Archives of
Transport System
Telematics

Volume 11

Issue 3

September 2018

Possible Directions for Development of C-ITS Services in Cities on the Example of the TRISTAR System

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ABSTRACT

During the previous EU financial perspective (2007 - 2013), we observed an intensification of the development of transport management systems using ITS services in Polish cities. One of the biggest territorially and functionally system is Tri-city TRISTAR system, the implementation of which was completed in 2015. The concept of the TRISTAR system and its architecture was developed in the years 2002-2007. Currently, we can observe the intensification of the development of C-ITS services, allowing for the exchange of information between the vehicle and the infrastructure or other vehicles. The existing transport management systems were not prepared, e.g. to communicate with vehicles, and use of Floating Car Data. For this reason, it is necessary to verify the architecture of the systems and indicate the directions of development, allowing them to adapt to the current state of technology and new ITS services. The article presents directions for the development of the TRISTAR system in functional, physical and logical terms. Directions of activities will be indicated to allow the system to be adapted to provide C-ITS services.

KEYWORDS: Intelligent Transport Systems, C-ITS services, transport

1. Introduction

For the Tri-City area (Gdańsk - Gdynia - Sopot), the possibility of creating a traffic control system [16] began to be considered in the mid-1980s. At the beginning of the 2000s, conceptual work was begun on the development of the Tri-City Agglomeration Intelligent Transport System - TRISTAR [9]. In 2006, an agreement was signed between the cities and a procedure was started to build a system which, from the moment of work on the concept through documentation and the execution stage, was completed at the end of 2015. At the time when the decision was made to build the TRISTAR system, there were already many advanced ITS systems around the world, which gave the opportunity to implement a modern solution based on the experience of other cities. The development of technologies in some areas has significantly accelerated and from 2006 to 2015 some of the technologies used in TRISTAR should be introduced or improved. The TRISTAR system has been designed in such a way that it is possible to extend it not only with subsequent elements of existing subsystems, but also with adding new ones. The system structure also enables to include C-ITS (Cooperative Intelligent Transportation Systems) services. The aim of the article is to present the state of works on C-ITS services in the world and the possibilities of their implementation into the TRISTAR system. As a result, the potential of existing ITS systems to be expanded with new services will be indicated, which in the future will probably transform into autonomous vehicle systems.

2. Application of C-ITS in traffic management systems

In accordance to the European strategy on Cooperative Intelligent Transport Systems [2] two C-ITS service packages have been defined divided due to the possibility of their implementation.

"Day 1 C-ITS services this is a list of technologically-mature and highly-beneficial services. When deployed in an interoperable way across Europe will produce a benefit cost ratio of up to 3 to 1 based on cumulative costs and benefits from 2018 to 2030. Day 1.5 C-ITS services is a list of services for which full specifications or standards might not be completely ready for large scale deployment from 2019, even though they are considered to be generally mature. Tables 1-3 are presented below with Day 1 and 1.5 services.

Table 1. Day 1 C-IST services - hazardous location notifications [2]

Type	Service name	Description
Day 1 services - hazardous location notifications	Emergency electronic brake light	It is a service aimed at preventing rear end collisions by informing drivers of hard braking by vehicles ahead. Using this information, drivers will be better prepared for slow traffic ahead and will be able to adjust their speed accordingly.
	Emergency vehicle approaching	This service aims to give an early warning of approaching emergency vehicles, prior to the siren or light bar being audible or visible. This should allow vehicles extra time to clear the road for emergency vehicles and help to reduce the number of unsafe manoeuvres.
	Slow or stationary vehicle(s) & traffic ahead warning	This service is intended to deliver safety benefits by warning approaching drivers about slow or stationary/broken down vehicle(s) ahead, which may be acting as obstacles in the road. The warning helps to prevent dangerous manoeuvres as drivers will have more time to prepare for the hazard. This service can also be referred to as car breakdown warning.
	Traffic jam ahead warning	Provides an alert to the driver on approaching the tail end of a traffic jam at speed - for example if it is hidden behind a hilltop or curve. This allows the driver time to react safety to traffic jams before they might otherwise have noticed them themselves. The primary objective is to avoid rear end collisions that are caused by traffic jams on highways.
	Hazardous location notification	This service gives drivers an advance warning of upcoming hazardous locations in the road. Examples of these hazards include a sharp bend in the road, steep hill, pothole, obstacle, or slippery road service. Using this information, drivers will be better prepared for upcoming hazards and will be able to adjust their speed accordingly.
	Road works warning	Enable road operators to communicate information about road works and restrictions to drivers. This allows drivers to be better prepared for upcoming roadworks and potential obstacles in the road, therefore reducing the probability of collisions.
	Weather conditions	The objective of this service is to increase safety through providing accurate and up-to-date local weather information. Drivers are informed about dangerous weather conditions ahead, especially where the danger is difficult to perceive visually, such as black ice or strong gusts of wind.

