Dynamic traffic management on motorways during reconstruction works

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ABSTRACT
The presented paper describes the latest results of a research project focused on the development and application of intelligent system for dynamic traffic management on highway in work zones. The presented system is a result of a research project funded by the Technology Agency of the Czech Republic and will be deployed in a pilot verification during the started reconstruction of D1 highway in the Czech Republic in the upcoming months. The system should help to increase the throughput of the reconstructed highway work zones and reduce the negative effects of the reconstruction work itself.

KEYWORDS: dynamic traffic management, motorway, reconstruction

1. Introduction
Modernization of the motorway network in the Czech Republic, which will be due to the lack of alternate routes conducted in full operation, requires maximum traffic flow in areas of highway closures. According to the conceptual project developed for the Czech Highways Authority, drivers are informed about the traffic situation before travel, during driving (by permanent electronic portals) and also at the traffic closures [1]. The aim of our project is not informing drivers only, but the effective dynamic control of traffic flow, that will increase the capacity of the profile.

Abroad these have been the experience with a similar solution – traffic lights that stop vehicles in each lane [2], variable signs informs the driver where should (must) merge in the continuous lane [3, 4] or about speed limit [5]. In the Czech Republic similar system has not been used yet, the dynamic control of traffic flow is used only for permanent application on the Prague motorway ring road [6]. Using in the closures requires a mobile system that can be moved in accordance with the procedure works and that has an independent power supply and wireless communication between their own modules and with external services as the National Transport Information Centre. During the project ViaZONE, which is supported by Technology Agency of the Czech Republic, we have developed a system that meets the above requirements, but also conservative requirements of Czech technical conditions and Roads and Highways Authority [7].

System is developed by composing of several cooperating components, which can use alternative energy sources. The system is controlled remotely by the control software that uses algorithms working with real-data on speed, intensity and occupancy for changing display of variable-message sign near the traffic closures. Data in real-time is generated by various traffic detectors that are installed on several pre-selected sections of the interested area. The control algorithms were tested in microscopic model (software Aimsun), which was calibrated and validated by real traffic data from Czech Republic, which were measured during the closure of the motorway D1. At the same motorway, in part with diverting two lines into one line, will be in the second half of 2013 a pilot operation of this system.

1.1 Mobility and portability of the system
The system was created to specifically meet the needs of fast and simple transport and installation in the location concerned
(taking into account the size and complexity of the installation) with a minimal risk for all workers. It is therefore possible to install the system even in places of major traffic accidents or unexpected phenomena that significantly influence the capacity of the road. The calibration, installation and setting of the entire system is quite simple.

1.2 The individual subsystems and physical devices in the infrastructure are cooperative

Physical devices in the infrastructure are connected together to a private wireless VPN network. All the functional blocks of the system interchange data and information, leading to the final target – the master station. The master station (or MASTER) allows the control and management of even remote devices, as well as retrieving the actual data from them.

1.3 System functionality

The system allows the usage of independent and various management functions depending on the needs of a particular location and needs of the investor and the user. Especially we are talking about management functions of warning about traffic jams, adaptable speed reduction, navigating to alternative routes, or dynamic control of a zipper.

1.4 System modularity

The individual portable stations in infrastructure are designed so that they contain the necessary evaluation unit in a box with an IP 55 cover. The particular evaluation units differ from each other depending on their usage (MASTER x SLAVE). Modularity (see Fig. 1) is possible thanks to a modular method, where based on the particular situation, the following detection or display (LED) devices can be connected to the evaluation unit:

- Wavetronix radar detector
- Radar measuring speed – for traffic jam length
- Detector for measuring arrival time – Bluetooth
- Weather station
- IP camera
- GPRS modem
- Xbee modem
- Portable variable traffic signage
- LED trailer

The individual stations can operate independently or in a network environment, again based on a particular usage. The system is thus ready to function in various layouts.

1.5 Being independent of electrical power supply

The stations are equipped with accumulators with rechargers. Power for the accumulators can be supplied by fuel cells based on methanol, photo-voltaic cells, or they can be powered from the standard 230V supply.

