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Developing a Traffic Management System Architecture Model

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Abstract

Stable urbanization trends lead to the concentration of the population in large cities, as well as the expansion of the car fleet, while there is a colossal lag in the development of transport infrastructure. This article is dedicated to exploring traffic management and the ways in which it can be performed. Various approaches to defining a transport system were explored, and the elements of a transport system were presented. Existing practices of traffic management system implementation in cities around the world were reviewed. We formulated the main purposes of using traffic management and elements of traffic management systems. Based on that, a traffic management system architecture model was created.

Keywords: Traffic Management; Intelligent Transportation System; Road and Transport Complex; Traffic Jams; Architectural Approach.

1. Introduction

A huge number of cars drive onto the roads of different cities almost every day. Generally, that number exceeds the accommodation capabilities, which results in numerous traffic jams being formed. It is believed that, on an average, drivers around the world spend about 100 hours per year stuck in traffic jams. According to the research conducted by experts from INRIX (The Moscow Times, 2018), among most congested cities in the world, Moscow takes the second place: drivers of the Russian capital spend an average of 91 hours a year in traffic jams, which makes up approximately 26% of their total time on the road. Other Russian cities that have very busy traffic include Novosibirsk (where drivers spend 52 hours a year in traffic jams), St. Petersburg (54 hours), Krasnodar (57 hours), Kansk (64 hours), and Magnitogorsk (73 hours). Londoners spend around 74 hours a year in traffic jams, and drivers

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in New York have it almost as bad as Moscow drivers, averaging 90 hours a year. Los Angeles takes the first place in this unfortunate rating with its 102 hours and almost 30% of driving time spent in traffic jams.

Experience shows that the problem of road congestion cannot be solved by building more highways, as a huge number of vehicles immediately would rush to a new section of the road, forming a traffic jam. It is necessary to organize an effective management system for the urban transport system. The creation of a reliable transport management system is important from both economic and social points of view. The more perfect the system, the more effective it is, and the higher the productivity and well-being of society as a whole.

Such system, when created and implemented properly, would optimize traffic flows throughout the entire city and increase the transport network's capacity by prioritizing specific type of transport in various traffic situations and providing information about the traffic condition to all parties involved. Maintaining traffic safety is also among main priorities of implementing a transport management system. Such systems allow not only to decrease the possibility of an accident happening but also provide the toolkit necessary to manage accidents in case they do happen.

The paper presents a review of the urban transport system and its elements, as well as analysis of the experience of managing the transport system in various cities of the world. The goal of this paper is to develop a model of the architecture for an urban transport management system.

2. Materials and Methods

Methods used in this study include analysis of existing approaches to defining the transport system and designing it, as well as analysis of existing cases and practices of creation and implementation of transport managements systems in cities around the world. The architectural approach was also used to create an architectural model of the transport management system and its components. In this case, an architectural approach to modeling was chosen because it allows to create a holistic vision of the research process in a structured form (Anisiforov et al., 2019). TOGAF was chosen as the architecture modeling methodology. TOGAF is the most widespread and recognized architectural methodology in the world. It has evolved from being an IT- and tech-oriented framework towards a complete architectural standard that provides a holistic view of the entire structure (The Open Group, 2018).

Generally, the transport system is defined as a set of connected workers, vehicles and equipment, elements of transport infrastructure and infrastructure of transportation entities, including a management system aimed at efficient movement of goods and passengers (Barthelemy, 2010).

The transport system is designed to meet the people's transportation needs of and includes the following components (Sivilevičius, 2010):

- road and transport complex;
- road users;
- environment.

The road and transport complex, as the name suggests, includes:

- street network, which is a system of streets and roads in a unified transport network of the city;
- personal transport;
- public transport;
- other elements of transport infrastructure.

The elements of the transport system function within the framework of a certain organization of transport processes, providing movement within the system by establishing links between the system's elements, also determining the rules and conditions for the interaction of elements during its operation (for example, the traffic code, contracts between the transport process participants, etc.). The presence of such an element of the transport network as people classifies the transport system as a man-machine, or organizational system (Djahel et al., 2015). A person, who has the ability to purposefully behave in a rapidly changing situation, to adapt to new conditions of the functioning system is an active element of the system. The presence of a multitude of people in the system leads to the formation of the collective behavior of its participants, which is a result of relatively independent behavior of individuals striving to achieve their own goals. The presence of active elements in the control object generates stable modes of operation of the transport system, since any disturbance external to the object is compensated for at the level of individual decisions of the system's subjects.

