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Digital Twins in the Intelligent Transport Systems

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Abstract

Traffic management problems in any city are acute. Previously, this problem was solved by control centers, now such centers require modernization based on digital twins and artificial intelligence. The introduction of Intelligent Transport Systems allows solving the main problems of the transport network and effectively developing it. In this article, the cases of ITS implementation are analyzed, a reference model of the services of such a system is developed.

Keywords: Digital Twins; Intelligent Transport Systems; Reference Model; Traffic Management.

1. Introduction

As city population grows, and the vehicle-to-population ratio grows accordingly, each large city faces the problem of efficient management of transport flows. Transport control centers are used to ensure normal traffic on the road network. As transport problems multiply, modernizing and digitizing transport through using intelligent systems (including synchronization with the main city services) is a priority area of development.

The main problems related to functioning of transport systems are the same for all cities. They can be systematized and divided into objective and subjective problems (Biriukov et al., 2015; Lobanov, 2005).

Objective problems:

- increasing vehicle-to-population ratio;
- intensified use of individual transport;
- decreased efficiency of urban passenger transport;

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- increased need for city residents to move;
- disproportion between the vehicle-to-population ratio and the pace of road construction;
- problems of urban planning and urban area development.

Subjective problems:

- imperfect system for organizing and managing the development of the road transport complex;
- insufficient legislative base at the local and regional level for managing the transport system of the city, region;
- insufficient information component when making management decisions;
- insufficient funding for the development of road networks and transport infrastructure;
- unresolved property issues and issues of delineation of property rights and management of transport infrastructure facilities;
- negative impact of the human factor.

First of all, transport control centers solve several tasks:

- organization of efficient traffic flow;
- monitoring of the road network;
- coordination of forces and means in the event of emergency situations in the transport system;
- informing participants about alternative routes in the event of emergency situations;
- control over the elimination of the consequences of emergency situations in transport.

The modernization of the centers is necessary, first of all, due to the increase in the information load on operators, which may lead to an emergency situation. The effectiveness of any transport (traffic flow) control center is determined by the implementation of appropriate Intelligent Transport Systems (ITS), which allow solving the objective transport problems indicated above.

Intelligent transport systems (ITS) are smart systems using innovative developments in modeling transport systems and regulating traffic flows, providing end users with greater information content and safety, as well as qualitatively increasing the level of interaction between road users in comparison with conventional transport systems. The ITS includes all services of the city, including traffic police, ambulance, fire departments and other services.

One of the key elements of these systems are digital twins, which use mathematical modeling methods to analyze the transport network and develop proposals for solving transport problems: optimization of traffic and pedestrian flows, public transport, traffic management, optimization of traffic lights, and investment justification in the construction of transport infrastructure. Combining the technologies for strategic transport planning with ITS solutions allows to use the capabilities of the existing transport infrastructure the most rationally and choose the right direction for its development in the future.

Technologies for managing transport systems of cities are actively developing; reference models of ITS services are required to accelerate project implementation, making it possible to develop and implement specific models of transport infrastructure together with appropriate information systems.

Analysis of the available literature indicates that this problem is still insufficiently studied. There is not enough information about the existing models of ITS services in the literature and cases referred to below.

The main purpose of this article is to review the existing cases of ITS implementation, develop a system of functional requirements for an integrated Intelligent Transport System, including a digital twin, and develop an architecture model for such a system.

2. Methodology

The main research method in this article is source analysis and modeling of intelligent transport system services using ArchiMate notation. The basic general scientific research methods used were analysis, comparison, classification, architectural modeling, expert judgment, as well as scientific generalization. The analysis covered the existing solutions for traffic management including the concept of digital twins. The main cases for consideration were the implementation of an intelligent transport system in the city of Chelyabinsk, Russia (according to the case of Simetra Company) and the case of the Main Roads Western Australia (MRWA), which is developing a digital twin to optimize planning and decision-making on the Australian road network.

The article is based on such studies as (Flynn et al.), investigating the creation of digital twins of roads and identifying some patterns and difficulties in the implementation of digital twins in this area; (Bouchermal et al., 2013) considering the technical aspects of ITS implementation; (Hoogendoorn, 2001) describing the main patterns and providing an overview of the main models and theories of traffic flow; (Cureton, 2020) analyzing digital twins in smart cities; (Kushchenko et al., 2019) discussing the simulation of traffic.

