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RESILIENT INFRASTRUCTURE

Z. Boros, J. Komačka, F. Buček
TPA Company for quality assurance and innovation, Bratislava, Slovakia
zsolt.boros@tpaqi.com

P. Ľos, M. Tereková, N. Šimuneková
Ministry of Transport and Construction of the Slovak Republic, Bratislava, Slovakia
peter.los@mindop.sk

M. Sura
Adviser to the Ministry of Transport and Construction of the Slovak Republic, Bratislava, Slovakia
sumi@post.sk

R. Rothbauer, M. Marko
Betamont, Zvolen, Slovakia
rothbauer.robert@betamont.sk

Z. Benkó
Slovak Road Administration, Bratislava, Slovakia
zsolt.benko@ssc.sk

From cradle to Grave – Improved Life Cycle Management of Road Infrastructure in the Course of Digital Transformation

ABSTRACT

The digital transformation brings social and technological challenges that will affect all citizens. Unfortunately, many of technologies, that are essential for the smart mobility, are only at the beginning of normal use in Slovakia. First pilot projects were focused on the usability of 5G networks in road transport and the verification of the readability of horizontal and vertical traffic signs in the real road traffic.

The sophisticated basis for Digital Asset Management is a digital twin of the Slovak road network. The software environment representing a set of applications and tools is called the Road Network Model Information System (IS MCS). Diagnostic devices are routinely used for complex acquisition of data on the quality of the road network as the part of the Road Management System. Data are processed to propose an indicative rehabilitation design and to create multi-year rehabilitation plans for the roads. The prediction of future degradation is estimated based on degradations functions derived from the long-time monitoring of 25 test sections. A part of the IS MCS are also data about traffic flow characteristics collected by Automatic Traffic Counters, that are also used in intelligent traffic system applications, and information from pre-selective systems for checking the total weight and axle load of heavy vehicles.

In Slovakia, there is still no systematized request from public or private investors for the introduction of BIM into a project practice. To help with the use of BIM, the Office of Geodesy, Cartography and Cadastre of the Slovak Republic has been providing a new digital relief model and a digital surface model of the entire country, that were created from aerial laser scanning data. The BIM application in Digital Asset Management was implemented by the municipality of the capital city Bratislava in 2022 through a pilot project of a three-dimensional model with all buildings, roads, but also trees, furniture, and other attributes. Construction companies follow their own path in learning about and applying BIM, where they apply their experience from all over the world. The successful example of BIM application in construction by private company can be the ongoing construction project of the R2 Kriváň - Mýtna expressway in the middle of Slovakia.

Big data collection relating to transport is concentrated within the National Traffic Information System project. Users and the professional public are informed from official sources about road traffic restrictions, traffic accidents and driving conditions on their travel routes

1. INTRODUCTION

The report in question includes a global view of achieved results and potential opportunities for the continuous improvement of road management in the extended system of digitization process, with an emphasis on data acquisition, systematic monitoring of assets as well as construction materials and their multiple reuse (qualitatively hierarchically conditioned) for the next mission in the service of road users. The focus for future is on the continuous improvement of possibilities of this activity using the available information databank about parameters in the BIM system in an interaction with the influence of traffic load, standard and exceptional climatic conditions in Slovakia.

The vision and strategies for the future direction of transport in Slovakia from the point of view of digital transformation are mainly summarized in the documents Strategy for Intelligent and Sustainable Mobility of Slovakia and Action Plan for the Digital Transformation of Slovakia within the topic of Intelligent Mobility, which is a part of strategic goal "We will create the foundations for modern digital and data economy and for the digital transformation of the wider economy" following the Program Declaration of the Government of the Slovak Republic for the period 2020-2024.

2. SMART MOBILITY

Smart mobility is a transformation of transport to its higher level. Thanks to advanced information and communication technologies, travel will be much more efficient, ecological, and sustainable in terms of environmental protection. Today's cities are facing a similar transformation that will take place in the world of transport. The world of smart mobility will be the world of IoT (Internet of Things), where means of transport, transport infrastructure, people and Smart City objects will communicate with each other and exchange information to make transport safer, more efficient, greener, and smoother. The principles of world of smart mobility are already starting to merge with the principles on which the world of Industry 4.0 is built (mutual communication links, information transparency, technical assistance, and decentralized decisions). Applying the principles of Industry 4.0 to the world of smart mobility, for example interconnectivity through V2X (Vehicle to Everything) and the transparency of information exchange, will enable data-based decisions to be applied, and assistance systems to support driving will be put into operation.

