Traffic management system in the city of Rijeka

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Abstract: *This article analyzes examples of good traffic management practices in several European cities. The practices analyzed relate to providing more accurate information about public transport arrivals, optimizing demand for crosswalks, reducing congestion in urban areas, and reducing demand for trips to parking lots in the city center. Smart mobility projects such as CEKOM Connected Traffic create high-quality urban transport solutions and promote innovative, sustainable, clean and energy-efficient transport modes. The aim of this paper is to present the positive results of different traffic management methods that lead to better traffic flow, less congestion, lower primary energy consumption and less pollutant emissions.*

The activities of this scientific research project are related to the development of innovative urban and multimodal solutions in the city of Rijeka. The primary outcome indicator will be a platform for aggregating data for urban mobility and transport decision making. The scope of the platform envisions more efficient use of public-private infrastructure, resources, and assets in the field of transport. In addition, it was necessary to accurately measure traffic, meteorological and environmental parameters in the city of Rijeka to protect the environment, increase safety and achieve sustainability of the transport system in the urban area.

As part of the research activities of the Connected Traffic project, a prototype solution for traffic simulations has been developed. The aim of the simulations is to show how the use of innovative methods in the context of intelligent solutions can manage traffic in urban areas. The purpose of the simulation is to test innovative scenarios and standard operating procedures for decision support.

Keywords*: INTELLIGENT TRANSPORT SYSTEMS, URBAN TRAFFIC MANAGEMENT, CITY OF RIJEKA, URBAN MOBILITY, SUSTAINABLE TRANSPORT.*

1. Introduction

Quality traffic management is one of the basic goals of the city authorities, considering that today it significantly affects the quality of life of citizens and at the same time represents a good basis for further economic growth. Traffic congestion is an obstacle to many urban areas around the world and requires the introduction of additional traffic management methods to address the problem. The conventional approach sought to eliminate the problem by additional road construction, but this option did not prove to be an effective solution. In the past few years, the issue has been solved by applying better management of existing capacities. Furthermore, such an approach requires additional tools that have proven to be an effective solution in traffic control through the examples of various cities.

The implementation of such systems meets certain criteria for increasing traffic safety, which are presented below in this paper through the above examples of good traffic management practices. Increased safety, reduction of air pollution, priority passage of various traffic participants, better control of urban areas and reduction of traffic congestion caused by road works or traffic accidents are some of the criteria as possible solutions to the problem of urban mobility in cities [1].

The paper "Review of Good Practices in the Introduction of Traffic Management Systems and Urban Mobility" provides a detailed review of examples of good practices in traffic management, while Chapter 3 of this paper provides a summary of the previously mentioned paper as a continuation of the analysis [1].

In addition to the examples of good practice, this paper seeks to present the transport system of the city of Rijeka and its further improvement of traffic management. Besides, the paper presents the City's involvement in Smart City Connected Traffic. Such a project aims to create an advanced information and communication system that will serve as decision support in urban mobility management. The purpose of the concept is to enable more efficient use of public-private infrastructure, resources, and property in the field of transport to protect the environment, increase safety, and achieve sustainability of the transport system in the urban area.

The development of innovative products and services expected after the completion of the CEKOM project will relate to the field of smart city technology and will be implemented through various pilot projects in the city of Rijeka, which will significantly affect the status of Rijeka as one of the smart cities in Croatia [2].

2. Urban traffic management

With the rapid development of cities, urbanization in the transport sector began to approach the limits of sustainability, especially in densely populated areas. However, the smooth flow of traffic is necessary for the quality of life, and at the same time affects the economic sector. Therefore, as the need for transport is constantly increasing, traffic jams, traffic accidents, reduced pedestrian safety and excessive environmental pollution are becoming more frequent.

Traffic management in urban areas where traffic flow is hampered by a large share of individual transport, inefficient traffic routes and inadequate urban plans, effectively solves traffic congestion problems and reduces the negative impact of traffic on the environment. Urban traffic management requires a balance between traffic throughput, safety and sustainability, which with a high population density, different modes of transport (pedestrians, cyclists, public transport, motorized vehicles) and a high proportion of shorter journeys, is quite a challenge [1]. The positive trend of rapid development of cities from year to year is becoming an increasing problem in most cities around the world. Urbanization of cities increasingly conditions mobility and brings traffic to the limit of sustainability, especially in densely populated places. Unhindered traffic is a major obstacle for the growing number of car users, but also for passive citizens in the role of pedestrians, cyclists and other users who are indirect participants in the city's transport network.