As a basis for writing an article, the National Standards of the Russian Federation are used: GOST R ISO 14813-1-2011 “Reference model architecture(s) for the ITS sector” which describes ITS service domains, service groups and services, GOST R 56294-2014 defines the requirements for the functional and physical architectures of intelligent transport systems, GOST R 56829-2015 defines the basic terms and definitions. Also, it is used the "Methodology for assessing and ranking local projects in order to implement the ITS implementation" of the Ministry of Transport of the Russian Federation, which describes the requirements for implementation projects, serves as a basis for the development of a reference model. In addition, the international standard ISO 14813-1:2015 is considered, as well as the initiative of the US Department of Transportation (U.S. DoT ARC-IT version 8.3), which describes the levels of ITS architecture and possible subsystems.

3. Results

Any metropolis has a traffic control center, where operators are largely responsible for making management decisions. A person in such a center is a source of errors, the employee's reaction speed is much worse than the system's reaction speed. This raises the problem of automating the activities of operators based on the introduction of ITS, whose efficiency depends, in particular, on using digital twins of transport streams. Ideally, the entire system should work autonomously without human intervention, while workers, in turn, should be only engaged in setting up such a system and monitoring (Levina et al., 2017; Singh et al., 2019).

The use of digital twins makes it possible to accurately simulate the real transport and road network and serves for implementing the approaches based on predictive analytics for making decisions on the development of the transport network, including performing calculations to assess its congestion.

In the context of the article, a ‘digital twin’ is understood as a module that reproduces a detailed digital model of the road and allows for modeling and experiments. The main purpose of use is to test solutions and the ability to simulate different situations. This model can be corrected due to the accumulated information received from the sensors of the road network.

In turn, intelligent transport systems help in solving the following tasks:

- optimization of the distribution of traffic flows in the network in time and space;
- increasing the capacity of the existing transport network;
- providing travel priorities for a certain type of transport;
- transport management in the event of accidents, catastrophes or measures that affect the movement of transport;
- improving road safety, which leads to an increase in traffic capacity;
- reducing the negative environmental impact of transport;
- provision of information on the state of the road to all interested parties.

The main components and participants of the Intelligent Transport Systems are (Borah et al., 2019):

- transport infrastructure;
- service and software infrastructure;
- vehicles;
- telematic equipment of transport infrastructure elements and vehicles;
- intelligent information boards, road signs and traffic lights with the ability to remotely control them;

- centers for collecting and processing information;
- decision making and traffic management centers.

The intelligent transport system of a modern city is:

- constant and prompt collection of information about the traffic situation on the roads (detectors, cameras, etc.);
- a powerful yet easy to use tool for storing, processing, validating and analyzing measurement data;
- a modern tool for predicting the traffic situation for the next 15 minutes and the next day, using constantly updated data from detectors in real time;
- the use of modern equipment for traffic light regulation and the creation of a single traffic control center in real time, as well as ensuring a prompt response of the traffic police to car accidents and other unpredictable situations.

Based on the above, there are three main functions of ITS:

- transport modeling (digital twin);
- traffic light regulation;
- monitoring, planning and management of the transport network.

To compile our analysis, we examined such traffic management systems as RITM3 (SIMETRA) (which can include modules such as PTV Vision Traffic Suite: PTV VISUM, PTV VISSIM, PTV VISWALK, PTV OPTIMA, LISA+ (Schlothauer & Wauer)), Trafficmap (AssetWise ALIM, Bentley), IRIS open source ATMS, Kimley-Horn Integrated Transport System, SWARCO AG (Traffic Management Software, 2020).

Let us consider an example of ITS implementation in Chelyabinsk, Russia. The intelligent transport system of Chelyabinsk is deployed on the basis of the information and integration platform RITM3. It accumulates data from all sensors and weather stations, helps control traffic lights (thanks to integration with an automated traffic control system), ‘see’ public transport and road works, predict traffic and use elements of artificial intelligence.

In addition to purely practical tasks to improve the situation on the road, the system helps the authorities to implement legislation. For example, it is convenient to store all traffic management projects in it, which the law of the Russian Federation requires to develop on each street. Thus, these documents are always available simply by hovering the cursor over the street on the map. This greatly simplifies the inspection of all technical means of traffic control, as well as construction work. For example, there is no need to contact all authorities in the city (gas service, management of electrical networks and communication providers) to install a traffic light, since the location of all communications is already in the system.

In addition, this system has powerful analytical tools. For example, ‘heat maps’ of a city can be displayed to visually trace the concentration of the population in different areas or, for example, the main centers of accidents. The system is designed specifically for traffic control centers and allows employees to use it as the main tool in solving problems of the transport complex.