It is important to realize the complexity of developing such a system, which forms a portable replacement of stationary ITS, but in conditions, where the location lacks electrical power, or where for example the space available for installation is very limited. Another important factor is the necessity of very fast installation, so that people who place the system in the locations are not exposed to any potential risks for too long. All these requirements place high demands on reliability and safety of the entire system. For this reason, normative for quality was set for the individual system components, which will be validated in a pilot traffic.

Quality normative defines the needs of quality of individual components, products and devices that form the developed management system. The set requirements can be used in the future as normative requirements for similar systems. The system will therefore be tested with strict requirements, so that the investors and users of the system can be assured that the portable and mobile management systems are safe and reliable. Individual quality norms have been established with regard to the future setting of technical specification which will be used in practice and in particular respect and based on the long experience of the operation of intelligent transport system, which aim to manage traffic flows. Qualitative (system) parameters are designed to suit particular subsystems, as well as the entire complex system:

- Continuity = 99%
- Integrity = 5 s
- Accessibility = 99.5%
- Accuracy (detection of intensity, speed and classification) = from 85% to 95%

Fig. 1. Scheme of the modular portable management system [own work]

2. Data collection subsystem

For the correct functioning of the system it was necessary to integrate detectors, which do not require time for calibration, but at the same time do not decrease the accuracy of the generated data. In this system, the accuracy is defined as the degree of
similarity between the measured and the defined value of the parameter/process/function:

\[ P[|p_i - p_{m,i}| \leq \epsilon_i] \geq \gamma_1 \] \hspace{1cm} (1)

Equation (1) states that the difference between the desired parameter and the measured parameter \( p_{m,i} \) does not exceed the value of \( \epsilon_1 \) at the confidence level of \( \gamma_1 \), where the relationship holds true even for the parameter vectors.

The requirement is given based on the particular used traffic detector and generated data. The system uses 3 different types of traffic detectors:

- Wavetronix HD125 detector is used to determine intensity, average speed and classification: For this detector there is a requirement that the accuracy of the number of vehicles (intensity) must not fall below 95 % at a 95% confidence level, for the speed it must not exceed 5 km/h at a 95% confidence level and for classification there is a requirement for accurate data in 85 % of intervals at a 95% confidence level.

- Radar detector to detect the length of the traffic jam in order to detect the average speed of traffic flow – there is a requirement for the measured speeds to be accurate within +/-3 km/h at a 95% confidence level.

- Bluetooth detector to measure the delay compared to the normal free traffic flow. For this detector there is a requirement that at least 95 % of all the vehicles equipped with active Bluetooth device on board are detected. During testing, economic and system advantages will be compared against data from floating vehicles.

3. Data transmission subsystem

The system uses redundant way of transferring data between the individual functional blocks – Slave and Master station and then between MASTER station and the central Server. For this purpose, Xbee 868 MHz and GPRS technologies are being used. In case of lost communication with Xbee, where stations use the DigiMash technology, the system automatically switches to GPRS communication via Virtual private network. This dual way of transfer significantly optimizes the level of accessibility of the service.

The observed parameter of quality is called Transfer accessibility which is given based on the particular used traffic detector and generated data. The system uses 3 different types of traffic detectors:

- Bluetooth detector to measure the delay compared to the normal free traffic flow. For this detector there is a requirement that at least 95% of all the vehicles equipped with active Bluetooth device on board are detected. During testing, economic and system advantages will be compared against data from floating vehicles.

4. Data evaluating subsystem

Data evaluating subsystem depends on continual evaluation of the measured data at regular intervals. The hardware part of the system consists of evaluation and computational devices. They can be divided based on their function, and especially based on their computational and disk capacity. We are talking about the MASTER and SLAVE. In general, there is a network, where one can remotely communicate (for example from an office) with the MASTER station, which then further mediates communication with the SLAVE stations. Each SLAVE station has its own unique IP address and can therefore be easily identified and it is possible to assign a specific function or task to a specific SLAVE station. This can be done in the management software.