Currently, there are two types of V2X communication. One is based on the communication using the 802.11p communication protocol standard, the other uses for the communication the environment of cellular networks. The V2X communication specification based on the communication in a wireless communication network - WLAN (Wireless LAN) supports the direct communication among vehicles, vehicles and road infrastructure, external computer networks, vulnerable road users (pedestrians, cyclists, motorcyclists, etc.), Smart City sensors, etc. The data transfer speed varies between 3-27 Mbit/s, the latency (delay) of end-to-end data transfer reaches 1-10 ms (depending on the network load), typically around 5 ms. The communication range is from 250 to 300 meters. It is essentially communication in a wireless WiFi ad-hoc network. Its minimum version can be created by two devices equipped with a V2X communication interface, that are within communication range of each other. The V2X communication in the DSRC 5.9 environment does not require the construction of any communication infrastructure, which is crucial for ensuring traffic safety in distant or underdeveloped areas.

Newer V2X communication uses cellular networks for mutual communication in a V2X environment, therefore it is called cellular V2X - C-V2X. The C-V2X uses 4G - LTE (Long-Term Evolution) wireless broadband data transmission or data transmission in a 5G network. The communication in the C-V2X environment uses two modes of data transmission. The first mode uses a conventional mobile cellular data network for data transmission, which allows vehicles, objects of transport infrastructure, pedestrians, etc. to communicate with each other via the Uu communication interface. The second mode uses for data transfer the direct communication among vehicles, infrastructure, pedestrians, etc. The speed of direct communication is around 13,5 Mbit/s and the range is around 500 meters. The start of operation of 5G networks on the territory of the Slovak Republic is a primary prerequisite for enabling the use of part of its capacity for the intelligent mobility and is estimated by the end of 2023. In 2022, the Faculty of Engineering of STU implemented a pilot project aimed at verifying the usability of 5G networks in road transport (V2X). During the test runs, the quality of connection, the latency, the speed of the transfer of data packages of various sizes were checked for all providers operating in Slovakia. The functionality of real application model was verified - the functional connection of the vehicle and a virtual vehicle at the level of real-time digital twin in the city infrastructure. By the end of 2022, the subsequent V2V (Vehicle to Vehicle) phase should take place again under the direction of FME STUBA (The Faculty of Mechanical Engineering of Slovak University of Technology in Bratislava), when the quality of the connection between two moving vehicles will be tested within the existing 5G networks.

The readiness of Slovak roads for the deployment of intelligent and connected transport was tested by a pilot project implemented by FIIT STUBA (Faculty of Informatics and Information Technologies of Slovak University of Technology in Bratislava) to verify the readability of horizontal and vertical traffic signs in the real road traffic under selected boundary conditions (traffic density, light conditions, pavement surface). The data collection vehicles were equipped with all necessary technologies, such as LTE/5G routers, cameras, radars, and lidars. The output of the project was the analysis of established facts, focused on the reliability of detection of various types of traffic signs on Slovak roads by sensors and methods that are standardly used in modern cars as a basis for advanced assistance systems, or autonomous driving at one of the required levels.