"A traffic control system generally uses traffic signals to control traffic flow at intersections and uses historical and real-time measured data to derive signal plans" [3]. Given the flexibility to adjust the measurement of traffic disturbances, the time control system can be characterized as a fixed and modern version. A fixed time control system, i.e., signal plans that are calculated offline and cannot be adjusted to real-time traffic flow disturbances are considered a conventional system, while the characteristics of a modern system are traffic response that can update signal plans according to current traffic data [3].

"Traffic control can be regarded as a multiagent application in which car-agents and traffic-light-agents need to coordinate with each other to optimize the traffic flow and avoid congestions" [4]. Agents' actions are mostly triggered by traffic information that is distributed in the environment on a practical and conceptual level. Therefore, abstractions from the environment naturally correspond to the scenario of the traffic control mechanism.

Effective traffic management requires ITS (Intelligent Transport Systems) instruments that have positive effects on increasing traffic flow, reducing pollution and increasing safety. For example, real-time information on environmentally friendly modes of transport such as walking, cycling and public transport can encourage citizens to use sustainable modes of transport more often, while optimizing traffic signal control can reduce fuel consumption and pollutant emissions. Research shows that the implementation of ITS in modern cities opens the potential to reduce greenhouse gas emissions by as much as 60 % by 2050 and the possibility of reducing the number of fossil fuel cars in urban transport by 50 % by 2030 [5].

3. Examples of traffic management systems in European cities

Examples of good traffic management practices include ways to address urban mobility in densely populated areas in terms of sustainability efficiency, safety and the environmental segment. The most common problems are traffic jams and accidents, problems with city parking and low pedestrian safety [1].

The purpose of introducing the RTPI system is reflected in greater reliability, more efficient system monitoring, reduction of congestion and decrease of external costs. Also, several European cities like Turin, Helsinki and London have introduced the RTPI system.

Displaying information about the arrival of buses at the station makes it much easier for public transport users to plan a trip. Access to real-time public transport arrival information is available at the station, it is also possible to access the information by entering the bus station number using the website or the DublinBus application. To facilitate the use of visually impaired people, the option of receiving information via SMS messages with the possibility of reading information by voice program has been introduced.

Automatic transmitters built into buses or GPS monitoring enable the operation of the bus arrival information system, while the software predicts the time of arrival at the next bus station. The control system then sends the data to the bus station notification screen, i.e., counting the minutes until the bus arrives. The vehicle location system is charged for data updating, which sends information at 30-second intervals, ensuring accuracy during the arrival time of the bus displayed on the notification screen. The National Transport Administration (NTA) monitors the reliability of the information to provide a better service [6].

The most common problems that can reduce the accuracy of information are operational segments such as [6]: technical difficulties, breaks, closed roads, mechanical problems and traffic congestion.

RTPI predicts the arrival of public transport using the location of the vehicle, so if the vehicle remains in traffic jams, the information on the arrival of public transport will be adjusted to current conditions.

Large crowds at pedestrian crossings are common in London, which is one of the largest cities in Europe. The implementation of the SCOOT system has contributed to a better and safer pedestrian crossing without the negative impact of slowing down road traffic [7].

The SCOOT pedestrian system is an effective way to manage traffic as it reduces congestion in densely populated areas, especially in pedestrian traffic. The system brings benefits in traffic management in terms of bus priority, traffic saturation control based on feedback, incident detection, online saturation measurement, vehicle emissions and pedestrian priority [8].

The collection of information is carried out at 3 890 distinct locations with the help of about 15 000 detectors that contribute to the optimization of traffic signals in favor of pedestrians, i.e., by optimizing the crossing time [9]. Furthermore, the SCOOT system uses cameras with the possibility of counting pedestrians at the pedestrian crossing, which solves the problem of uneven pedestrian traffic. Moreover, if the camera detects enough pedestrians, the system will approve the road crossing, while in situations when there are no pedestrians at the pedestrian crossing or if a pedestrian presses the road crossing button and gives up, the system will not allow crossing the road [10].

Twenty years ago, Stockholm had major problems with traffic jams, especially in the city centre. Therefore, it was decided by the city authorities to introduce fees for entering vehicles in certain areas of the city. The charging of a fee for entering a certain part of the city by vehicle was introduced in Stockholm, given that such an example of good practice has already shown satisfactory results in London [11].

The introduction of a fee for vehicles entering certain zones has resulted in a reduction in CO_2 emissions by 14 % or 25 000 tons per year, or a reduction in transport by 22 % or 100 000 passengers per day with a reduction in travel time by 30 to 50 % [12].

Fees are charged using a system based on wireless RFID (Radio-frequency identification) technology. Furthermore, the system uses a toll charger and a traffic signal device in combination with an operating system developed by IBM [11].

