CETRA[2018]

5th International Conference on Road and Rail Infrastructure

17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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CETRA^{2018}
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

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POTENTIALS AND ADVANTAGES OF APPLYING GEOGRAPHIC INFORMATION SYSTEMS IN VARIOUS FIELDS OF TRAFFIC ENGINEERING

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Abstract

An enormous amount of data in real space and better means of collecting, storing, analyzing and modeling are available through to the use of modern ICT solutions. Geographic Information Systems (GIS) are developed to make their basic operations a matrix for a thorough knowledge of the real world. With the development of modern information and communication technologies, these systems have become the means of an integrated, multidisciplinary approach to research, regardless of the space size and the dynamics of phenomena in it. Using the power of GIS systems, it is possible to improve and facilitate operations in all segments of traffic engineering, from planning to traffic management by performing spatial analyzes with appropriate visualization. Real benefits of using GIS are reflected in possibility of integrating spatial data with other types of information, such as various measurements in traffic and traffic statistics, into a single application for complex analysis. GIS enables the detection of patterns that would otherwise be difficult or impossible to notice, and provides additional assistance in essential understanding of complex real systems such as the transport system itself.

Keywords: geographic information systems, traffic data collection and analysis, traffic planning and modelling

1 Introduction

Given their great expansion over the past couple of decades and their wide application in different disciplines, geographic information systems (GIS) have no unique definition, but are adapted to the specific application. The ESRI [1](Environmental Systems Research Institute) company, considered to be a pioneer in problem solving using GIS, as well as the creator of the most commonly used GIS software, defines GIS as a computer-based tool for mapping and analyzing things that exist and events that happen on earth [2]. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps.

Traffic is an activity that in its basis has the task to use the means of transport to change the place of people and goods [3]. Therefore, by its nature, it is inevitable that traffic engineering will require collecting, analyzing and usage of a large amount of data that contains a spatial component. This set up of things clearly shows why it is not only appropriate, but rather necessary, to use GIS as a supporting tool for traffic engineering.

In the beginning, GIS was used in traffic only as a tool for better visualization of existing data and previously conducted analyzes and research. But GIS certainly provides far greater possibilities than mere visualization. Today, GIS is used as a powerful tool for analyzing large

DOI: https://doi.org/10.5592/CO/CETRA.2018.735

amounts of data generated by a complex system such as the traffic. It performs demanding spatial analyzes while at the same time helping in making decisions important to many segments of traffic engineering. GIS can be used in traffic planning, modeling and analysis of traffic infrastructure, traffic management and control, analysis and utilization improvement in lack of parking space issue which is the acute problem of urban areas. GIS also enables mapping and analysis of incident situations in traffic with the purpose of improving the level of safety and reducing the number of dead and injuries. It can be used for mapping noise caused by vehicles, as well as environmental pollution, and performing other complex spatial analyzes with appropriate visualization. Real benefits of using GIS are reflected in possibility of integrating spatial data with other types of information into a single application for complex analysis. That includes data such as various measurements in traffic, traffic statistics, physical condition of roads and other information collected by different field techniques, or modern sensory methods of remote detection. The aim of this paper is to give an overview of good practices from application of GIS in traffic engineering, as well as unused potentials and new services that can be realized in the future.

2 General usage of GIS in traffic

Although it does not represent advanced GIS functionality, the very existence of digitized roads of all categories and corresponding databases with information on these roads (horizontal and vertical signaling [4], radars, traffic counters, toll collection, major objects along the road, etc.) can make a significant contribution. The existence of such a system primarily helps in planning the journey and determining the optimal route between any two destinations connected to the road network. This also helps in the processes of maintaining and improving the existing traffic infrastructure, planning, road design and determination of geometric characteristics of new roads. It enables facilitating and simplifying the work of experts in the field of traffic who (with all relevant data in one place and visual display) could, for example, get a better insight of the real causes of traffic accidents.
GIS allows the integration of existing developed systems and data (for example, importing CAD data) into GIS software, thus consolidating all company-level information to make it easier for presenters and decision makers to make decisions. Using mobile and remote sensing GIS solutions significantly reduces time and effort to collect data from remote locations, increasing the amount and quality of collected data, and real-time update.
GIS applications perform evaluations on the feasibility and consequences of various transportation alternatives based on travel demand forecasting models, position of settlements, environmental impacts etc. Many companies have recognized the benefits and are continuously working to exploit the benefits of GIS software, e.g. [5, 6]. Their primary goal is more efficient functioning of the company and simpler provision of services to other legal entities. GIS is used to support decision making through the analysis of spatial and other related data, which necessarily includes support for planning. Key effects achieved using GIS:

- more precise long-term planning in different areas
- better management of existing resources in order to achieve savings and prevent the occurrence of damage and disturbance to the natural environment;
- more efficient and better quality of management and maintenance of infrastructure;
- more efficient and fairer collection of revenues by accurate recording of all subjects liable for payment;
- by creating distributed spatial databases used by public companies and state authorities, the flow of data will be accelerated, and thus resolving the requirements of citizens, investors and other legal entities.