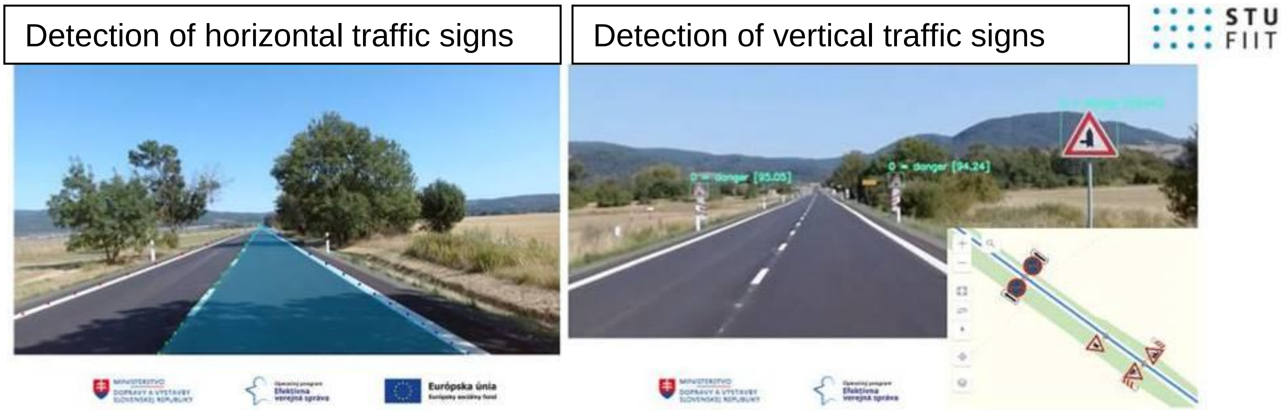

Figure 1 – Detection of traffic signs

Several general questions regarding the concept of smart mobility need to be addressed to successfully implement smart mobility into everyday life. Many of technologies, that are essential for smart mobility, are only at the beginning of normal use in Slovakia (for example 5G, Edge computing or HD maps). These data need to be processed and analysed. The processing time of operational data should be minimised to ensure a vehicle has sufficient time to respond adequately. Therefore, a question is, which architecture should be chosen.

The advanced IoT communication environment in the world of smart mobility has great potential to reduce the number of traffic accidents to a minimum, reduce transportation costs, and reduce environmental pollution caused by transportation. The ability to communicate in the communication environment of the world of smart mobility, and that is the IoT environment, will become a necessary condition for entering the full-fledged world of smart mobility. Even the most modern autonomous vehicle will not become a part of the world of smart mobility if it is not able to communicate in this world. Conversely, even a very old vehicle will become a full-fledged part of the world of smart mobility if it is equipped with a communication interface that allows it to communicate with other participants in the world of smart mobility.

3. DIGITAL ASSET MANAGEMENT

Digital asset management should enable to create a digital representation of roads, giving previously inaccessible insights to help maintain, operate, and improve safe, clean, digital roads. Result of digital asset management is a comprehensive digital twin model of a road network. With the digital twin enabled, there is a potential to track the past and predict the future as we move to future-enabled mobility.

The software environment representing a set of applications and tools, which is used in Slovakia for the implementation of digital asset management, is called the Road Network Model Information System (IS MCS) and is managed by the Road Databank Department of the Slovak Road Administration (SSC). The road network model is a set of digital data stored in a central database.

The prerequisite for further processing and analysis of data in the digital asset management is a data acquisition. Due to huge amounts of data and their quality, the deployment of intelligent and innovative methods and tools is necessary more and more often.
In Slovakia, a complex acquisition of data on the quality of road network by diagnostic devices has been introduced as part of the Road Management System. Individual measuring devices are attached to a measuring vehicle or to a trailer. These devices collect continuously data on the following parameters:

- FWD KUAB - bearing capacity of pavement,
- Profilograph - unevenness of pavement surface,
- Skiddometer - longitudinal skidding resistance of pavement,
- Videocar - continual video record of pavement,
- Linescan - digital image of the pavement surface.

Basic data processing consists of the entry of outputs of diagnostic devices into the central database (Road Databank). An application software of diagnostic device can be used for the import of field data or data can be edited by Road Databank Department staff.
The SSC directly uses data for various application systems within the IS MCS – a pavement management system, bridge management system, system for assessing routes for transportation of oversized loads, traffic planning, traffic engineering and traffic accidents.
The Road Databank currently provides data at the various levels of processing and in various forms to the Ministry of Transport, the offices of self-governing regions, the Statistical Office of the Slovak Republic, the Armed Forces of the Slovak Republic, the Presidium of the Police Force of the Slovak Republic, the Office of Civil Protection, universities, project companies, research institutes and many others.
Data included in the Road Databank is base for the vector model of Slovak road network. The Department of Pavement Management System uses the Road Databank and road network model for supporting activities and processes not only for your own needs but also for other departments of the state administration, municipalities, cities, schools, research institutes, private sector, etc.

Figure 2 – IS MCS portal – digital model (twin) of a road with selected parameters

The software application “DU-SK” was developed to monitor long-term changes in variable parameters of pavement and to verify applied degradation functions. It is used as a tool supporting the research and development within the Pavement Management System. Twenty-five road sections with varied pavement structures, representing the most common pavements in Slovakia, were selected, and they have been monitored for a long time. The initial source of information is the initial capture (sometimes also called the zero measurement) of existing state of all monitored parameters. The outputs of this application are real degradation models of pavement damage for each of monitored section. The degradation functions for the individual monitored variable parameters are derived from the degradation models. The application allows the road manager to better plan the rehabilitation schedule and its method depending on the type of pavement, traffic intensity and other criteria.