Payment is made by contactless method or by using an electronic toll collection device that charges directly from the user account. Video cameras with an ANPR (Automatic number-plate recognition) system installed are also in use, enabling the record of the number of registration plates on the vehicle or the vehicle identification without a toll collection device to control the payment of the fee [11]. User billing options for the traffic saturation zone are as follows [13]:

- direct debit ("autogiro") - enables automatic debiting of the user's bank account or offers the possibility of combining with an electronic account,
- electronic invoice ("e-invoice") - the possibility of using Internet banking,
- payments - at the end of each month, the Swedish Transport Agency (Transportstyrelsen) sends a salary card to the owners of vehicles registered in Sweden.

Not all vehicles are required to pay a fee for passing through certain zones, e.g. [14]: ambulances, buses, diplomatic vehicles, people with disabilities, military vehicles, hybrid or electric vehicles, motorcycles and mopeds, and vehicles registered in other countries.

The introduction of toll zones has resulted in a reduction in traffic amount of about 20 %, which is equivalent to 100 000 passes per day through toll zones. The load on the main roads was also reduced by 30 – 50 %, which reduced the variability in travel time, while the emission of harmful gases was reduced by 10 – 14 %. Given the introduced fees, more than half of drivers decided to replace the passage of toll zones with alternative routes, while other drivers passed through the toll zone at the time when there is no toll.

In large urban areas, there is often a problem of finding a parking lot, so city authorities with "tools" for parking management are trying to reduce vehicle traffic or relieve the load on roads in certain areas. The parking management in the city of Vienna began in 1994, in addition to the long-term reduction of the need for parking. One of the primary reasons for the introduction was to provide many parking spaces with certain benefits for residents living near the parking lot. [15].

With the implementation of the parking management system, parking requirements have been reduced by 20-40%, while as an additional result, the behavior of traffic participants has changed. Furthermore, the introduction of the new system has led to higher demand for other forms of transport (mostly increased use of public transport, changing routes or shorter stays in certain areas), thus reducing traffic congestion and the negative impact on the environment.

The primary objectives of the parking space management system are [15]: reduction of car traffic and harmful impact on the environment, a better situation for parking and public transport (reduction of unauthorized parking), improved availability of cargo and delivery; renewed public space and improved road safety, higher revenues to improve urban transport, improved urban housing environment.

Parking management requires one form of transforming a part of the city district, i.e., turning one part into short-term parking zones. The price of parking increases from 1.20 to 2 euros per hour, which resulted in lower demand for parking.

Revenues from parking management are earmarked for further investment in the improvement of the Vienna transport system. The principle of parking management policy emphasizes that traffic costs are borne by traffic users and not by society.

To take full advantage of the implementation of the parking system in the city of Vienna, it is necessary to observe and apply a traffic management model such as: increase short-term parking fees, improve sufficient capacity and high-quality public transport, introduce affordable annual public transport tickets, development of "Park & Ride" system facilities, use of municipal residential garages, amendments to building regulations to reduce minimum parking requirements [15].

4. Traffic management in the city of Rijeka – project Connected Traffic

Taking practices of several European cities as an example, the use of the well-known ITS measure in this area provides remarkable results in increasing the overall efficiency of the road transport system. By using such services, cities create an efficient, safe, and sustainable transport system. They provide tools that enable efficient traffic management and have a positive impact on increasing traffic throughput, reducing pollution and increasing safety.

The City of Rijeka is currently using an automatic traffic management system which, with its technological capabilities, aims at optimal traffic management in the given conditions. The system is modular and easily adapts to new traffic conditions, and with its modern technology, it enables the control of traffic lights depending on the actual (current) traffic loading the traffic network. The system also enables upgrading of traffic subsystems from different areas of traffic, which significantly contributes to an additional increase of inflow within the city [16].

The current operation of the Automatic Traffic Management System (ATMS) has enabled: maximum utilization of the existing traffic network in the center of Rijeka, better flow of the main longitudinal directions - traffic corridors, direct 24-hour monitoring of traffic in the city center, automatic remote control of traffic lights, central reprogramming of traffic lights or individual traffic zones, immediate fault diagnosis and faster troubleshooting, automatic collection of traffic load data and savings in electricity consumption of about 51% compared to old traffic lights.

Through the participation of the City of Rijeka in the research and development activities of the project Connected Traffic, elements of the entire decision support system within smart cities are defined with the possibility of application in traffic. Solutions using cloud computing technologies will enable easier integration of electronic applications to improve communication and availability of public and commercial services for citizens and businesses [17].