GIS will be very helpful even if it is only used as a tool for visualizing previously conducted research and traffic analysis. It gives a rich view with much clearer and simpler insight into

collected spatially related data than the classic descriptive or tabular display. A good example is certainly the analysis of the bus travel matrix in Turkey in GIS Environment [7] where the collected data is used to determine the gravitational areas between the different provinces. The system allows creating queries and thematic maps such as the map of the level of connectivity with the capital city for individual provinces by bus transport.
Duran-Fernandez R. and Santos G. [8] have presented a GIS model of the national road network in Mexico for estimating the shortest route by using the information on average speed for every section on the network according to its hierarchy, regional location, toll status and administration. Such systems are used by ordinary users, but they are certainly more important tool for emergency services (ambulance, fire services...) in planning optimal routes for response to incidental situations.
The Ministry of Canton of Sarajevo in its presentation in 2009 offered a solution for managing the maintenance of roads integrated in GIS [9]. A total of 335 main, regional and local roads were recorded and processed, 377 road sections, 463 kilometers of roads.The collected and spatially referenced data includes spatial signaling (signs, traffic lights, directional signs, horizontal signaling), a pavement (type, width, visual assessment of the condition), equipment (protective fences, lighting), railroad crossings, objects (service facilities, bridges), as well as the history of road maintenance.The main purpose of this GIS solution is to support the decision-making system, development of annual and five-year plans and maintenance programs, and long-term forecasting.

3 Safety and incident management

Every year, according to the WHO [10], 1.25 million people die on roads around the world. One of the most effective methodologies for improving traffic safety is the management of black spots [11]. This refers to the procedures for their determination and the taking of appropriate measures for their removal and preventive action for the future. GIS is a solution that will facilitate the collection and storage of data, as well as the process of analysis and determination of black spots on the basis of collected data. Using GIS, it is possible to identify and analyze critical road sections, to see the spatial distribution of hot spots, the dynamics of increasing/decreasing the number of accidents over time. GIS also enables the identification of the main causes of accidents in accordance with the collected attributes (information on the circumstances of the accident). It allows combining with other data from the database, and to determine the interdependence of the position of the black spots and other important objects on the map, as shown in Figure 1.

Figure 1 Traffic accident black spots determined by Negative Binomial regression method and the number of repeatability within the 9-year period.[12]

In the past period, the number of studies using GIS as a tool for analyzing traffic accidents has increased significantly. An overview of methodologies used, the areas to which they were applied, and the comparison of the Moran's I, Getis-Ord and Kernel density spatial methods can be found in [13]. Kernel density spatial method in ArcGIS software (product of ESRI) was also used in Shafabakhsh G. et al. [14] to determine traffic accidents patterns in complex city traffic network and to categorize intercity regions based on standard deviation in terms of distance between crashes (categorization of the area according to disaster-prone criterion). Critical locations from given research were reported to traffic police department and urban department of transportation for treatment.The results of the study also confirmed high crash-prone zones are concentrated more in core areas of the city and that the higher level of traffic interactions generates more safety problems. Yang S. et al. [15] present an interesting way to use GIS for determining critical areas where severe accidents happen. They created two maps, one showing the accident rates, and other showing economic costs caused by accidents. Calculation of spatial difference between the two maps provides an insight in areas that have high economic-cost-to-the-accident rate ratio. This kind of analyses can be used as a basis for traffic safety engineers to further investigate these areas.
The accuracy of the output results in many ways depends on the quality of the data input into GIS system. The current way of registering traffic accidents in leads to two problems. The first are non-unified traffic data recording processes, which makes the data incompatible and requires a lot of effort to bring it into a form that can be stored in a single database. Another problem is the way of determining and recording the position of a particular accident. Instead of apsolute spatial representation (geographical coordinates), descriptive and relative methods are still being used (address, postal code, road stationing, and even position relative to some nearby objects). For this purpose, it is a very imprecise and outdated way of determining the exact location of the accident. Certainly, the use of modern technologies such as GPS in combination with GIS would significantly affect the accuracy and unification of data. Modern technologies will offer a better input data which would enable a more precise determination and analyses of the position of the critical points. It is expected that European Union will standardize a model [12] that uses spatial statistical methods supported by GIS which uses the empirical Bayesian techniques. This model is intended to help in illuminating the accident analysis studies and eventually help in reducing traffic accidents.
In terms of successful and timely reaction to incidents, Huang B. and Pan X. illustrated a method [16] for deriving an optimal dispatching strategy for incident response by integrating GIS, traffic simulation, and optimization systems. In this method, the optimization model minimizes the total travel time of all the response units while maximizing the total levels of severities of the incidents to be dealt with given under current available response resources.