SLAVE stations with their attached traffic detectors send defined data in user-defined intervals to the MASTER station, where they are compared and system functions are initiated based on predefined algorithms. The subsystem has a defined requirement for the continuity of the system, which is the ability of the system to fulfill the desired processes without (unplanned) disruption (maximal length of disruption must be defined in advance) during a defined time interval. The continuity of the system is defined by equation 3.

\[ P[|r_i - r_{m,i}| \leq \epsilon_i] \geq \gamma_4 \] \hspace{1cm} (3)

The equation (3) shows that the difference between the desired ratio of successfully performing the function/process without a disruption \( r_i \) and the measured value \( r_{m,i} \) of this ratio does not exceed the value of \( \epsilon_4 \) at a level of confidence of \( \gamma_4 \).

The parameter is given in units of time. It is defined that at a 99% confidence level, it is possible to have at most a 5 s failure of the service in a 1 minute interval. The testing will consist of 100 measurements and failure of service for longer than 5 seconds can only occur once.

This requirement is defined in the same way for each block separately and also for the remote management system in the central server.

5. Actors – display subsystem

This subsystem forms the feedback of the controlling module for displaying messages and symbols. Actors are responsible for controlling traffic and two types of variable traffic signage are distinguished in the system

- LED trailer
- Portable variable traffic signage LED

Both devices have integrated evaluation SLAVE or MASTER device, so it is also possible to integrate a detection device to both of them, allowing the construction of complex telematic stations from these display units, including the detection of traffic flow and temporary monitoring by cameras.
5.1 Portable VMS LED

Portable variable traffic signage (VMS) serves to give warnings, bans or information to drivers on highways or roads. They consist of a LED panel and a supportive framework, which is firmly attached to the guardrail or placed on a stand. The VMS has a discontinuous inverse display. The design of the supportive framework and the entire portable VMS is adapted for frequent transport and the consequent shocks of the entire device. All the screw joints are secured against release and all movable parts are secured against spontaneous movement during transport.

The LED panel conforms to all associated Czech regulations and norms. The active area of the VMS panel is matte black. The display consists of dual-color full LED matrices with a size of 48x48. Top corners consist of white and yellow LEDs, the rest of the matrix are white and red LEDs.

5.2 LED trailer

Part of the system is also integrated LED trailers. The box installed on the trailer contains accumulators, rechargers and microcomputers, with cables allowing the attachment of external detection devices. There is also a power supply based on methanol fuel cells, which ensures energy supply to the system. There are places where it is possible to connect to the mains, so the trailer can as well be powered by 230 V.

The upper and bottom panel are both equipped with intensive LEDs and optical system that prevents their blinding or staining, lenses are covered with anti-static and self-cleaning surface. The panels are approved based on EN 12966-1. The upper panel consists of red and white LEDs 64x64 in a 20 mm grid, maximum symbol size being 1280x1280 mm, the bottom panel has red and white LEDs 64x80 in a 20 mm grid, maximum symbol size being 1280x1600 mm. Symbols displayed on both panels are programmed by the user. The control of LED intensity can either be regulated automatically based on the surrounding lighting conditions, or manually. The capacity of the system is 1 500 symbols on both upper and bottom panels. To emphasize the displayed symbols it is possible to have those blinking 15 to 60 times per minute, or display a simple animation.

6. Conclusion

The described system will be tested for the first time during a longterm closure of the busiest highway D1 for about 3 months from August to October 2013. During this time, the reliability, safety, accuracy, efficiency, and of course the effects such a system has on the behavior of the drivers, will all be analyzed. The project results and conclusions will be summarized in a methodological instruction, which will define the minimal requirements for the components, the complex system as a whole, but also for the actions associated with its installment and maintenance.

The system developed is unique in its robustness and modularity, which allows its utilization for other traffic projects as well. The experience gained from the evaluation of the project and the development of the mobile system will allow us to further continue in this field and to a certain extent we will also help to increase safety and smoothness of traffic in critical places during road works.

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Bibliography