4.1. Research and development activities

Through the research and development of the project activities of Connected Traffic, the aim is to create a platform for monitoring, coordinating, informing and managing all traffic in the urban environment, using the latest technologies and bringing together all the resources relevant to the insight of the necessary information related to the mobility of users. Particularly emphasis shall focus on the environmental component and the encouragement of alternative innovative and intelligent forms of transport. The platform will be able to accept and process the planned amount of input data in real-time and expand it as needed for future requests and traffic increase [18].

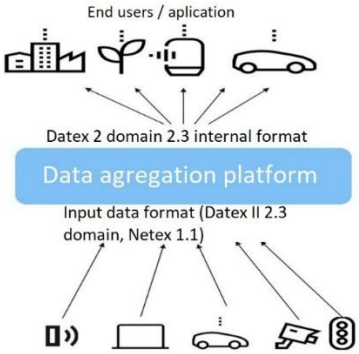


Figure 1. *Data Aggregation Platform [18]*

The basic functionality of the data aggregation platform is to transform, store and forward data received at the input, southbound interface from the senses and/or systems and/or applications to the southern interface according to the applications and systems that will use that data, as illustrated in Figure 1.

4.2. Technological concept

The existing results in this paper relate to all previously completed activities of the Connected Traffic project that the partners have successfully carried out. The preliminary activities were defining the scope of the project, which will serve as the produced platform for controlling, coordinating, informing, and managing the total traffic of the determined area. After the broader zone of the city of Rijeka was defined as the designed area of the project, all the existing documentation regarding urban and spatial planning and proposed solutions were examined.

By completing the questionnaires and conducting interviews with key stakeholders of the traffic of the wider urban area of the city of Rijeka, an analysis of the existing transport system and identification of the source and type of data has been performed. The need for analysis is implied by a large amount of data present in the transport system, which will grow further with the introduction and implementation of innovative technologies. Therefore, the collection of data is needed to create a basis for decision support. The main participants are direct representatives of road, maritime, air, and rail transport. In addition to them, other relevant participants of the transport system have a significant role in the elaboration, which also contributed significantly to the further definition of the project platform [2].

The most important and critical elements of the transport infrastructure for carrying out measurements to be carried out in the experimental phase of the project were identified. Consequently, the partners determined how the traffic, meteorological and environmental parameters will be measured for the traffic flow analysis. The measurement of traffic parameters will make it possible to obtain quantities showing the efficiency of the transport system and the level of service. By measuring meteorological parameters, traffic participants will always have an insight into current conditions that directly affect traffic safety, but also the current state of the roads. Furthermore, measuring ecological parameters will provide an overview of the real state of the environment of the urban area, i.e., insight into the level of

environmental pollution by CO_2 emissions. By further parameters elaboration, the project partners have identified and analyzed functional requirements for traffic, ecological and meteorological sensors that will meet the functionality of these parameters under different conditions. For the traffic parameters, the following sensors functional requirements are identified: identification and categorization of traffic modes, counting of traffic modes, simultaneous monitoring of all vehicles, identification of movement/routes for each vehicle, calculation of movement speed for the vehicle and pedestrian, calculation of standing time at the intersection for the vehicle and pedestrian, calculation of deceleration/acceleration for the vehicle, calculation of time of passing through the intersection, and advanced functionalities including detection of deviations and linking of information. Concerning meteorological parameters, the following functional requirements are determined: measurement of atmospheric conditions, temperature, humidity, dew point, air pressure, wind speed and direction, type, amount and intensity of precipitation and horizontal visibility. Ecological parameters are: particulate matter, volatile organic compounds, nitrogen oxide, carbon monoxide, sulfur dioxide and other greenhouse gases [2].

The project activity is analyzed in detail by exploring the technological concept of sharing and exchanging resources, infrastructure, and assets in the field of transport using the sharing economy platforms. This activity aims to achieve a more environmentally friendly transport system and to increase safety in the city area by using sharing concepts and benefits. Through the conducted interviews with end-users, as well as potential sharing economy stakeholders the possibilities of applying four concepts in the context of a smart city were defined: Centralized market supply, sharing public administration vehicles, encouraging multimodal transport and easier access to events.

Although all concepts are positively perceived by end-users and potential stakeholders through detailed evaluation and analysis, the concept which refers to easier approach to events was selected for further project activities development as the best evaluated and potential serviceable one.

Research and definition of advanced traffic analysis algorithms at intersections for detecting traffic anomalies and detecting incidents and dangerous situations have been made. Connected Traffic project partners have defined the technological concept of a data aggregation platform in the function of decision-making in urban and multimodal transport and urban mobility, which would make the platform a central place for sharing general traffic information to improve road safety. Intersections and traffic corridors where device tests would be carried out are also defined [18].

