index, ti , is calculated by TomTom for major cities in the world(Verbavatz & Barthelemy, 2019).

Thus, to calculate the time needed to travel by car, the following formula applies:

$$t_m = \frac{dist(s,p)}{v_m} \times (1 + t_i)$$

The travel time from point p to point s, in case of a journey by public transport (PT) can be calculated as follows:

$$t_{PT} = \frac{dist(s,s_s)}{v} + t_{asteptare} + \frac{dist(p,s_p)}{v} + \frac{dist(s_s,s_p)}{v_{PT}} \times (1 + t_i) \text{ where,}$$

t_{PT} Time you need to travel by public transport,

dist (p,s_p) represents the required walking distance from the leaving p to the nearest station s_p

dist (s,s_s) represents the required walking distance from the starting point s to the nearest station s_s

dist (s_s,s_p) is the distance you need to travel by public transport from the nearest public transport stop to the place of departure to the nearest public transport stop to the place of arrival.

and v_{PT} – - the average speed of public transport between $s_p and\ s_s$ by applying the correction factor, given by the traffic index, ti (Verbavatz & Barthelemy, 2019).

Thus, if the travel time by car is shorter than the travel time by public transport, $t_m < t_{PT},$ the likelihood that one will choose one's car as a means of transportation instead of foregoing public transport increases.

In summary, it makes sense to reduce travel time by public transportation in order to reduce the number of vehicles on the road, i.e. the number of car drivers. This can be achieved by increasing the number of people who have easy access to public transport and reducing waiting times. (Verbavatz & Barthelemy, 2019) (Buchanan, 2019)

1.6 Traffic simulation

Traffic is an integral part of any virtual environment that attempts to realistically describe today's world, whether it is a video game, a movie, or a virtual routing application. On the other hand, traffic is a worldwide problem with direct impact on the economy, energy consumption and the environment. Traffic simulation is an important tool for analysing malfunctions as well as for creating real-time traffic scenarios. (Wilkie , et al., 2010) (Knoop, 2020)

Real-time digital representations of road networks are available both GIS and download, but the level of detail in these data is not immediately useful for many traffic queries. Traffic simulations take place in a network of bands. These should be represented in full detail, including the number of lanes on a road, intersections, fusion zones, ramps, etc. (Wilkie , et al., 2010)

Simulating the travel route with GIS -T-based applications provides the user with alternative routes to reach the desired destination under the conditions specified by the user. The applications used for navigation simulate alternative routes depending on the situation on the ground, events reported by crowdsourced components, cumulated with traffic statistics, and provide not only navigation instructions and distances, but also realistic time estimates for the chosen route. There are more complex simulation applications that analyse the impact of weather conditions on traffic, depending on three weather conditions, namely normal, rainy and foggy.

Currently, most traffic simulations are performed for routing applications. Unfortunately, at least in Romania, the GIS -T systems are used only sporadically for road design and traffic planning.

2. Analysis of road infrastructure using GIS - Oradea case study

In recent decades, geographic information systems have evolved from tools for mapping and managing geospatial data to modeling, analysis, and simulation applications, and have become an indispensable tool for decision-making systems in a variety of fields such as urban planning, economic development, disaster response, environmental protection, and transportation. emergency response, environmental protection, traffic management, etc.

Geospatial data and geographic information systems have proven to be indispensable tools for urban management. While 50 years ago the software GIS was used to automate the process of creating map without including analysis operations, today GIS systems integrate complex geospatial information with non-spatial database with applicability in urban planning and management.

Due to its ability to capture the full dynamics of time-dependent traffic phenomena, traffic simulation, the geographic information system, has become a popular tool for testing the feasibility and evaluating the impact of a transportation planning design. GIS -T provides an ideal environment for designing and testing traffic incident response strategies. (Huang & Pan, 2007).

2.1 Metodology

To perform the proposed analysis, we used public spatial databases containing the road network of Oradea, downloaded from the local government website. In addition, on-site traffic information and different public documents such as the general map of Oradea, public transport maps and materials published on Google Maps, Open Street, and Waze were collected. The collected information was integrated into a specially created spatial database. The following figure shows schematically the methodology used.

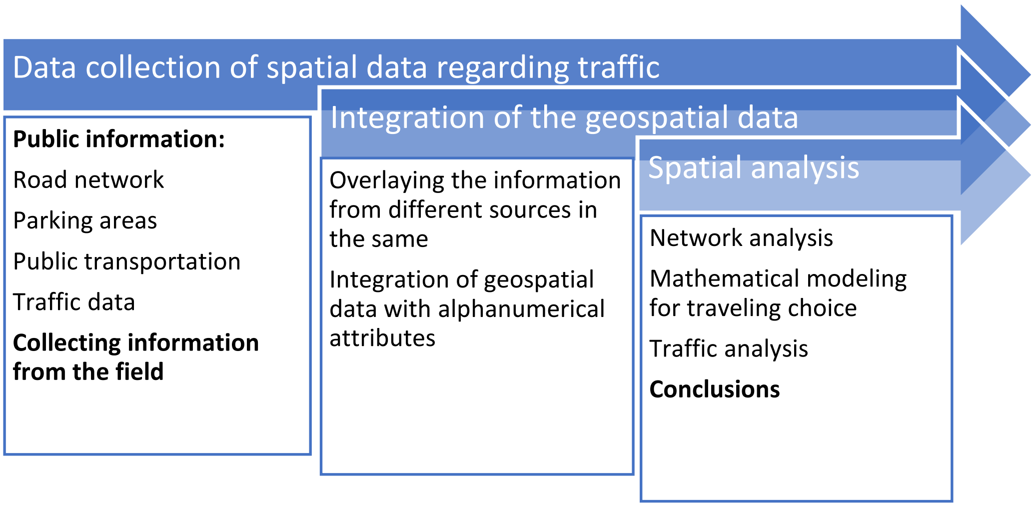


Figure 10 Methodology of traffic analysis (Droj , et al., 2022)

In this way, the detailed identification and parameterization of the road network was performed:

- the road network was defined as a graph with the corresponding database to be used as a base map in the mathematical modeling and presentation environment for the traffic simulation;
- Likewise, the entire public transport network was defined;
- the traffic-generating areas were identified;
- the collected traffic data and the traffic data from the city's master plan were integrated into the database;
- real-time traffic data were integrated with collected traffic and transportation data.

The mathematical model presented in chapter 1.6. was used to estimate the travel decisions of the inhabitants of the Oradea metropolitan area. Network analysis, traffic analysis, and travel simulations were used to identify the factors that lead to traffic congestion in the city. (Droj , et al., 2022)

2.2. Road Infrastructure in Oradea City

Currently, Oradea's road network consists of almost 900 roads with a total length of 432 kilometres, covering about 10% of the city's area (8,346 km2). The transit traffic has a great impact on Oradea municipality, as the city is situated at crossroads of the national roads DN1, DN76 and DN79, 9 km away from the Borș customs.