Another possibility is to display the main correspondence of the townspeople, this gives an understanding of where and where the residents are moving from. Correspondences are calculated on the basis of a set of factual data in a mathematical model of the city's transport and passenger flows; this makes it possible to predict scenarios for the development of urban transport infrastructure.

The traffic management system includes systems such as traffic violations reporting, incident detection, vehicle counters and classifiers. All this data is transmitted in real time to the Transport Control Center, allowing to receive real-time updates on the conditions and availability of urban transport (Traffic Management Systems: Optimizing Traffic with Existing Infrastructure, 2020; Vilken et al., 2019).

Let us take a closer look at the modules that are embedded in the system:

- a module for displaying all activities developed within the framework of transport planning documents on the map;

- a module for visualizing the current traffic situation, which allows to calculate the current traffic load of the road network and a short-term forecast for the development of the traffic situation.
- a monitoring module that automates and visualizes the control of mobile objects (vehicles or personnel) moving along the roads and performing various types of work;
- a module for modeling traffic flows, which allows to integrate transport models into the information system, edit and update them.

A tool for the development and optimization of traffic light control modes (Dhingra, 2020), calculation of regulation safety parameters, development of coordinated control (graphic-analytical method), as well as the development of adaptive control algorithms with the subsequent possibility of assessing the characteristics of traffic by means of existing integration is also implemented in the system under consideration.

As mentioned earlier, the transport modeling function (‘digital twin’) is one of the global ITS functions. Consider the models and features of digital twins of transport streams.

Macroscopic models are used for transport planning and for creating optimal conditions for functioning of public transport. It is important that it is the macroscopic approach that allows integrating all traffic participants into a single model, taking into account their individual characteristics (Transport modeling: types of models and their features, 2019). It is suitable for the development of transport systems in cities and regions (Abdelwahab et al., 2019).

Simulation or microscopic models allow to objectively look at traffic flows in urban environments or on highways with heavy traffic. On their basis, various factors can be optimized, for example, the nature of traffic patterns, the throughput of a road section, the efficiency of signaling devices, the characteristics of pedestrian flows, etc. (Souza et al., 2017).

Pedestrian flows are an integral part of road traffic. Organizational decisions when planning them allow to see their interaction with transport. This is relevant not only for the daily operation of roads, but also under certain conditions: mass events, concerts, exhibitions, etc.

The dynamic model draws special attention. It allows to analyze the complexity of the current situation and predict the nature of traffic flows in relation to the risks of road accidents, when traffic lights are turned off or in the event of repairs.

Modeling of traffic flows is carried out on the basis of the information collected about the features of the functioning of transport systems, which include:

- the degree of congestion of the transport system;
- average speed indicators;
- indicators of the volume of transportation of goods, passengers and the cost of this time;
- loads at certain intervals;
- the number, frequency and length of congestion;
- traffic intensity.

Initially, the simulation of traffic on a road or its section depends on the project. The package of documents provides the technical and economic characteristics available, the development programs used, the regulatory documents serving as the framework for the operations. Information on climatic conditions at different times of the year should also be provided. This approach allows to correctly assess complex nuances and problem areas in modeling. Next, the optimal software allowing to complete the tasks is selected. Additional transport surveys may be needed, as well as a population survey on the current transport system.

Calibration of the transport model is one of the stages. It is based on comparing the calculated data with the actual data and their variations. The reporting documents must provide an analysis of the simulation results along with the presented materials. If all parties to the process agree with the provided transport model and its technical innovations, the remaining task is obtaining approval from the regulatory authorities and updating at the facility. An optimized transport system implies coordinated operation of all types of transport and pedestrian flows with high efficiency rates at low economic costs.

In an effort to optimize data collection and information sharing for road network management, Main Roads Western Australia (MRWA) needed to display and present accurate traffic data to stakeholders and the public. To achieve this, MRWA required a state-of-the-art mapping interface to display and present traffic data collected in Western Australia, which was used to aid road maintenance and ensure the efficiency and safety of the road network. Traffic data also includes information that the MRWA collects about vehicles traveling on Western Australian roads, in particular, the number and type of vehicles, speed, and, in some locations, vehicle sizes. Therefore, Trafficmap was developed to provide public access to traffic data and provide MRWA employees with the data they need to make informed asset management decisions. The Integrated Road Information System (IRIS) monitors and stores MRWA road asset management information as part of an asset information system using linear and spatial coordinates that supports MRWA's business processes. MRWA also uses this system to manage and disseminate traffic information. In addition, the modules of the system manage the infrastructure of the transport network and all related information, including about assets, their condition and attributes of roads, which gives MRWA a wide set of data for reporting information on road assets (Stone, 2020).