The urban transportation system is formed by a set of streets and transport passages, as well as underground, elevated or surface transport lines that may not be connected to the street network, for example, subway lines, overpass or isolated sections of tram lines, etc. (Cascetta, 2001). A defining feature of urban transportation networks is their inextricable connection with the city, characteristics of settlement, building features, terrain, climatic features, etc. Thus, an urban transportation system can only function successfully in close coordination with other urban systems. The close relationship between the characteristics of the transportation network and the city affects the organization of transport, its working conditions, efficiency, etc.

The transport networks of new cities are planned in such a way as to create the most efficient transport links between various regions and external transport and ensure their capacity for the future. Many features of transportation networks are associated with the history of their development. In historic cities, the characteristics of transport networks were determined by completely different requirements and were inherited from previous eras. Naturally, it is not always possible to rationally modernize them to meet modern requirements. That creates the need to find ways of managing the existing networks efficiently.

In large cities in the United States, there is a system implemented that allows to provide traffic light priority to approaching buses. Bus stops are equipped with screens that show the most up-to-date information about the routes, schedules, locations of approaching buses, and other relevant data (Filho et al, 2020). This helps passengers stay informed on the traffic situation and gives them an opportunity to plan their trips with more accuracy and comfort.

In addition, in the United States, as well as in Europe, a system of toll roads was introduced, as well as another toll system that restricted access to the city center. Such measures are introduced in order to push people towards public transportation, reduce the amount of personal vehicles on the roads, and alleviate the situation on the roads. Additionally, the funds raised from the toll roads can be used to further improve the city's transport system and make it ever more comfortable for everyone.

In Berlin, a traffic control center was organized in 2003, which majorly improved the traffic situation in the city. The purpose of the Berlin Traffic Control Center is to register and assess the traffic situation in the city. Thus, all types of transport are integrated into an effective city traffic management system. The system monitors individual and public transport, as well as, importantly, commercial vehicles.

When the Traffic Control Center went into operation, there were a total of 50 web cameras and over 200 infrared sensors in the city (Astarita et al, 2018). The obtained array of road traffic data is sent to the central traffic management, Computer Analysis Center (consisting of 40 servers), which controls 22 outdoor electronic display devices, as well as the network of existing data centers.

The Traffic Control Center evaluates traffic data for the entire transport infrastructure of Berlin and provides short-, medium- and long-term traffic forecasts. The information obtained from intermodal routers can combine different modes of transport for a specific trip. In addition, there are information systems for road construction sites and city events.

Another example of a city with an effective traffic management system is Seoul. Seoul's high-speed bus network, with dedicated lanes, state-of-the-art bus stops, priority traffic signals at intersections, and real-time information for passengers and operators, is an example of solving many transport problems for existing and emerging cities and metropolitan areas in the modern world.

The Seoul government has implemented a bus control system using intelligent transportation system technology. The terminals of the global GPS system, built into all buses, allow the bus control center to track the location of buses and their speed, regulate the order of work and the number of buses on the route, establish feedback with the driver, including in the event of emergency situations, provide passengers with information about the arrival of buses at stopping points in real time (Astarita et al., 2018).

Five types of bus routes have been developed in Curitiba, Brazil, in order to ensure that citizens can get anywhere in the city easily and with no extra costs, ranging from express lines running along the city's five main transport arteries to a dense network of relatively short routes covering the entire city. Furthermore, the so-called 'metro stations' were created: these are glass cylinders raised above the ground, parallel to the bus route and adjacent to it.

The doors open simultaneously at the station and on the bus. Passengers get off the bus through one end of the station and board through the other, which also resembles the organization of traffic in the subway.

Larger buses, wider doors, a comfortable station and automatic traffic light control – traffic lights can be switched from inside the bus, which gives them priority – all this allowed to carry 3 times more passengers per hour, and 3 times faster than on a regular bus. This cuts the costs by 69%, reduces fuel consumption, pollution, noise and cost, and reduces the time it takes to commute to and from work every day (Astarita et al, 2018).

In a lot of Russian cities traffic managements systems and command centers are successfully implemented. One of the examples is Chelyabinsk. Currently, its system has been used to connect all of the city's traffic lights and over 500 video sensors into a single network the main purpose of which is to track traffic (Burmistrov et al, 2020). All the data collected through those devices is transmitted to the central control center, sometimes also called the situation center. There, operational decisions are made in order to alleviate the situation on the roads, reduce traffic, and make roads safer.