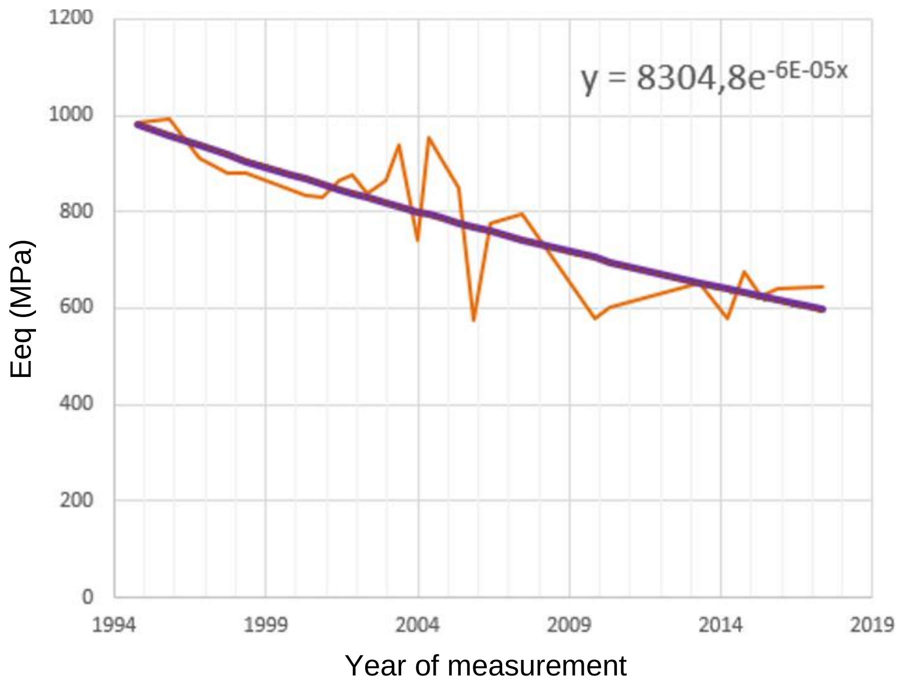

Figure 4 – Degradation model of pavement damage with a degradation function for the parameter: Equivalent modulus of elasticity of the pavement, Eeq

The software application "Pavement" developed within the Pavement Management System is used to monitor and evaluate the road network state based on pavement diagnostics measurements and main inspections of roads. The classification of pavement serviceability and the evaluation of pavement bearing capacity (including the calculation of required thickness of overlay) are together with traffic engineering and economic data processed to propose an indicative rehabilitation design and to create multi-year rehabilitation plans for the road administrator considering various maintenance or repair alternatives through cost-benefit analysis. The application also allows visualizing almost all parameters of the roadway and road traffic through diagrams in line projection.