Based on the analyzed experience and cases, existing solutions, a reference model of the services of the Intelligent Transport System was developed.

This model includes the following services, which are headed by an information system (for storing and accessing information from past periods), a digital twin of the transport and road network (a mathematical model of a road transport network) and artificial intelligence (a system of algorithms for information processing and decision-making):

- Service for visualization of the current transport situation. This service allows to display the traffic situation in real time, based on the readings from sensors installed on the roads. It is directly linked to the digital twin of the transport and road network.
- Service for modeling transport and passenger flows. It is aimed at short-term and long-term modeling of flows based on artificial intelligence algorithms that analyze information from previous periods stored in the information system (including from sensors installed on the road transport network). In addition, integrating this service with predictive analytics and a digital twin of the road network allows to display information about problem areas of the city. In turn, the data obtained is used to plan the development of the transport network.
- Service for monitoring mobile objects (operating on the road transport network). This service allows to track the works taking place on the roads, including the departure of special equipment (for example, cleaning machines or repair equipment). In addition, it allows to show cars belonging to the police or ambulances.
- Service of events developed within the framework of transport planning documents. It allows to view in real time what activities are planned for a specific section of the road (including taking them into account when building forecasts for the digital twin), as well as to track all restrictions associated with the desired section (including showing the markings of the electric, gas, water supply networks;
- Service for the integration of the system with the police, transport police, fire department. This service is used for rapid exchange of information with the headquarters of ambulance services, traffic police and police. Thanks to integration with the information systems of the city services, it is possible to promptly transmit information and respond quickly in case of an emergency.
- Incident-tracking service. This service allows to automatically recognize (based on artificial intelligence algorithms that assess the situation through video surveillance cameras) accidents that have occurred on the roads, record them in the current traffic situation, make forecasts for the development of the traffic situation, and also promptly transmit information to city services even before the participants or eyewitnesses to the traffic accident call.
- Service for controlling the modes of traffic light objects. Based on predictive analytics, artificial intelligence algorithms, and the modeling of traffic and passenger flows, this service allows to automatically monitor all traffic light objects of the road transport network within one city and select effective operating modes to avoid traffic jams and traffic collapse during peak hours.
- Predictive analytics service. This service uses artificial intelligence algorithms, as well as information obtained from other services, which then serves for constructing short-term and long-term forecasts. These forecasts act as the basis for the operation of other services, and can also be displayed separately for making decisions on

adjusting the system as a whole. In addition, thanks to integration with external systems, this service sends information to interactive map Internet services and allows to promptly update information about traffic jams and traffic problems and correct the traffic flow.

- Traffic management service. This service allows to provide directive control of transport streams, as well as indirect control of transport streams.
- Traffic rules compliance control service. This service provides the collection of data, which is the evidential base of the facts of traffic violations, provides the collection of data on the parameters of traffic intensity, provides data transfer to law enforcement agencies and ITS subsystems.
- Service of meteomonitoring and monitoring of the road network condition. This service allows you to collect data on weather conditions, in accordance with them, change the road network management modes, and also allows you to warn about the road temperature and the possibility of ice on specific parts of the road. In addition, the module provides for monitoring the condition of the road network and emerging problems with the road surface.
- Digital Twin of the Road Network Component allows to simulate different traffic situations, superimpose the movement of flows, helps in planning the development of the transport network (for practicing the introduction of new road sections, new road objects).

All the described services with their functions, as well as application components (digital twin, artificial intelligence and information system) are included in the common framework of the intelligent transport system (Anisiforov et al., 2019). One of the main conditions for effective work of the given system is the presence of a convenient, adaptive and understandable user interface, which allows to display predictive analytics reports, display a detailed city map with all objects, incidents, with predicted and current traffic flows.

The functionality described in this model is due to the document of the Ministry of Transport of the Russian Federation "Methodology for assessing and ranking local projects in order to implement the ITS implementation" event.

If this model does not contain services similar to the names of modules or functionality given in this document, it is assumed that such functions are performed by a combination of services. Functionality that has specific characteristics depending on a particular country of implementation is not considered in this model and is listed in the discussion of this article.