While creating the system, city officials set a goal of uniting authority organizations into a single network that would include traffic police, fire department, emergency medical services, and other municipal services. It is crucial for emergency services to have the most up-to-date information to prevent accidents and timely assist in their case they do happen. The integration proposed in Chelyabinsk would allow collecting, analyzing and sharing all the data between these organizations in order to create a comprehensive look at the state of the city and the region and ensure full cooperation between all structures.

Among the system’s main features is accident analysis. Every week traffic police compiles the data accumulated in that time period and sends it to the command center for thorough analysis. Through this analysis the main spots where accidents took place are detected, as well as possible factors that caused the unfortunate event to happen. Based on that, adjustments are made to the transportation system. For example, accidents happened because the vehicles there weren’t enough time for them to make the turns needed; that can be fixed by extending the time the traffic light shines green by a few seconds. These small adjustments help greatly improve townspeople's experience of the roads.

The system was first proposed in preparation for the Shanghai Cooperation Organization summit and is currently in the stage of active development. At the moment, partial integration of all emergency services and various components into a unified intelligent transportation system is implemented, but already at this stage the system is making the roads much safer and the transportation more comfortable.

3. Results

Traffic management systems are used to regulate city traffic and help people get to their destinations quickly and safely. Such systems use sensors and cameras to monitor, control and respond to traffic conditions. The sensors can be found on the city roads as well as in the vehicles themselves (Lepekhin et al., 2019).

Nowadays, in Russia the transport management sector is controlled by the following regulations:

- GOST R 56829-2015, which sets terms and definitions used in the ITS field;
- GOST R 56294-2014, which defines requirements for functional and physical architecture of ITS;
- Methodology for assessing and ranking local projects in order to execute the ‘Implementation of intelligent transport systems providing the automation of traffic management processes in urban agglomerations, including cities with a population of over 300 000 people’ action within the framework of the ‘General system measures for the development of road facilities’ federal project of the national ‘Safe and high-quality roads’ project. This document contains requirements for local projects, the procedure for evaluating and ranking local projects based on the analysis of integral evaluations of local projects, architecture of an intelligent transport system of urban agglomeration, technical requirements for a local project, etc.

As is evident, regulations in Russian transport management system area are only now starting to develop and there are still very few of them, while in other parts of the world transport management standards have gone through several stages of revision. These different levels of advancement shown all over the world prevent a creation of a consolidated international set of standards that would allow to systematize all the knowledge collected and methods developed in the field. And since there is no unified standard yet, this results in the lack of proper coordination of actions of different participants in the implementation processes of transport management systems. All these factors considered, a need to create a uniform architecture model of a transport management system rises.

We compiled the main purposes and elements of traffic management systems by analyzing the existing implementations of traffic management systems and the Intelligent Transportation Systems available in the market. The main purposes of using traffic management systems include (Heremobility, 2019):

- Reducing traffic jams through traffic flow optimization;
- Tracking traffic conditions to make real-time changes in traffic prioritization;
- Reducing air pollution;
- Ensuring a stable flow of public transport throughout the city, prioritizing public transport at intersections;
- Creating an effective accident response system.

Traffic management systems generally consist of the following elements (Srivastava et al, 2013):

- Traffic control center;
- Intelligent Transportation System (ITS);
- Various sensors, including GPS and in-road ones;
- CCTV cameras.

The cameras and sensors collect data on the current state of traffic conditions of busy city roads in real-time which is then transmitted to the Intelligent Transportation System that informs the Traffic Control Center (Zheng et al., 2019). Every two seconds, the system calculates whether it is necessary to adjust traffic activity.

The scope of ITS includes traffic and mobility management, managing the movement of vehicles and assisting drivers, enhancing the transport infrastructure, and providing improved interfaces for transport systems. The systems are used in car parks, traffic lights, toll booths, bridges, and roads. With their help, it is possible to create interconnected transportation systems with open communication between devices and vehicles. ITS can actively manage traffic so it flows smoothly and public transport arrives as scheduled (Miz et al., 2014).

According to Russian State Standard GOST R 56294-2014, ITS is a system that integrates modern information and communication technologies, and is designed for automated search and acceptance for implementation of the most effective scenarios for managing the transport and road complex of a region, a specific vehicle or a group of vehicles in order to ensure mobility of the population, maximize indicators use of the road network, increasing the safety and efficiency of the transport process, comfort for drivers and transport users.

ITS ensures that citizens have access to real-time information about traffic and public transportation conditions. This reduces travel time for commuters and makes traveling throughout the city easier, safer and more comfortable.