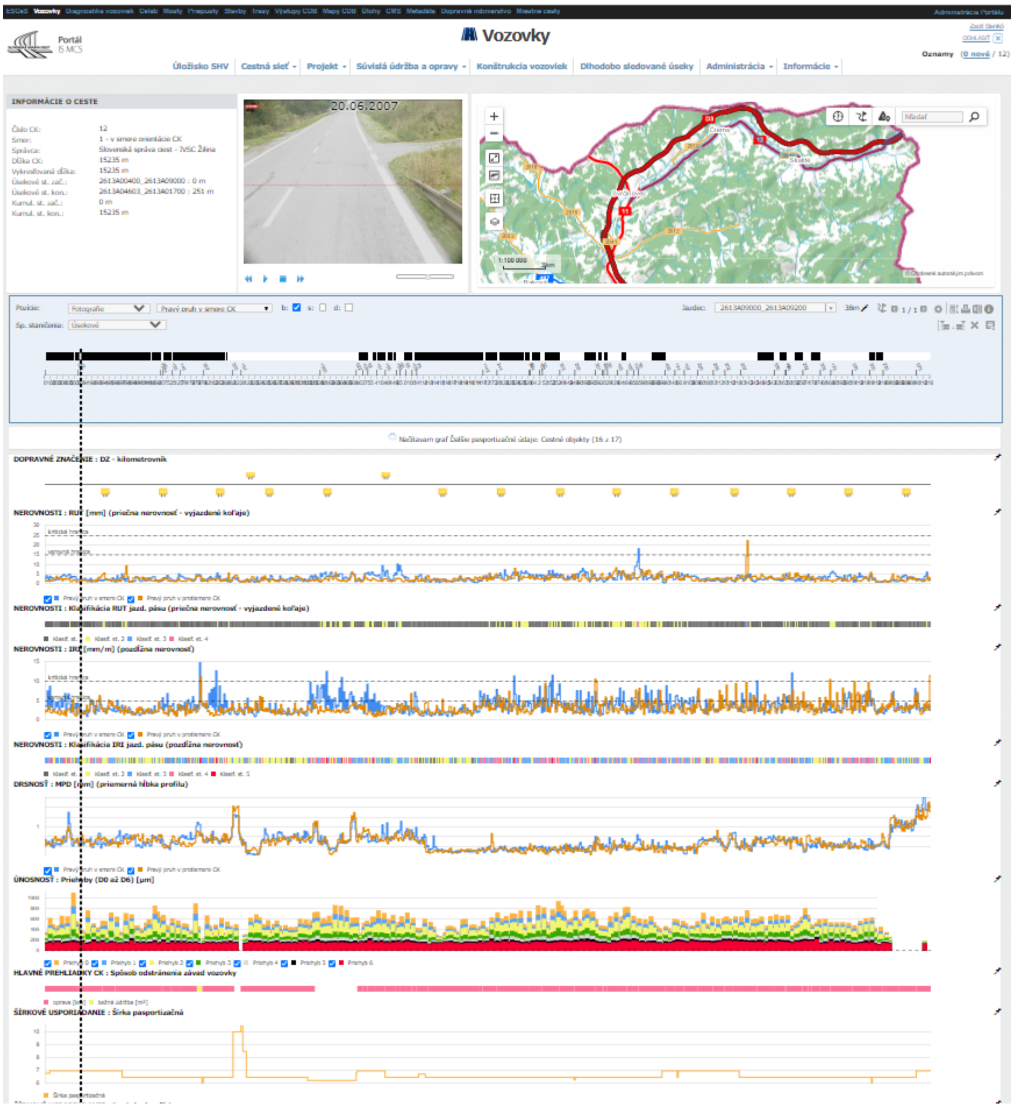

Figure 3 – Clear and complex information regarding the state of a road network section - an example from the "Pavement" application

Effective planning of the construction and maintenance of transport infrastructure requires the systematic acquisition and analysis of a large amount of data - not only about the technical condition, but also about traffic characteristics. The need for a wider introduction of ATC (Automatic Traffic Counters) is embedded in the conceptual and development documents of the transport sector. These are in line with general trends in the direction of transport and investment planning within the European transport area. Devices for automatic acquisition of traffic flow characteristics are an important source of data that can be used for the solution of various traffic-engineering tasks. The traffic flow characteristics can also be used for the verification of the justification of the implementation of planned investment plans against the background of the infrastructural development of road network. The ATC (Figure 5) provide data for most applications of intelligent traffic systems. They count the passing of vehicles through a lane and thus replace manual work of human counters. The ATC work without restrictions, in any mode, under any climatic conditions.