The following figure shows Oradea's road network according to the city's Master Plan.

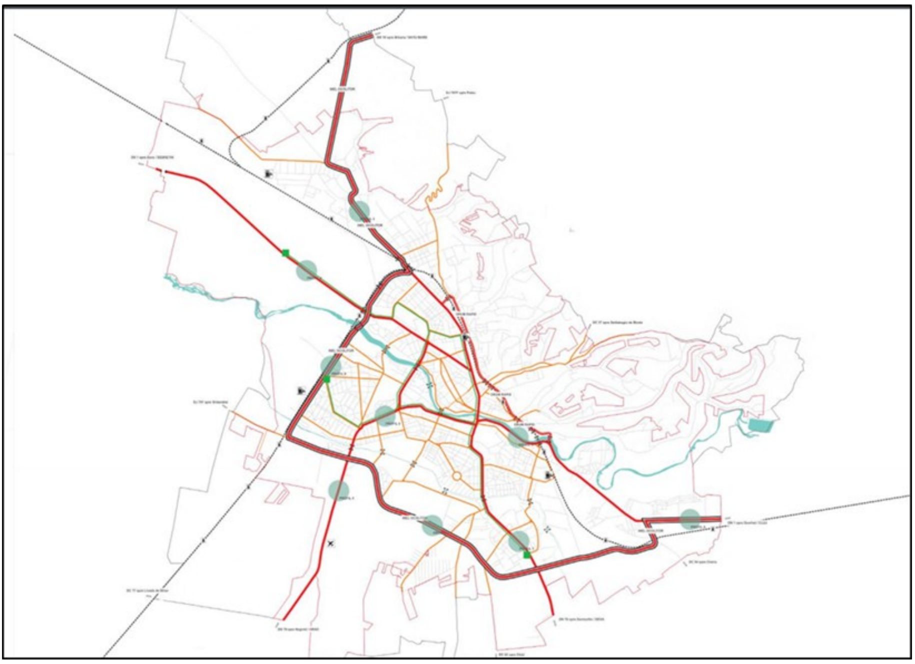


Figure 11 The street network according to the Master Plan of Oradea

Currently, the road network in Oradea is facing some problems, namely:

1. unbalanced distribution of roads;
2. unbalanced intersections in relation to the capacity of the adjacent roads;
3. partial synchronization of traffic lights that cause congestion;
4. narrow streets in the historic part of the city;
5. congestion caused by bridges over the Crisul Repede;
6. overlapping of the streetcar line with the lane causing traffic jams during rush hours;

2.3. Public Transportation

Public transport is provided by Oradea Transport Local SA (abbreviated O.T.L. SA) with trams and buses from 5:00 to 24:00 The number of public transport vehicles and their frequency varies throughout the day based on the estimated number of travellers, so most vehicles run during rush hours, i.e. between 5: 00-08: 30 and 13: 00-17: 00. The bus network includes 27 lines that cross the entire territory of Oradea, including the newly built residential areas..

The trams operate on the 5 main lines 1N, 1R, 2, 3N and 3R, as well as an extension line for the industrial area of Calea Borșului. Currently, the extension of the tram lines is being worked on with the purpose of introducing a new tram line.

Unlike road transport, public transport can only operate according to a predefined timetable and only on the infrastructure of existing stations. The predominant use of trams makes any change or extension of the route dependent on major infrastructure works.

The following figure shows the public transport services in November 2021.

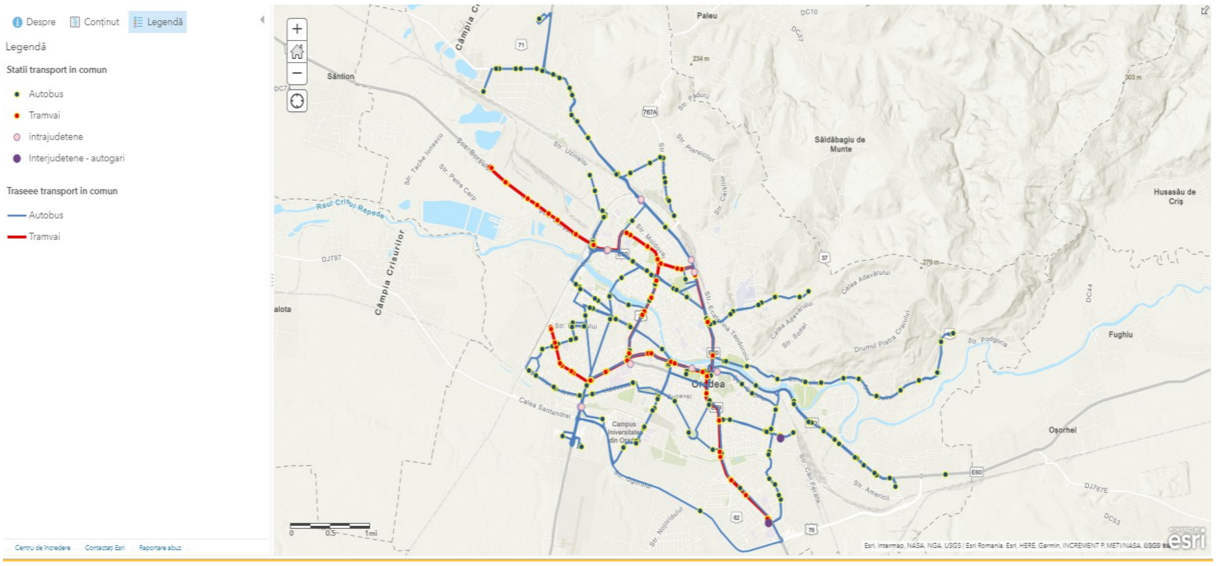


Figure 12 The public transport routes in Oradea (as of November 2021) – map created by author

Since 2012, public transit ridership has declined. While in 2012 an average of about 120,000 customers used public transport on a working day, almost 2/3 of them by tram, their number has now dropped drastically. As for the regularity of using public transport, in 2012 37% of the municipality's population used it daily, 20% frequently (less than 4 times a week), 27% rarely and 16% never. Currently, less than 30% of residents use public transportation daily, 18% frequently (1-4 times per week), 32% rarely, and 20% never.

Public opinion, supported by the local government, believes that the unpopularity of public transportation is due to the growing number of cars. However, after analysing public transport using spatial analysis methods and applying GIS, several existing malfunctions in the public transport network were identified.