ITS gathers information from sensors, including GPS devices and road cameras (Levina et al., 2017). There are five main applications that make up an intelligent transportation system:

3.1. Advanced Traffic Management System (ATMS)

The ATMS uses data collected from sources such as traffic lights and car parks in order to manage traffic. These sources provide updated information about the current status of traffic, which allows the ATMS to actively control traffic and provide guidance to drivers for a safer, faster driving experience. The ATMS includes the following functions:

- Redirecting traffic from congested areas by controlling traffic lights, thus reducing traffic jams;
- Adjusting toll rates on roads that have them in order to direct people towards using public transport instead of personal vehicles;
- Providing traffic participants with relevant information, i.e. available parking spots.

3.2. Advanced Vehicle Control and Safety System (AVCSS)

The AVCSS uses sensors installed in vehicles to alert drivers about potential danger and give them information on how to avoid these situations. Until the time comes when vehicles are completely autonomous, AVCSS can provide automation that augments and assists human driving. Some of the AVCSS functions are:

- Preventing errors in human driving through automated control of a vehicle;
- Preventive measures against dangerous situations on the road, as well as help in managing those situations if they happen;
- Cruise control, lane keeping and parking assistance.

3.3. Advanced Public Transportation System (APTS)

The main purpose of the APTS is to provide people with necessary information about buses, i.e., seat availability, location, and estimated time of arrival. The system also can be used to optimize the flow of transportation routes, for example, by delaying buses running ahead of schedule. The APTS consists of the following modules that allow it to manage public transport in the most effective way:

- Real time passenger information systems;
- Automatic vehicle location systems;
- Bus arrival notification systems;
- Systems providing priority to buses at intersections.

3.4. Commercial Vehicle Operation (CVO)

The CVO combines the functions of the previous components to manage commercial vehicles, such as buses, ambulances, trucks, and taxis. CVO methods include automatic vehicle monitoring, which allows to track performance and driving behavior. This is important since bad behavior on the road can result in accidents and other potentially dangerous situations (Chen et al., 2016).

Another function that the CVO module has is fleet management. It allows to better manage commercial fleets using the data gathered. That way an organization can monitor its fleet to reduce costs by tracking fuel consumption, checking the driver's compliance with routes and protocols, analyzing operating costs, etc. These methods are used to promote communication between regulatory agencies and drivers, reduce operational costs and enable the efficient transfer of services and goods.

According to Russian State Standard GOST R 56294-2014, the functional and physical architecture of ITS should be developed in two stages: first, preliminary models are created, then the final versions of the algorithm are formed based on the preliminary ones. Preliminary architectural models are based on the idealistic ITS model. The final versions of those models are based on the refined ITS model, significantly detailing all the functions and elements of the system.

Figure 1 shows an architectural model of a unified traffic management system, consisting of all the above-mentioned elements.