Table 2. Day 1 C-IST services - signage applications [2]

Day 1 services - Signage applications	In-vehicle signage	This service is a vehicle-to-infrastructure (V2I) service that informs drivers of relevant road signs in the vehicle's vicinity, alerting drivers to signs that they may have missed, or may not be able to see. The main purpose of this service is to provide information, give advance warning of upcoming hazards and increase driver awareness.
	In-vehicle speed limits	Are intended to prevent speeding and bring safety benefits by informing drivers of speed limits. Speed limit information may be displayed to the driver continuously, or targeted warnings may be displayed in the vicinity of road signs, or if the driver exceeds or drives slower than the speed limit.
	Probe vehicle data	The purpose is to collect and collate vehicle data, which can then be used for a variety of applications. For example, road operators may use the data to improve traffic management.
	Shockwave damping	Aims to smooth the flow of traffic, by damping traffic shock waves.
	Green Light Optimal Speed Advisory (GLOSA) / Time To Green (TTG)	GLOSA provides speed advice to drivers approaching traffic lights, reducing the likelihood that they will have to stop at a red light, and reducing the number of sudden acceleration or braking incidents. This is intended to provide traffic efficiency, vehicle operation (fuel saving) and environmental benefits by reducing unnecessary acceleration.
	Signal violation/ Intersection safety	The primary objective of this service is to reduce the number and severity of collisions at signalised intersections.
	Traffic signal priority request by designated vehicles	The traffic signal priority request by designated vehicles allows drivers of priority vehicles (for example emergency vehicles, public transport, HGVs) to be given priority at signalised junctions.

The list of C-ITS services is not final, and only as mentioned above contains items that are currently available for implementation in a short time. Several proposed services closely related to urban areas and access management with use of V2I (vehicle to infrastructure) communication have already been identified:

- special lanes reserved for designated vehicles (i.e. public transport, electric vehicles),
- restricted zones (low-emission, congestion control), temporary zones (following major incidents i.e. terrorist attack, traffic accident)
- tunnels and bridges for designated vehicles.

Other examples of additional urban C-ITS services are:

- management of loading and unloading areas for freight vehicles with V2I
- Public Transport Vehicle Approaching – paused public transport vehicles/off-loading passengers with V2V
- Public Transport Vehicle Approaching – parking and intersections with V2V
- access and speed management (i.e. near schools or selected priority zones etc.) - subset of in-vehicle signage with V2I
- temporary traffic light prioritisation for designated vehicles (cultural, sport events etc.)
- subset of traffic light prioritisation for designated vehicles with V2I

- collaborative perception of Vulnerable Road Users (VRUs) - subset of VRU road user protection with V2V
- collaborative Traffic Management – subset of connected, cooperative navigation into and out of the city with V2I

Table 3. Day1.5 C-IST services [2]

Day 1.5 services	Off street parking information	The provision of on-street parking information is intended to bring efficiency benefits to drivers and help to reduce emissions in urban areas by reducing the time spent 'cruising' at low speeds.
	On street parking information and	The provision of on-street parking information is intended to bring efficiency benefits to drivers and help to reduce emissions in urban areas by reducing the time spent 'cruising' at low speeds.
	Park & Ride information	The provision of Park&Ride information is intended to reduce congestion in urban areas and also shift travel from cars to public transport.
	Information on AFV fuelling & charging stations	The objective of this service is to broadcast electric vehicle charging point availability and AFV fuelling point information to relevant vehicles.
	Traffic information and smart routing	The provision of traffic information and smart routing services to vehicles is intended to improve traffic efficiency and aid traffic flow management.
	Zone access control for urban areas	This service is intended to manage access to specified zones. Using this information, drivers will be better informed and will be able to select the most appropriate route for their journey.
	Loading zone	This service is intended to support the driver, fleet manager and road operator in the booking, monitoring and management of urban parking zones specific to freight vehicles.
	Vulnerable road user protection	This is a safety focussed service, which is intended to protect vulnerable road users. In this case vulnerable road users are considered to be pedestrians and cyclists only.
	Cooperative collision risk warning	This service is intended to minimise the risk of collisions between vehicles, for example when overtaking, or when merging with traffic.
	Motorcycle approaching indication	This service is intended to increase safety and prevent collisions between motorcycles and other vehicles.
	Wrong way driving	V2I safety focussed application intended to prevent accidents caused by wrong way driving. Incidents of wrong way driving can lead to serious accidents on high speed roads as approaching drivers perform swerving manoeuvres to avoid the oncoming vehicle. Advance warning of wrong way driving has two main functions: firstly, to alert the driver that they are driving in the wrong direction, and secondly, to warn surrounding vehicles of the danger.