Furthermore, the identification of key and critical parts of infrastructure elements within urban agglomeration that were identified as locations suitable for testing and validation of solutions defined 4 final intersections out of the proposed 7 that will be equipped with video surveillance and video analytics. The final intersections and general representation of the system are shown in Figure 2. Anomaly detection of selected intersections consisting of video surveillance equipment with coordination for power supply and transmission of signals to the surveillance center, data storage servers, client computers, and associated video analytics software, and data processing, distribution and display software are shown. [18].

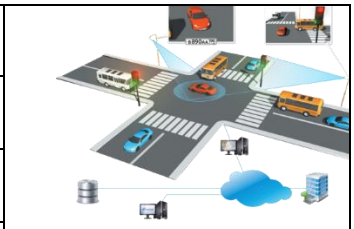
SELECTED INTERSECTIONS	
R24 – Strossmayerova – Tito square	
R26 – Žrtava fašizma – Fiumara	
R88 – Brajdica – Delta	
R29 – Jelačić square	

Figure 2. *List of intersections and system views in principle [18]*

Further s research and development steps of the project will focus on the design and future realization of a complete integrated system, including a center for management and monitoring, targeting services and organizations whose activity is related to transport, but also on the possibilities of a wider use of the system in the function of smart cities. A consequence of the system will be the possibility of increasing the level of safety in the protection of people and property through preventive procedures [17].

4.2.1. Testing innovative scenarios using simulation tool

As part of the research activities of the Connected Traffic project, a prototype solution for traffic simulations has been developed. The aim of the simulations is to show how the use of innovative methods in the context of intelligent solutions can manage traffic in urban areas. The purpose of the simulation is to test innovative scenarios and standard operating procedures for decision support.

The development of a simulation model forms the basis for a prototype simulation solution. Regarding the functionality and sustainability of the simulation model, the urban area and the wider administrative area of the city of Rijeka were considered. The process of creating a simulation model required the use of multi-layer traffic models integrating the macro, meso and micro levels of traffic simulations, the creation of a traffic network, i.e., the creation of a basic road network as well as the categorization of traffic and the regulation of intersections. Demand zones were then defined based on the travel needs of different social groups by population and trip purpose. In addition, OD matrices or definitions of travel demand for a given time interval were created.

Simulated scenarios are defined that describe traffic phenomena, trigger specific action strategies, and test key traffic parameters. They also serve as decision support for traffic management and precede the prototype traffic simulation solution. The defined traffic scenarios consist of regular and extraordinary events and traffic conditions.

SIMULATED SCENARIOS	REGULAR TRAFFIC EVENTS	Illegally parked vehicles
		Traffic condition
		Emergency intervention/Passage of VIP vehicles
	TRAFFIC CONDITIONS	High traffic density/Traffic congestion
	EXTRAORDINARY EVENTS	Manifestation-Road closure
		Roadworks-overregulation

Figure 3. *Simulated scenarios* [2]

The events and conditions usually require the initiation of certain actions that fall within the scope of traffic management and may exceed the authority of the traffic control unit or trigger the execution of certain automated procedures. Within the framework of the developed traffic simulations, it is possible to create various performance policies and analyze them in terms of selected traffic variables and traffic parameters to improve traffic efficiency and

increase the level of service. To create a simulation, six dynamic scenarios were created (Figure 3), representing a combination of traffic events with previously defined standard operating procedures.

5. Conclusion

Nowadays, choosing the optimal solution to the traffic problem of urban centers is not an easy task. We are witnessing excessive use of passenger vehicles in cities, which are facing increasingly unfavorable traffic situations every year. Finding an effective solution for most cities is still a great challenge. It is necessary to satisfy several segments such as bandwidth, safety, environmental awareness, economic cost-effectiveness, and many others.

As one of the output project indicators, a set of advanced analytical solutions is developing to support decision making in the field of urban traffic. The system defines new standard operating procedures that can be activated manually, automatically based on values received from the data aggregation platform, and automatically through direct notification. In addition, incident situations as well as regular and extraordinary traffic scenarios have been defined for the detailed development of prototypes for traffic simulations. Simulation models have been developed to test specific traffic scenarios resulting from defined standard operating procedures.

By applying the defined elements of the decision support system in transport, the efficiency of the Traffic Management Center in Rijeka will be improved. The platform will be tested in the function of the Center for Monitoring and Management of Integrated Traffic thus enable automatic distribution of data with easy availability to all interested users. There is no doubt that through the mentioned activities mentioned of the project Connected Traffic the city of Rijeka will certainly contribute significantly to its further development of the transport sector.

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