First, spatial aggregation was used to analyse the distribution of public transportation stops in Oradea. As explained in the previous chapter, spatial aggregation combines multiple objects, in this case public transportation stops, into a single entity based on their location in a given neighbourhood. The encapsulated value was calculated using the aggregation formula. A gradient colour palette was used to display the analyses to show larger values with darker shading. The following figure shows the concentration of stops in each neighbourhood:

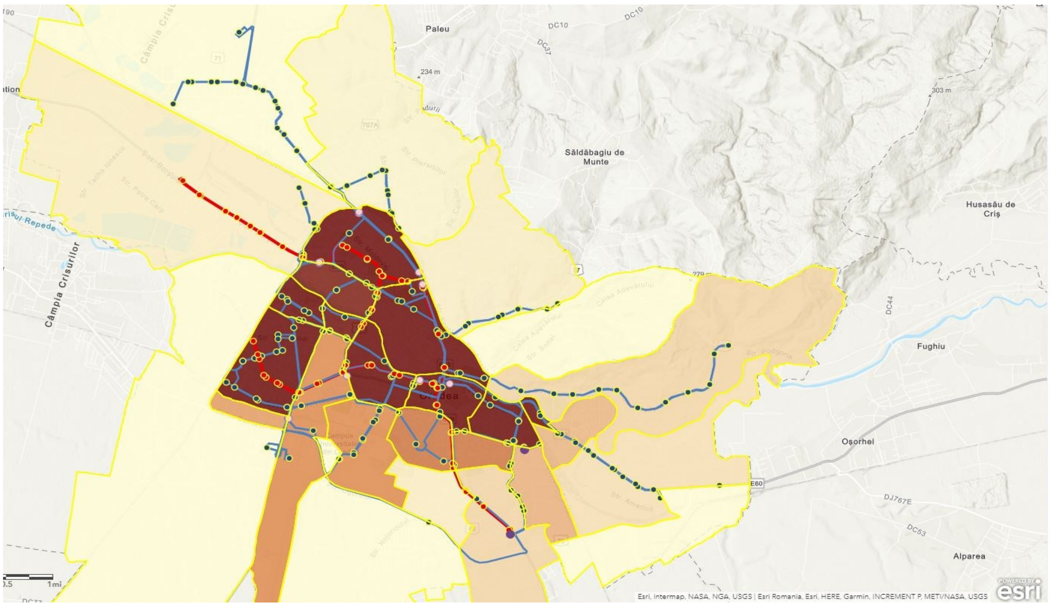


Figure 13 Concentration of stops per neighborhood (created by autor with ArcGis online)

As you can see from the figure above, despite the expansion into the new neighborhood, the new transit services only cover a very small area. To make matters worse, many transport lines are only served by 2 vehicles every hour or half hour, which shows the motivation of residents to choose alternative methods of public transportation. The distance to the nearest station represents another important consideration when choosing a mode of transportation. Proximity analysis is used to determine areas near an object that are not necessarily in its vicinity. Buffer zones are the most popular method of proximity analysis, but buffer zones are represented by a regular geofield, at a certain distance around the selected object and based on its geometry. In the figure below, the buffer zones are shown within a radius of 500 m for each public transport station, in this case the accessibility is considered as a function of the distance as the crow flies. So, the buffer zones are not relevant in the case of traffic modeling and the application GIS -T, therefore network analysis must be used.

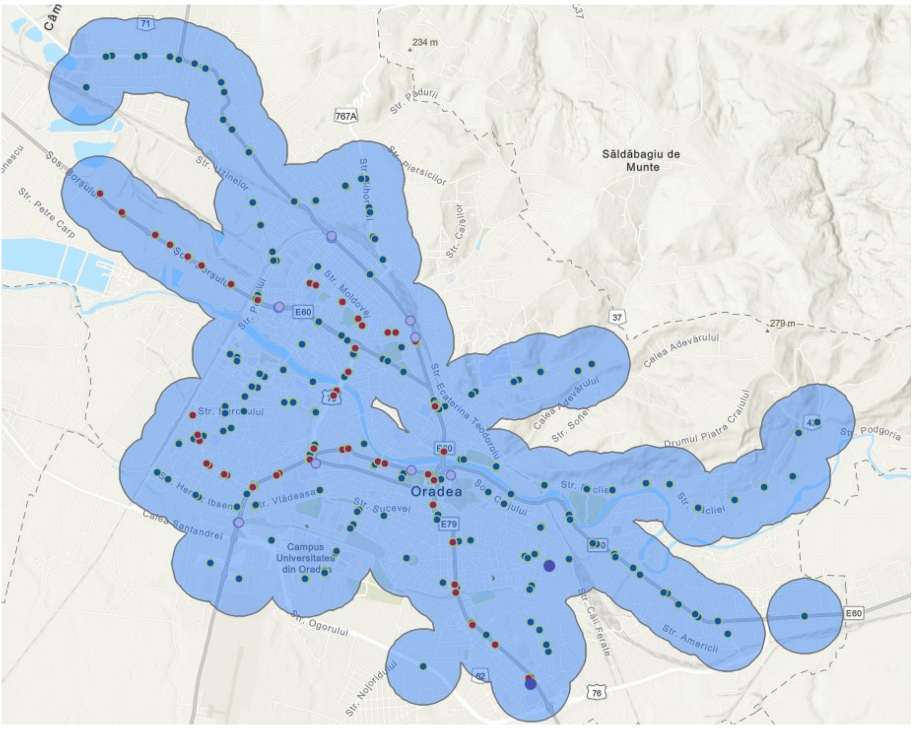


Figure 14 Buffer zones at distance of 500 m to public transport stops

Service area analysis can be used to determine the area that is accessible from or to a location. However, unlike buffer zones, this analysis takes into account the structure of the road network and various obstacles. The outcome of the analysis is an area which can be traversed in a given time or distance. Therefore, in order to evaluate public transportation coverage, we perform a service analysis to determine the accessible area from a public transportation stop or bus stop. This network analysis was performed considering the following parameters: Walking distance in 10 minutes travel time. The result of the analysis is an area that can be reached in a period of five minutes to a public transport stop. The generated areas were merged to present the results.

In the figure below, we have highlighted the areas that are within a 10-minute walk from a public transportation stop.