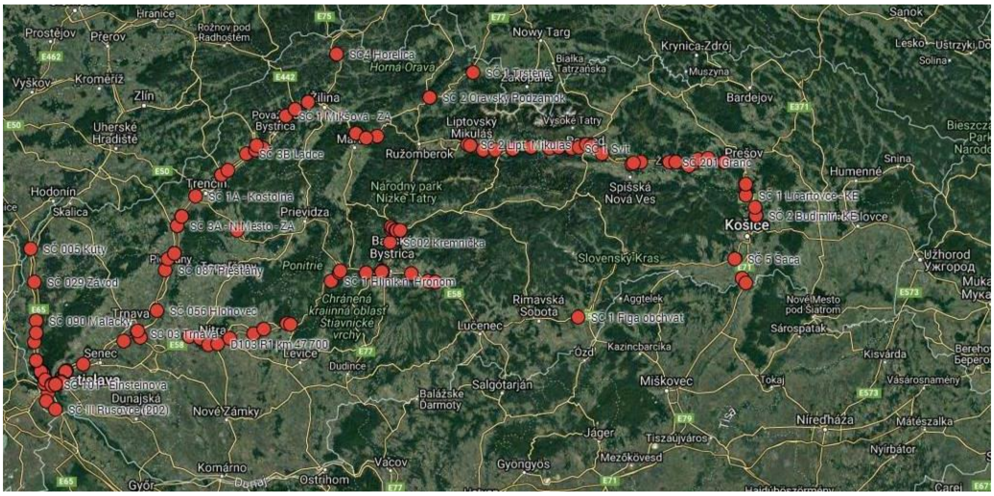

Figure 5 – Deployment of ATC on highways and expressways in Slovakia

The ATC are currently used at 144 locations on highways and expressways, and only at 15 locations on Class I roads. An assessment of feasibility to cover all 860 counting sections on Class I roads in Slovakia is currently being prepared.

A part of data acquisition on traffic characteristics on Slovak road network is also the detection of axle load level of heavy vehicles. Pre-selective Weight-in-Motion (WIM) systems built-in pavements are used within the global system for checking the total weight and axle load of heavy vehicles applied in Slovakia. They record the weight of vehicle while driving without speed restrictions. However, these systems are not a full-fledged weighing device. Therefore, in the case of detected overload, the vehicle is diverted by variable traffic signs to an area where the vehicle is officially weighed on highly accurate fixed dynamic weighing devices with the assistance of the police.

4. BIM APPLICATIONS

Building Information Modelling (BIM) represents a process based on a digital model that represents a physical and functional object with its characteristics. It serves as a database of information about the object during its entire life cycle (conceptual design, project, analysis, construction, service, reconstruction, and eventual demolition). The BIM is based on the cooperation of all professions, information sharing and coordination of individual activities. Based on this cooperation, a unified model with defined parameters of individual constructions in the object is created, which contributes to greater design efficiency. Then, this model is not only a simple 3D representation, but becomes a sophisticated virtual building expressed in 5D. The fourth dimension is added to the model by another quantity, which is a time aspect during construction. The fifth dimension is an expansion of the model by price parameter.

A special benefit of digitization in the BIM process is absolute transparency and permanent archiving of information about technical parameters (quality) of work and its parts. To ensure digitally planned continuous construction, it is necessary to take extensive preventive measures in the process of material engineering and technological preparation. Interactive procedures for entering the results of laboratory and field tests into the BIM system using a digital platform are tested and verified during the construction.
In Slovakia, there is still no systematized request from public or private investors for the introduction of BIM into a project and, subsequently, implementation and operational practice. The BIM system is mainly used in civil engineering, even if not to the full extent, from initial designs, through implementation, to building management. Construction companies operating on the Slovak market follow their own path in learning about and applying BIM, where they apply their experience from constructions from all over the world.

4.1. Digital 3D terrain models for BIM

A prerequisite for creating BIM is among others existence and availability of digital 3D terrain and relief models. Since 2017, the Office of Geodesy, Cartography and Cadastre of the Slovak Republic has been providing a new DMR 5.0 digital relief model and a digital surface model (DMP 1.0) of the entire territory of the Slovak Republic, created from aerial laser scanning data.

The entire territory of the Slovak Republic is divided into 42 locations. The scanning takes place gradually in individual locations from the west of Slovakia to the east. Currently available subscription sites for users are highlighted in green in the Figure 6. The projected completion date of the project is 2023.