The general scheme for the described model is shown in Figure 1.

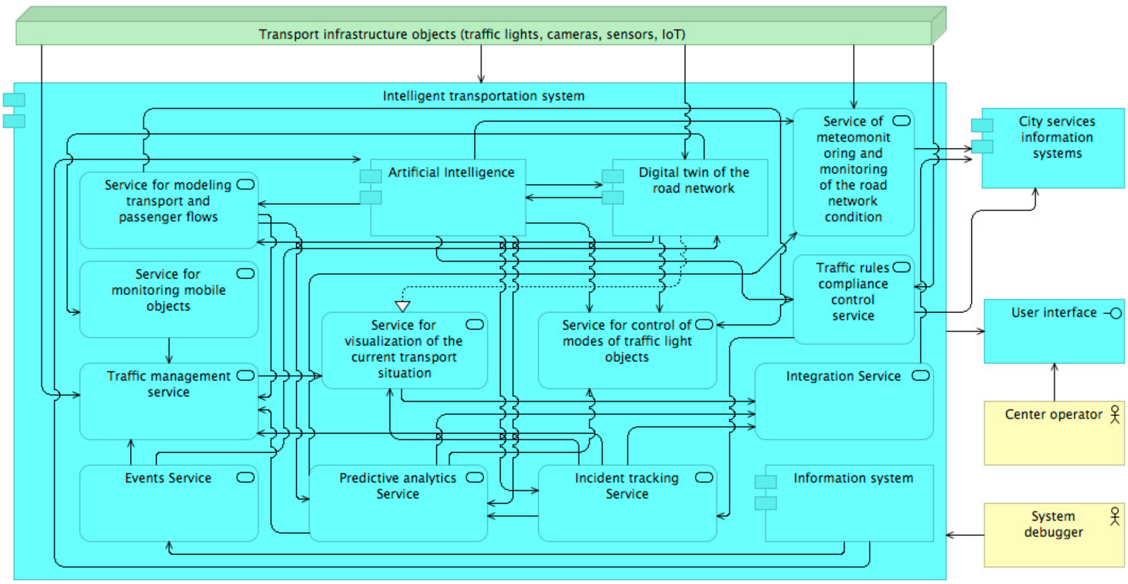

Fig. 1. Reference Model of Intelligent Transport System.

It can be seen from the presented reference model of the Intelligent Transport System which basic services should be included in the system in order to provide functionality that allows solving the main transport problems. We believe that these services fully satisfy the modern transport problems of cities, ensuring that the traffic management system (transport control center) is integrated into the overall city management system, thus allowing to implement the concept of a smart city in practice.

4. Conclusions

The presented reference model fully meets the three main functions of an Intelligent Transport System, which were described in this study. Furthermore, the developed model fully solves the following tasks: organizing efficient traffic flow, optimizing the distribution of traffic flows, managing city services in case of accidents and emergency situations, providing information about the situation on the roads to all interested parties, developing transport infrastructure.

The system allows for a constant and prompt collection of information about the traffic situation, which is processed by artificial intelligence algorithms and serves as a basis for future forecasts.

Based on our findings, we can conclude that implementing an ITS improves a number of indicators: reaction speed, number of errors, road network throughput, increased safety on the roads, which also leads to an increase in throughput, and a decrease in the negative environmental impact of transport.

Thanks to integration of the Intelligent Transport System with other city services, there are positive effects on the reaction speed of ambulance, traffic police and other city services.

The operation of transport control centers changes qualitatively with the introduction of ITS: operators perform only a controlling function and influence the adoption of strategic decisions on modernization and development of the transport network, based on the obtained analytical forecasts. Specialists in debugging and configuring such a system play a key role in this case.

The main obstacle to introducing ITS is the underdeveloped infrastructure. The possibility of implementing the system is determined by the presence of sensors, surveillance cameras, IoT and other infrastructure located on the road transport network.

The model presented in this article serves as a basis for infrastructure planning and helps to speed up project implementation.

In the Russian ITS development standards, the services of these systems include modules that allow ensuring national security. Aspects of these services are not included in this study and may be the basis for new scientific papers on this topic. Also, the article does not consider the services of electronic payments in transport, since information is needed about existing payments in a certain region.

Further directions of research include analysis of such issues as: Advanced Traffic Management Systems (ATMS) and their difference from ITS; as the next step in the development of a reference ITS model, attention should be paid to formulating the requirements for the technological infrastructure of the road network, for the implementation of the presented model.

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