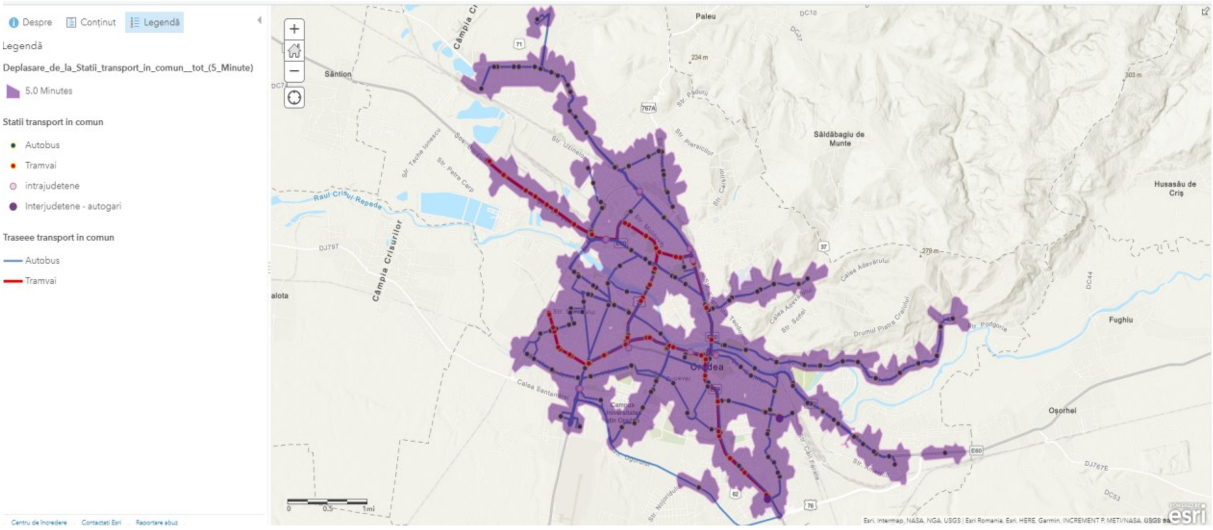


Figure 15 The areas within a 10-minute walk from a public transportation stop ((Droj , et al., 2022)

In 2020, the OTL company is launching a real-time monitored public transportation system based on a protocol with Google Maps. This application can be used to track all the routes served by OTL and the transportation program, allowing citizens to optimize their travel times. However, it was found that many areas are not adequately covered by public transportation, including the central area where the following schools are located: General Education School "George Coşbuc", National College "Mihai Eminescu", National College "Ady Endre", Special Technological High School No. 1. Also in this area, all streets are one-way, so the resulting congestion extends throughout the day, not just at rush hour before 8 a.m. and around 2 p.m.

Overlapping the map created for public transportation accessibility with real-time traffic data showed that there was significant congestion in the central area of the city, an area without public transportation.

The following figure shows a traffic analysis using real-time traffic data that highlights congestion in the city center due to the inaccessibility of public transportation during times when children are going to and from school.

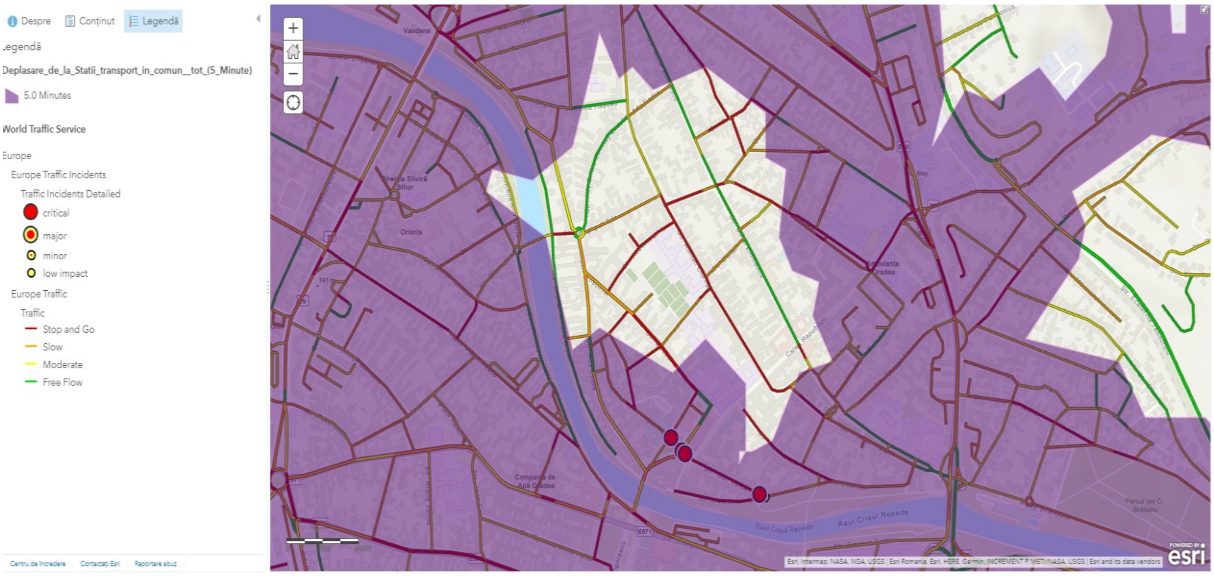


Figure 16 - Congestion in the city center of Oradea in 4.06.2021 14, (Droj , et al., 2022)

Similarly, traffic analysis was conducted using real-time traffic data that showed congestion in residential areas around 5 p.m. when the active population returns from work. The following figure shows the traffic situation at 5 p.m. in the city centre.

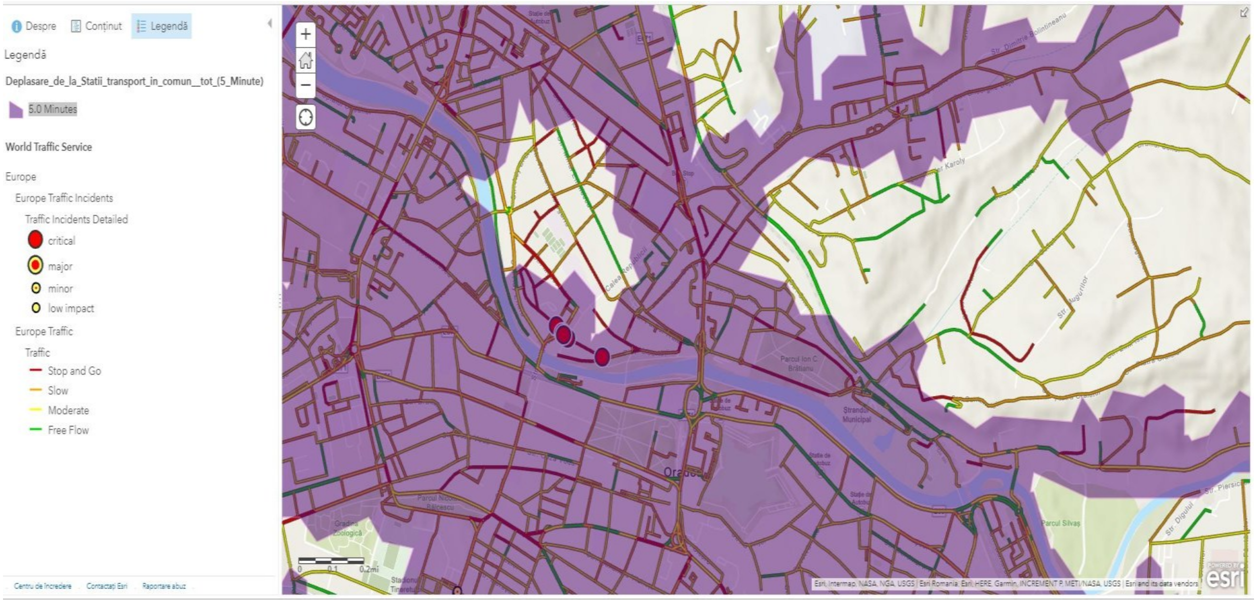


Figure 17 Congestion in the central area due to inaccessibility of means of transport 17.05. 2021 at 17 clock, (Droj , et al., 2022)