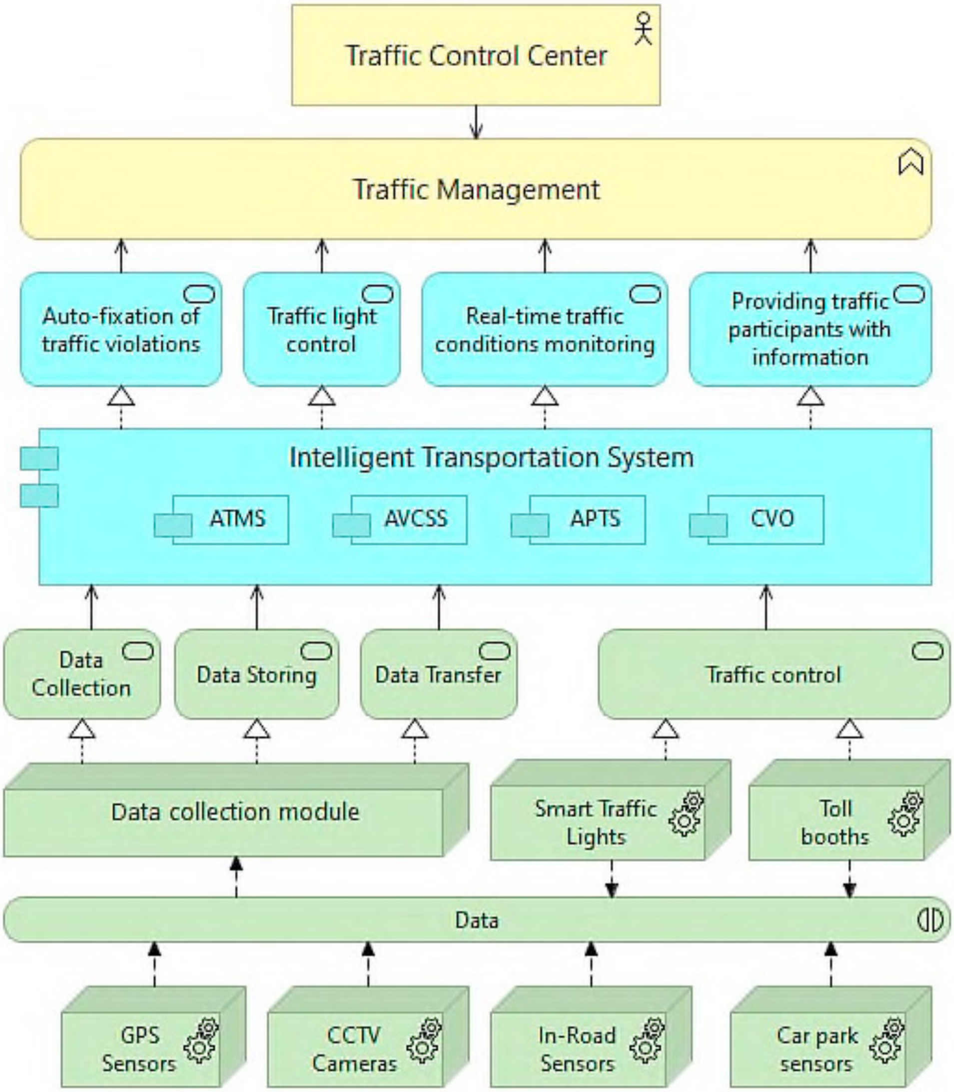

Fig. 1. Traffic management system architecture.

Using the presented model as a basis for a comprehensive traffic management system will allow to create an effective system that will significantly improve the traffic situation, resulting in higher productivity of the transportation system and of society as a whole, improving its overall well-being.

4. Conclusion

In today's age of rapid urbanization, it is very important to make cities as comfortable for their inhabitants as possible, and that means ensuring they have an ability to get to their destinations fast and safe (Lepekhin et al., 2018). Creating a traffic management system is a crucial step in turning that aspiration into reality.

The focus of this paper was on the modern traffic systems and the ways of their effective management. It was discussed how usage of ITS, sensors, cameras and implementing a traffic control center can greatly improve the traffic situation in a city.

The goal of this article was to develop a model for the architecture of urban transport system management. The following tasks were completed:

- transportation systems were analyzed and their elements described;
- several cases of implementation of traffic management systems around the world were presented and analyzed;
- elements of traffic managements system were compiled and the mechanism of their cooperation was described;
- an architectural model of a traffic management system was proposed.

The architectural model created over the course of this study can be used as a reference model for traffic management systems as it accumulates all existing approaches to organization of systems of such class. Due to the fact that this model unites all the different modules used to manage various factors of traffic in one single network, it grants a comprehensive look at the traffic situation in the area (city, region), thus making the transportation system much more efficient and easier to control. As we already mentioned, the proposed model is a reference model, which means that in the future it can be used as a basis for the automation of the transport complex in various areas.
Implementation of the unified system proposed in the created model will allow the optimization of the traffic situation in order to reduce traffic jams; as well as that, it will also help in adjustment of the flow of public transport to provide people with comfortable and reliable means of transportation. Another benefit of using such system is increase in road safety, since the analysis of accumulated data about accidents and their causes will help in making adjustments to the transportation network, thus making it much safer for all parties involved. Not only will the results of traffic analysis help improve the current infrastructure, it will also influence the city expansion and the ways that new districts are build and equipped allowing new roads to be comfortable and safe right away. All these adjustments will improve the urban environment and greatly enhance the quality of life for all townspeople.
We presented examples of implementation of similar systems in Berlin, Seoul, Curitiba, and Chelyabinsk; however, those systems include only certain components of the proposed system's functionality. This system has not been implemented fully as yet. That can be explained by several difficulties that surround organization of such a complex structure, in particular, a large number of structural elements that comprise the transport system, as well as the complicated nature of the connections between those elements and the fact that the system is heavily influenced by a wide range of different factors of the internal and external environment.

The authors distinguish two main directions for further research. The first direction is the further development of the proposed architecture by integrating new functional subsystems into it, as well as new digital technologies and tools. The second research direction is the integration of the proposed transport management system with other urban intelligent systems to implement the concept of a single integrated urban environment.

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