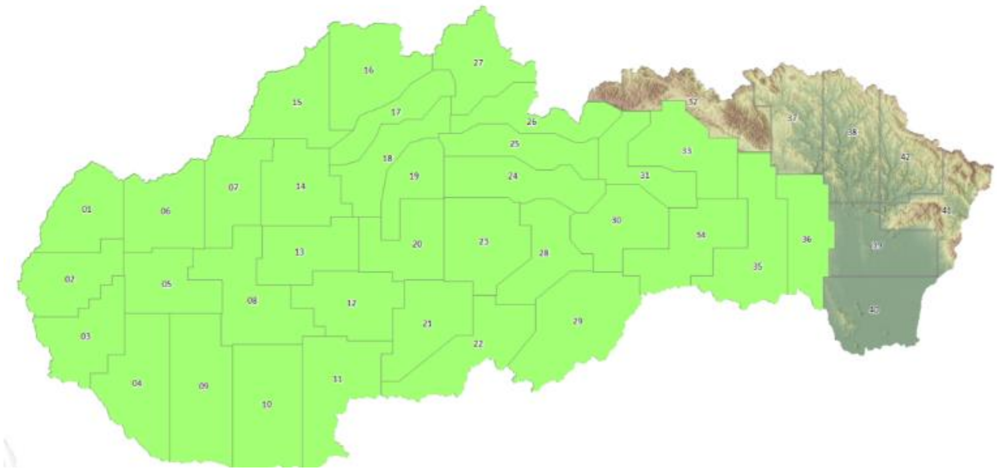

Figure 6 – Current coverage of the Digital surface & relief models (green)

Due to the large volume of data (several TB), the data provided offline by location is entirely brought by the customer, or external HDD sent. Smaller scale data (sections) can be downloaded via the Map Client software application.

4.2. BIM applications in construction

The most modern versions of drones are slowly reaching the construction sites in Slovakia, while these devices are not only used for mapping the terrain, but thanks to the use of improved software and other sensors, they are very suitable for e.g., when collecting data that can be used to calculate the volumes of earthworks. Compared to the usual method of calculation by geodetic methods, they provide significant time savings with the higher accuracy. So far, their deployment is exclusively in the hands of construction companies and on large construction projects.

As an example of successful BIM application in construction by a private company in practice, the ongoing construction project of the R2 Kriváň - Mýtna expressway (mostly made up of bridge structures), located in the middle of Slovakia, can be considered. The initial data acquisition was carried out using drones and UAVs with LIDAR in the form of a 3D point cloud. Subsequently, the map of construction area and actual shape of terrain was made in high detail. This was followed by internal modelling based on a 2D design, while the BIM models consisted of solids as well as surfaces (earthworks, excavations, SP items, etc.). The model also contains non-graphical information (attributes). Outputs from the BIM model are used for visualizations, control of construction machines, logistics planning, time planning, listing of works, quality control and construction progress.

Figure 7 – Data acquisition by drone on the construction of R2 Kriváň - Mýtna

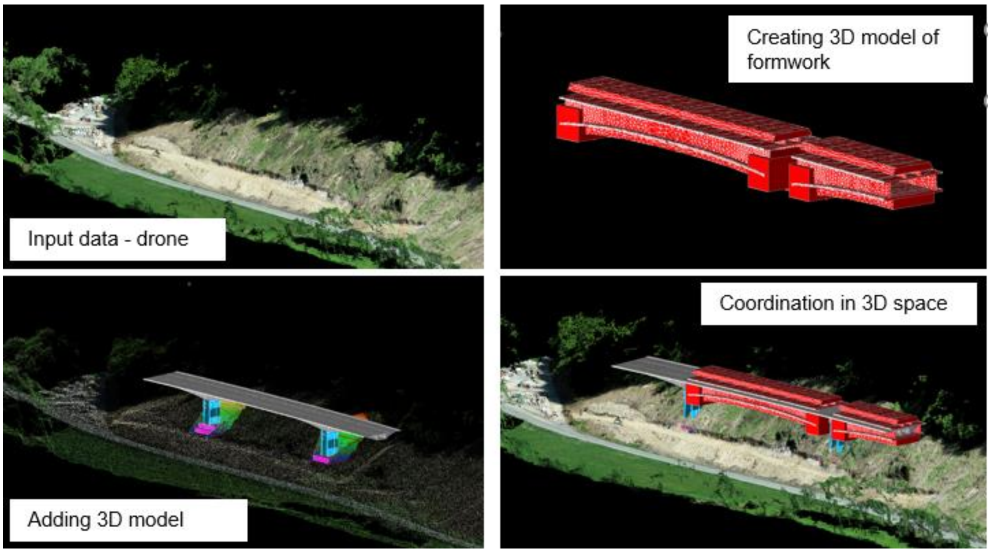

Figure 8 – Construction of R2 Kriváň - Mýtna - from data acquisition by drone to 3D model

4.3. BIM applications for digital asset management

A different perspective on the topic of digital asset management was implemented by municipality of the capital city Bratislava in 2022. The pilot project of three-dimensional model with all buildings, roads, trees, furniture, and other attributes was prepared. It is possible to assign data from databases to individual elements (e.g., information about individual parcels and buildings) directly from the cadastral portal. The digitized copy of reality consists of more than 12,000 buildings. The map also shows greenery located on municipal land. The three-dimensional model will be used by office in various ways in the development of the city district.