In the above figures, we have highlighted the areas without easy access to public transportation and roads with traffic problems. The choice of travel route depends not only on the network of public transport, but also on the time cost of the trip, especially for parents who need to take their children to school before going to work. As we pointed out in the previous chapter, the travel time for a car trip is given by the formula: $t_m = \frac{dist(s,p)}{v_m} \times (1 + t_i)$

Since the TomTom traffic index is not calculated for Oradea, we considered 55% for Oradea and 45% for the suburbs based on the typical traffic estimated by Google Maps. The average speed in the rush hour is about 25 km/h, and the average distance for Oradea is 6 km and for the suburbs 15 km.

In estimating travel time, it was assumed that both the departure and arrival points were in areas accessible by public transportation, with an average walking time of 10 minutes from each point to the next station. The waiting time during peak hours was estimated to be 10 minutes for Oradea and 25 minutes for the suburbs of the city. The time needed to get from a point p to a point s, in the case of a public transport trip, is calculated according to the following formula (PT):

$$t_{PT} = \frac{dist(s,s_s)}{v} + t_{asteptare} + \frac{dist(p,s_p)}{v} + \frac{dist(s_s,s_p)}{v_{PT}} \times (1 + t_i) \text{ unde,}$$

For the municipality of Oradea we estimated $\frac{dist(s,s_s)}{v} + t_{asteptare} + \frac{dist(p,s_p)}{v}$=30 minutes, and for the Metropolitan area we estimated $\frac{dist(s,s_s)}{v} + t_{asteptare} + \frac{dist(p,s_p)}{v}$=45 minutes.

In the table below the analysis of the time needed to travel is present:

Figure 18 Estimating travel time

	Population	Surface (kmp)	Average distance	Traffic index	Time of travel with PT t_{PT} (minute)	Time of travel t_m (minute)
Metropolitan Area	350000	773	15,69007	45,00%	92,07021	54,60145
Oradea	250000	125	6,309431	55,00%	48,92829	23,47108

Based on the analyses, we can conclude that the travel time by car during the rush hour is half of the travel time by public transport, both in the urban area and in Oradea, even if both the departure and arrival points are at an acceptable distance from the transport stations.

To estimate the cost of commuting by each mode of transportation, we can find the average hourly income for the time required and the daily cost of the car, including parking fees, as well as the hourly income for the time required and the cost of tickets for public transportation.

In developing countries, many inhabitants prefer to use public transport because commuting by car reduces travel time but increases travel costs. In the financial evaluation of time lost in traffic, the cost of public transportation in Oradea became very expensive due to the large time difference required to travel compared to using one's own car.

This analysis concludes that achieving efficient public transport has a significant impact on reducing the number of vehicles on the road. However, the general assumption, also held by the local administration, that traffic congestion is primarily caused by the increasing number of cars and the lack of parking spaces, is invalidated by the analysis conducted.

As we have argued in this chapter, in order to reduce the number of vehicles on the road and the number of car drivers, it is imperative to reduce travel time by public transportation, which can be achieved as follows:

- Increasing the number of people who have easy access to public transportation by expanding transit lines both in new neighborhoods and in the metropolitan area and city center;
- Reducing waiting times by increasing the number of public transportation vehicles on each line;
- Introducing additional lines to avoid transferring to another means of public transport.

2.4. Traffic Congestion

Congestion occurs when traffic volume exceeds the capacity of the available road; this point is commonly referred to as saturation. There are a number of specific circumstances that cause or exacerbate traffic congestion. Most reduce the capacity of a road to a certain point or over a certain length, or increase the number of vehicles required to move a given amount of people or goods. (Bull, 2003) About half of the traffic congestion in Oradea is recurrent and due to the high volume of traffic during peak hours; the other half is due to traffic disruptions, road works, and meteorological events. In terms of traffic, rainfall reduces traffic capacity and speed, leading to more congestion in the road network.

In order to analyze the traffic volume in Oradea, the following methodology was applied:

- We collected traffic data from Oradea reflected by waze.com and Google Maps;
- We estimated the capacities of each road section using the methodology proposed by Transport of London and presented in Chapter 1.

As a result of the analysis conducted, the following main deficiencies were identified:

- Decreased traffic capacity mainly in the side streets in the historic center, but also in the neighborhoods with social housing;
- Decreased capacity of some streets as a result of the conversion of some parts of the street into longitudinal parking lots;
- Reduced traffic capacity on streets serving the new residential neighborhoods
- Several intersections that are not subject to traffic restrictions under the Ford-Fulkerson methods presented in Chapter 1.

The following figure shows the most critical area in terms of excess capacity and the highest density of intersections (junctions) where traffic flow restrictions are not met.

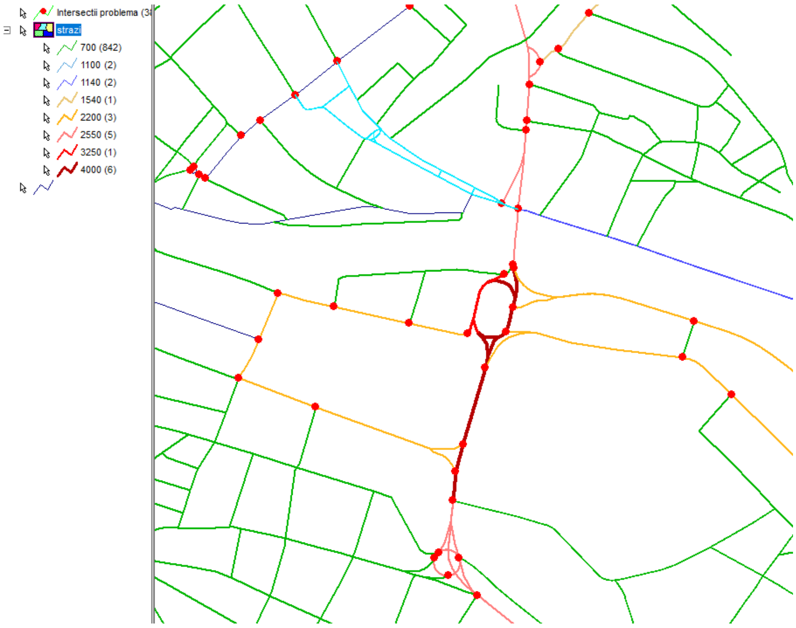


Figure 19 Junctions where traffic flow restrictions are not met

2.5 Conclusions

The analysis presented in this chapter concludes that traffic problems in Oradea are diverse and have increased in recent years due to:

- the increasing number of vehicles;
- the narrow streets in old town;
- the streets of downtown are mostly one-way streets;
- an insufficient public transport network, so that the city districts are not accessible by public transport;
- The river Crişul Repede divides the city in half, and only 4 bridges allow crossing by main roads with high capacity;
- the overlapping of the tram line with the roadway causes traffic jams during rush hours;
- Insufficient number of arranged parking spaces;
- Infrastructure works for rehabilitation of existing network,
- Extending gas network in different areas of the city.

As outlined in this chapter, in order to reduce the number of cars on the roads and therefore the number of people driving them, it is imperative to reduce the time required to travel by public transport, which can be achieved through the following measures:

- Increasing the number of people who have easy access to public transportation by expanding transit lines in the new neighborhoods, metropolitan area, and downtown;
- Reduce wait times by increasing the number of public transit vehicles on each line;

Introducing additional lines to avoid transferring to other means of transport.

- Demand reduction can be achieved not only by optimizing public transport, but also by
- Reducing the cost of public transportation
- Park-and-ride facilities, which make it possible to continue the journey by public transport from a distant parking lot.
- Facilities of this type are usually found at major public transportation hubs, at highway on-ramps in suburbs, and on the outskirts of smaller cities.
- Differentiated taxation of parking lots depending on their location.

Traffic congestion can be reduced not only by reducing demand but also by increasing road capacity (supply), but generally these methods require much higher costs due to infrastructure investments.

On the other hand, capacity can be increased in a variety of ways, but latent demand must be taken into account or it may be used more than expected. Increasing traffic capacity can be achieved by:

- Increasing the capacity of roadway segments (e.g., adding more lanes, removing local obstacles such as bridge piers, and widening tunnels);
- Increasing capacity on the entire roadway (usually by widening lanes);
- Creating new routes, building bridges, new road sections, bypasses;
- Traffic management improvements by:
    - Designating bypass lanes
    - Designating special lanes for public transit
    - Prohibiting heavy truck traffic and school vehicles during peak hours
    - Installing variable message signs along the route
    - Improving road markings and signs
    - Streamlining on-street parking
    - Planning work schedules
    - Synchronizing traffic signals and adjusting traffic lights and green waves to traffic volumes o Real-time traffic monitoring to provide real-time traffic counts
    - Parking guidance and information systems, that provide dynamic guidance to motorists on available parking spaces
    - Active traffic management.

Optimizing public transport has a multiplier effect on reducing pollution and sustainable urban development. Fewer people commuting by car has a direct impact on traffic. Smooth traffic flow can dramatically reduce time spent in traffic, but it also has other positive impacts on people and the environment. Road traffic is a major source of air pollution, and less congestion would lead to lower fuel consumption.

The main advantages in applying the methodology, spatial analysis, simulations and modeling proposed in this study are (Droj , et al., 2022):

- It can be applied to any urban agglomeration and extended to similar cities and regions.
- Can be used to alleviate traffic congestion and prioritize public transportation.
- Can be used to analyze the degree of improvement in environmental efficiency.
- Can be used as a basis for economic analysis.

The major weakness of the model is that it does not take into account the subjective transportation decisions of local governments and the patterns of social transportation that directly and indirectly affect residents and businesses.

3. Usage of GIS in traffic analysis - Study case

Most urban areas have developed organically over time. Originally, cities were developed so that the population could meet their basic needs for sleep and food. Later, as society evolved, the needs of the population increased and urban infrastructure was created to meet other immediate needs: Water, sewerage, recreation, etc. Today, the development of cities is done through urban planning based on technology, geospatial data, models and scenarios..

Urban redevelopment is the way to upgrade, redesign and plan an urban area for its sustainable development.. (Wang, et al., 2011) However, even if land use is optimized and rationalized, urban redevelopment can cause a series of disruptions in the transportation system. In this chapter, we will analyze how urban redevelopment of a major intersection affects traffic in the area and adjacent areas.

3.1. Presentation of the context

Cities around the world are growing, affecting the increasing mobility of the population, leading to ever-increasing traffic problems: Traffic jams, congestion, accidents, but also indirect effects such as pollution.

As we pointed out in the previous chapter, with the economic development of Oradea, traffic problems have also increased. Among the main causes of traffic congestion, we include:

- The natural barrier formed by the river Crișul Repede;- narrow streets, mostly one-way, in the historic center;
- the overlap of the tram line with the traffic lane;
- Through traffic, especially small vehicles on the east-west (Cluj-Borș) and north-south-west (Deva-Satu Mare) axis, which runs through the city's internal road network and is a major burden in the area of Independence Square and Gheorghe Magheru Street.

In accordance with the above, it is emphasised that the most critical area for traffic in Oradea is and was the area next to the Dacia Bridge, Independence Square in the south and Gheorghe Magheru Street in the north.

In view of the high number of accidents that have occurred at the intersection Traian Park - Dacia Bridge - Gheorghe Magheru Boulevard, Oradea City Hall plans to build a new underground passage under Gh. Magheru Street and abolish the traffic lights in the fall of 2019. Gh. Magheru Street has two lanes for each direction, but one overlaps with the tram lines, and the starting point of the street is the busiest bridge in Oradea.

The proposed investment was initiated to solve one of the most problematic intersections in the city, but without an analysis of how the diverted traffic will be distributed due to the inability to turn left. In the figure below, you can see the Traian Park - Dacia Bridge - Gheorghe Magheru Blvd. traffic light intersection in its existing configuration in November 2019.