4 Air and noise pollution

GIS can be used as a tool for mapping and visualizing the effects of noise and air pollution caused by traffic, as shown in Figure 2. By bringing in data related to nearby settlements and some more important facilities (such as schools and hospitals) that are particularly sensitive to these negative consequences of traffic, it is possible to detect critical locations and propose appropriate improvement measures. The basis for any calculation of noise and pollution generated by traffic is annual average daily traffic (AADT). The accuracy of estimation directly depends on the quantity and quality of the collected data. In most cases, AADT information is collected only on major roads, while for other roads data is unavailable or at best incomplete for performing some successful analysis. In this case, GIS can be used to estimate the amount of traffic on roads for which there are no data based on simulation of probable journeys through the road network [17]. With a relatively small set of available data and using GIS, it is possible to estimate AADT for minor road using routing importance in a regression analysis along with the road class, urban or rural location and AADT on the nearest major road. In addition to AADT, noise estimates require information about the traffic attributes of the model as well as the objects along the roadway to include the attenuation effect of urban buildings and other obstacles. This is a significant challenge and a painstaking job, especially in large cities with dense traffic networks and a large number of buildings. The existence of a GIS system enables the automatic extraction of these data from existing maps and databases and their insertion into the final traffic noise calculation model [18].

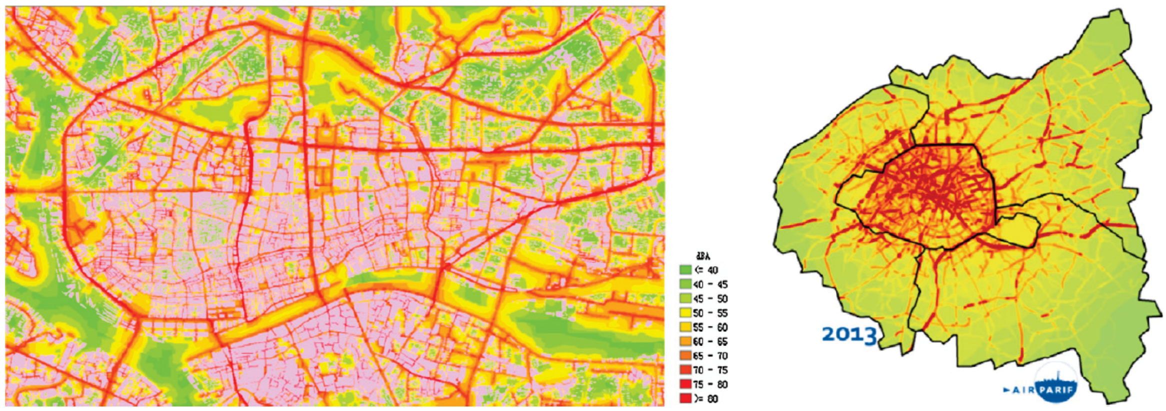

Figure 2 (left) Night traffic noise map for Guangzhou Inner Ring Road.[18] (right) Average annual daily concentrations of NO2 in Greater Paris in 2013. Areas where the European limit (40 µg/m3) has been exceeded are represented in red. Inner Paris is located in the central area.[19]

An even more serious problem than noise is air pollution caused by traffic. Recent studies report that outdoor air pollution will become the main environmental cause of premature death in the next few decades (OECD, 2012; WHO, 2014; World Bank, 2016). Air pollution is a world wide burning issue. GIS can be used as a tool for detecting particularly critical areas with high levels of pollution and planning the actions of politicians and engineers to reduce emissions and exposure, as it was presented in "quick scan" method[20] for assessing the resilience of urban areas to outdoor air pollution. This method that was conducted in Greater Paris aims to localize air pollution "hot spots" and is created to be reproducible in different urban areas. The method is based on the calculation of the capacity of an urban area to decrease air pollution emissions, the capacity to decrease concentrations, and the capacity to decrease exposure using a GIS based grid approach.

5 Conclusion

Digitizing traffic information allows their easier exchange and availability to a much wider range of users. When such digitized information is stored in appropriate geographic databases with visualization and analytical tools, the job of traffic engineers can be greatly facilitated. GIS can be used at all stages of traffic engineering, and the benefits of GIS can be used by all participants, from field workers in organization of daily jobs to top management for making important and strategic decisions. The most demanding and time-consuming work related to GIS is collecting data. In order to make this work as easy as possible, it is necessary to harmonize the method of collecting data related to traffic on national, and even at the international level. This would ensure that the data collected can be used in an adequate way in GIS software, and that the results of the various research can be combined and compared. The cumbersome task of collecting, organizing and storing input data in GIS can be significantly simplified and facilitated by using the modern sensing and information technologies, such as remote detection, cloud computing and big data processing techniques. In addition to promoting and encouraging the use of GIS software in traffic engineering, it would be useful to standardize the models and methods used in the diverse and numerous applications of GIS tools.

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