Figure 9 – Digital twin of municipality Nové Mesto in capital city Bratislava

5. BIG DATA & SMART DATA SOLUTIONS

5.1. Transport big data collection – NSDI

The approval of project financing is by default conditional on the processing of feasibility studies or comparison of costs and benefits, whose methodologies require a detailed analysis and reliable forecast of traffic load development. Until now, however, this data is mostly requested from road managers and carriers individually, ad-hoc for individual projects, which is both bureaucratic and time-consuming, and moreover, obtaining historical data is usually limited, even impossible.

To concentrate all available traffic data in Slovakia, the so-called NSDI (National Traffic Information System) project was created. The basic task of the NSDI is to fulfil the function of the central national access point in terms of Directive 2010/40/EU of the European Parliament and of the Council of July 7, 2010, on the framework for the introduction of intelligent transport systems in the field of road transport and for interfaces with other modes of transport and subsequent delegated regulations.

NSDI was officially launched in 2015 and has so far collected various transport-related data, primarily in the field of road transport: both static/long-term (e.g., on infrastructure) and dynamic/up to date. A part of the project is therefore from 2017 also the "odoprave.info" web portal, which provides comprehensive information on the current traffic situation in the Slovak Republic, as well as services related to transport, in one place. Based on the reference model of the SSC road network, ordinary users and the professional public are informed from official sources about road traffic restrictions, traffic accidents and driving conditions on their travel routes.

Traffic incidents could also be reported by public providers (drivers) through the portal and mobile application. However, it must be stated that the operation of the call centre was too costly, and the number of public providers was not very high. Therefore, the quality of this dynamic information was far from the level of similar commercial applications. Due to this, the functionality was stopped in June 2022. In the future it will be limited only to providing information from "state" sources (e.g., about planned exclusion of traffic), possibly also in the form of an API for commercial applications.

However, due to the incorrectly set concept of the NSDI project (proprietary solution including several unnecessary functionalities) and disadvantageous contractual requirements, it was not possible to further modify and expand the system in accordance with the identified needs. In 2022, the cooperation with the external provider NSDI was therefore terminated and the system was taken over by the Ministry of Transport of the Slovak Republic.

Currently, the so-called the NSDI 2 project, which will transform NSDI into an open modular system, is being prepared. Data storage will remain the core of the system, but it will be expanded with other database resources, primarily from the field of multimodal transport infrastructure and public passenger transport (if possible, including also transport data). In the future, it will be possible to supplement the system with other modules, such as a module for the electronic collection of statistical data, a registration and licensing system for carriers or a clearing module for the introduction of so-called “uniform” ticket (integrated across all carriers at the national level).

Information requested by third parties (including information in terms of the above-mentioned delegated regulations) will be converted into appropriate exchange formats (DATEX II, etc.) and provided via query and report, application (API) or OLAP tools in the public part of the system. The raw data will be accessible to the analytical department of the Ministry of Transport in the non-public part. The intention is to gradually collect and build a detailed database, including panel data for improving the quality of analytical activities and subsequent decision-making processes in the field of planning and development of transport infrastructure and service of the territory.

5.2. Smart data applications

Since 2021, the National Highway Company has launched the most modern linear traffic management in Slovakia on the Bratislava highways D1 and D2. A system of so-called “smart road” was introduced. It should increase the capacity of congested sections by ten to twenty percent compared to the state without active management. At the same time, the occurrence of traffic jams and their extent should decrease, the flow of traffic should improve. In the case of traffic incident, the safety of road traffic should be also increased by early warning of drivers.

Input data for the control system is collected by 178 sensors located on the highways. These are mainly vehicle detectors, road, and weather condition sensors (temperature, rain intensity, visibility). The system verifies and evaluates the collected data, then models traffic processes and creates short-term predictions of further development. Based on this, if necessary, variable traffic signs are activated to control the traffic flow and provide important information to drivers. The management of variable traffic signs takes place automatically, their settings is re-evaluated every 60 seconds (earlier in the case of more serious incident). In ideal conditions, the signs are inactive, but when they worsen or traffic incidents occur, the relevant symbols (restrictions, prohibitions, or warnings) will light up on the signs.

Figure 10 – Linear traffic management in Bratislava

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