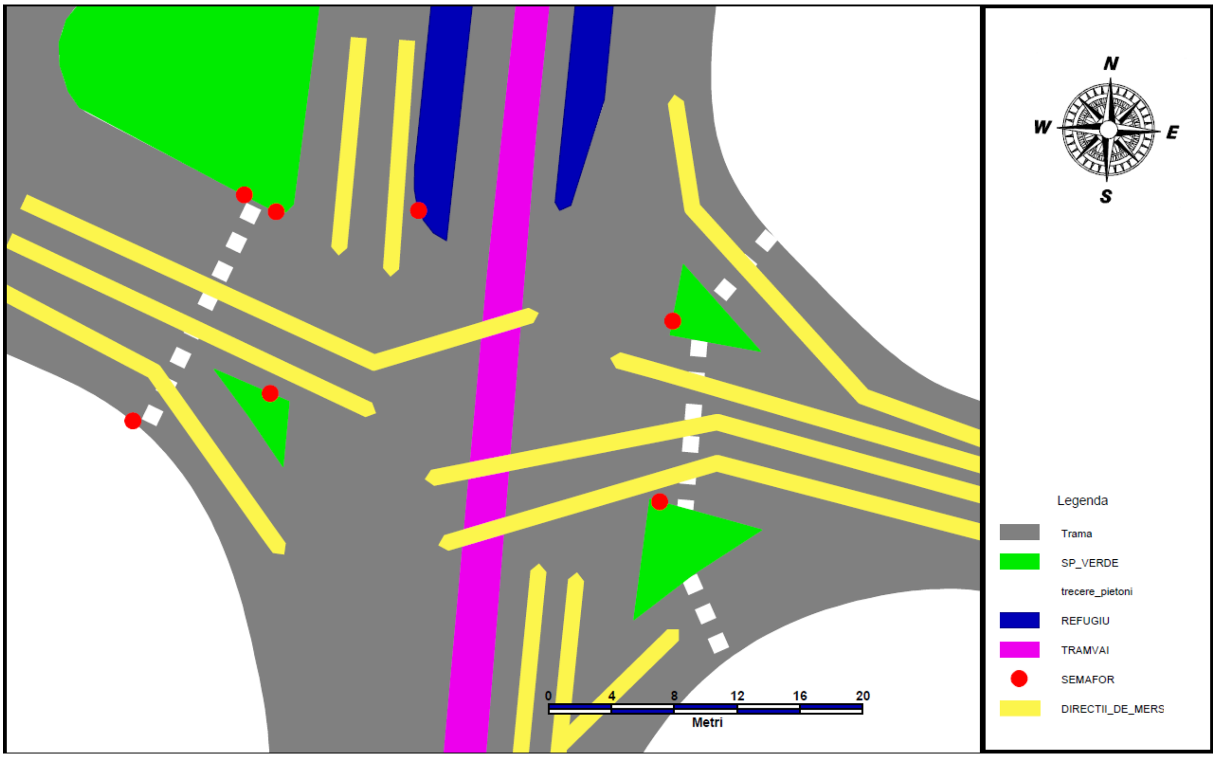


Figure 20 The intersection Traian Park - Dacia Bridge - Gheorghe Magheru Boulevard

In this study, we proposed to analyze the impact of this investment on transport and the socio-economic impact of the new investment on this particular area.

To conduct this case study, we performed repeated traffic analyzes by overlaying the information provided by Esri or Google Maps on real-time traffic data with orthophoto images of Oradea that allow the identification of agglomerations. extensive traffic in the central area of the city.

The following figure shows the result of the traffic analysis made in Oradea on November 7, 2019 at 2 p.m., one day before the start of the traffic restrictions in Magheru Street due to the construction works for the underpass (which started on November 15, 2019).

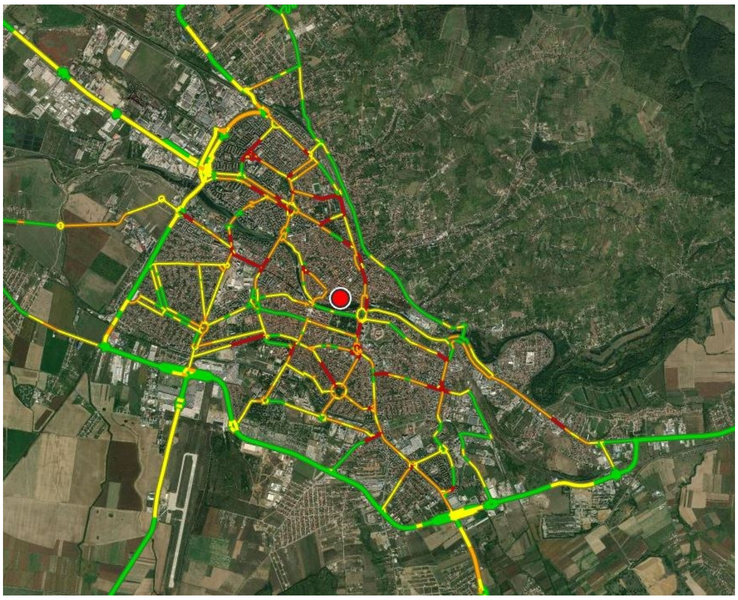


Figure 21 Traffic in Oradea , 15th November 2019 at 2 p.m.

As you can see in the figure above, the blocked and red marked sectors are only on the important traffic arteries, usually caused by traffic lights, on the road section before the traffic light crossing. In general, in the city center we can see streets with all types of traffic situations reflected in the colors: red - the slowest traffic, orange - slow traffic, yellow - medium traffic and green for normal traffic.

3.2. Tracking traffic and congestion during construction works

To track traffic during construction, we performed repeated traffic analysis by overlaying real-time traffic data information provided by Esri through Living Atlas World Traffic Services and Google Maps, respectively, with orthophotos of Oradea.

The real-time data used in the study, provided by Living Atlas World Traffic Services, Google Maps and Waze, is collected through crowdsourcing. Thus, road users provide the actual location data along with the voluntarily shared traffic information. The above applications, by collecting the location of all users/traffic participants, determine the level of congestion, average speed, passing road capacity, information underlying simulations, traffic analysis, and routing.

The regular analysis of the traffic situation in Oradea after November 15, 2019 has shown that the speed on most of the city's roads has decreased significantly due to the start of construction and related traffic restrictions, the sections have become orange. We can also notice an increase in traffic problems on the city ring road and other secondary roads, where previously the average speed was high and which were mostly marked with the code green.

Figure 22 Tipical traffic in february 2020 during rush hour around 2 PM

In the figure above, is presented the typical traffic volume on a working day in February 2020 around 2 pm (created by the author with Google Maps) .

The outbreak of the Covid 19 pandemic and the quarantine imposed had a significant impact on traffic. As in all major European cities during the quarantine, road traffic in Oradea came to a standstill. Despite the implementation of the above-mentioned infrastructure works and the associated restrictions, the city has become "green" in terms of traffic. (Droj & Droj , 2020)

The traffic analyzes conducted in the period after the quarantine declaration underline these aspects. In the following figure you can see the traffic volume in Oradea on April 29, 2020 at 14:00.

Figure 23 Traffic volume in Oradea on April 29, 2020 at 14:00 (created by author)

As can be seen in the figure above, in Oradea, as in other European cities, traffic has disappeared, the only crowded areas are on the road sections affected by the construction works.

With the end of the quarantine period and the resumption of the school year, traffic returned to the streets of Oradea. Due to the state of emergency and the large number of students who continued their schooling online, the number of road users is much lower than before the pandemic COVID 19, but due to the construction works, the traffic in Oradea is very busy.

The following figure shows the traffic situation on September 17, 2020 at 8:00 a.m.

Figure 24 Traffic volume in Oradea on 17 September 2020 at 8.00 am (created by author)

On October 26, 2020, Magheru Passage was opened to the public. The problematic crossing has received a new configuration: the direction of the Dacia - Gh. Magheru bridge allows fast passage without blockages regardless of the time, crossing Magheru Boulevard is easy, but it has become impossible to turn left.

In the following figure you can see the traffic situation on October 26, 2020 at 2 pm, after the reopening of the passage..

Figure 25 Traffic volume on October 26, 2020 at 2 pm (created by author)

The return of all students to school in May 2021, even though the emergency situation was not lifted and students did not physically return to class and some companies still allowed online work, negated the positive effects of Gh Magheru passage. The Dacia - Magheru Bridge direction of travel is much smoother than before the passage, but traffic is backed up at the adjacent intersections. The road users who turned left before the investment have changed their route. Most of them have chosen the Gh Magheru - G. Enescu intersection, and the congestion created at this intersection extends to the Dacia Bridge for the direction SN or to the Traian Park for the direction EV.

Figure 26 Traffic volume on May 17, 2021 at 2 pm (created by author)

As you can see in the figure above, the traffic situation on May 17, 2021 at 2 pm shows a traffic jam on the entire section of Gh. Magheru Street.

3.3. Conclusion

Urban redevelopment is an important step in the development of a city that can have major negative or positive impacts on traffic. The main reason for traffic congestion after redevelopment is unfounded planning without an accurate model to predict traffic demand and an efficient traffic evaluation system.

When analyzing the causes that lead to traffic congestion, it is often found that urban planning was carried out without correlating and coordinating redevelopment and proposed new functions with mobility problems, and that traffic demand exceeds the capacity of transportation facilities after redevelopment. Such a situation is also found in the case of the Traian Park - Dacia Bridge - Gheorghe Magheru intersection redevelopment.

Although the urban redevelopment scenario solved the problem of traffic flow from the intersection in S-N direction, it affected the adjacent intersections and caused traffic congestion and massive obstructions, especially during peak hours. Therefore, the solution for the design of the Traian Park - Dacia Bridge - Gheorghe Magheru Blvd. intersection can be considered flawed from a traffic engineering point of view, as the traffic modeling was based on incomplete and insufficiently justified assumptions and the actual situation on the ground was not known.

In summary, without a rigorous analysis of the traffic impacts for both the baseline situation and the redesign and adaptation plans for the scenarios in the planning phase, an optimal urban solution cannot be achieved.

Conclusion

To achieve the objectives, several theoretical and practical aspects of the applicability of geographic information systems in traffic analysis have been addressed.

The first phase explored theoretical and practical elements related to the use of geospatial data in traffic analysis, the possibilities of modeling road infrastructure in GIS, and ways to simulate traffic using data collected voluntarily and involuntarily from traffic participants.

The second step of the work was to combine research techniques with mathematical models, graph theory and network analysis to analyze the existing situation and model urban traffic to use it as a support for urban planning. The analysis of the existing situation is the most important basis for the formulation of urban management decisions. In this context, the possibility of using geospatial data in traffic analysis and its impact, as well as the applicability of GIS technology in traffic analysis and as a decision support tool for road infrastructure investment planning were evaluated.

În cadrul acestui raport de cercetare ”Aplicații ale sistemelor informatice geografice în analiza traficului” s-a realizat un studiu de analiză a traficului, prin care s-a urmărit îmbunătățirea serviciilor de trafic și a siguranței participanților, prin supravegherea și analizarea volumului de obiecte aflate in mişcare, a ambuteiajelor şi a altor probleme ce pot să apară.

General Conclusion

În această lucrare s-au prezentat cercetările realizate în domeniul aplicabilității sistemelor informatice geografice în analiza traficului, în vederea optimizării traficului și a eficientizării planificării urbane durabile. În continuare, se vor prezenta concluziile ce reies din studiile de caz, testele și aplicațiile realizate, analizate și descrise în această lucrare.

Principala concluzie a prezentei lucrări, o reprezintă oportunitatea integrării datelor geospațiale aferente domeniului rutier modelate în GIS, cu modelele matematice, date de trafic în timp real și cu proceduri de analiză și simulare a rețelelor pentru o analiza integrată a traficului și a transportului public și implicit pentru identificarea facilă a elementelor care generează aglomerație de trafic în interiorul orașului.

A doua concluzie, o reprezintă aplicabilitatea tehnologiei GIS și de crowdsourcing în analizele de trafic precum și necesitatea utilizării acestora în asistarea deciziei pentru planificarea investițiilor de infrastructură rutieră. Prin exemplele prezentate am demonstrat faptul că riscul în inițierea unei investiții de infrastructură poate fi redus prin utilizarea unor metode moderne de suport a deciziilor bazate pe tehnologia GIS.

În concluzie, prin aplicațiile prezentate în această lucrare, am demonstrat necesitatea integrării datelor geospațiale cu cele de crowdsourcing precum și a metodelor analitice, matematice și geospațiale în vederea furnizării unei imagini cât mai fidele a situației existente și de eficientizare a traficului urban. Analiza și optimizarea traficului urban reprezintă una din elementele esențiale ale dezvoltării durabilă a localităților.

Direcții de continuare a cercetărilor

Cercetările prezentate în lucrarea de față au fost focalizate în domeniul aplicabilității ale sistemelor informatice geografice în analiza traficului și a necesității utilizării acestora în planificarea urbană, această cercetare reprezintă doar o etapă intermediară în vederea îndeplinirii obiectivului principal al lucrării de doctorat.

Obiectivul principal al lucrării de doctorat este de a studia aspecte teoretice și practice ale utilizării tehnologiei GIS în administrația locală și regională, în vederea asistării deciziilor și a managementului urban.

În vederea continuării și aprofundării cercetării se va realiza următorul raport de cercetare: ”Sistemul informatic geografic – instrument de analiză și modelare spațială în dezvoltarea urbană și regională.”

Tables of figures

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Acronyms

ANCPI	Agenția Națională pentru Cadastru și Publicitate Imobiliară
GIS	Geographical Informational System
INSPIRE	Infrastructure for Spatial Information in Europe
OGC	Open Geospatial Consortium
PUG	Plan Urbanistic General
WMS	Web Map Service
WFS	Web Feature Service