There are also a number of barriers for the implementation of C-ITS services. They are associated, among others, with [17]:

- compatibility with existing legislation (data privacy and security),
- standardisation and interoperability (has already been initiated by CEN, ETSI and ISO),
- cooperation between stakeholders (parallel developments in different existing systems),
- technology risks (consumer acceptance due to technical issues like perceived safety issues, quality, robustness)
- financial barriers (stakeholders have other funding priorities and budget constraints)

Very important is to clearly demonstrate differences between C-ITS and standard ITS systems and what it can offer on top of existing ITS systems and services. Many of existing system have similar to C-ITS services but have technical differences between the different methods in terms of how the information and advice is communicated to travellers and between different actors [1]. The presented C-ITS services will be a very important step towards development of connected and automated mobility and also mobility as a service (MAAS).

The exchange of information between connected vehicles should allow to reduce the negative impact on the environment even more than the ITS systems described in [6] due to the greater availability of information. It is also possible to increase the level of safety thanks to the possibility of informing the managers, among others, about the dangers detected by the vehicle driving in front of us (e.g. information about sudden braking). Currently, numerous projects are being carried out, including pilot projects both in Europe and in the world aimed at, among others, assessing the benefits of implementing such solutions. An example is the project implemented by the "Queensland Department of Transport and Main Roads". Analyses show that the implementation of C-ITS can contribute to a 20% reduction in accidents and a 3% reduction in fuel consumption in the case of 100% Connected Vehicles (CV) for new vehicles [5].

C-ITS services under the name ITS-Spot service were implemented in Japan in 2011 [15]. The base of this system was over 1600 DSRC antennas used for communication with vehicles. As part of C-ITS, information on traffic conditions (travel times, traffic disturbances), information on traffic safety (e.g. surface condition, unfavourable weather conditions) was provided. At the same time, more than 700 navigation devices compatible with C-ITS were distributed to various road users. They were asked about the quality of C-ITS services after 5 to 19 months. Most of the services met with a high efficiency rating of over 50%. For the least useful was "Still image information of traffic condition" at the level of 42% satisfaction. The highest rated service was "Emergency information" with a level of 100% efficiency.

Several dozen projects related to C-ITS are currently being completed or are currently being implemented in Europe. One of the most interesting projects was NordicWay implemented in the Scandinavian countries in 2015-2017. The goal of the project was to prepare for a decision regarding the comprehensive implementation of C-ITS in partner countries. As part of this project, communication using a mobile phone network for C-ITS services (so-called ITS-G5) was implemented for the first time. Also in Europe, a number of pilot projects such as FREILOT implemented in 2009-2012 were carried out, the aim of which was to reduce by 25% of the fuel consumption of heavy goods vehicles in the urban area by transmitting information from traffic lights to the vehicle [4]. In the international Compass4D project implemented in 2013-2015, C-ITS services were implemented to improve safety and reduce fuel consumption. More than 600 vehicles and over 1,200 drivers from seven European cities took part in the project [17]. Another project is the C-The Difference pilot implemented in, among others, Bordeaux, which developed a smartphone application that provides the GLOSA service and information on traffic incidents [3]. In urban areas, therefore, C-ITS services are implemented, among others. related to the providing of information about incidents on the road, and information allowing to reduce emissions, e.g. by providing information on the recommended speed to the next intersection with traffic signals. Currently, most of the traffic management systems in Poland have the basic infrastructure for the development of C-ITS solutions, also the TRISTAR system is ready to provide C-ITS services, e.g. GLOSA through a mobile application on a smartphone. We should also expect the development of these services in Poland in the coming years and thus should improve the safety and efficiency of road traffic.

3. Assessment of ITS services in the TRISTAR system

The TRISTAR system has been developed based on the original architecture modelled on American architecture and European architecture FRAME. The Fig. 1 presents the TRISTAR system architecture. The bodies responsible for co-financing projects from EU funds recommend the use of the European ITS Framework Architecture (FRAME) to identify the real needs of cities in the field of Intelligent Transport Systems implementation. In connection with ongoing work on Program Support Action (PSA) for the European Framework Architecture for Intelligent Transport Services called FRAME NEXT, it is worth considering verifying the current TRISTAR architecture for consistency with the FRAME architecture, also indicating the location for C-ITS services. The systematics of ITS services as part of research activities [12] can be useful. As a result, it will be possible to identify priorities in terms of functionality that are actually desired by residents and decision makers. In addition, it will be beneficial to increase the possibilities of integration with other systems, which will also be developed.

Traffic Control System (TCS) is a basic element of the entire system due to cooperation with the majority of other systems. The implemented TCS in the current area of the Tri-City indicates the necessity of successive inclusion of intersections in the vicinity of already added in order to improve traffic management processes and increase the impact of the TCS. The applied EPICS and BALANCE algorithms give the possibility of fluent reaction to the existing traffic situation. A very big advantage is the possibility of remote uploading of signalling programs, which enables quick response in the event of an unusual traffic situation and the current uploading of corrections and modifications. A typical modification of the signalling program takes an experienced engineer a few to several minutes. The scope associated with the priorities for public transport vehicles operates at junctions depending on the assumptions adopted by the designer of a specific signalling program. The basic assumption is that the public transport vehicle is delayed by the assumed time value in the range of 4 levels, one of which is reserved for privileged vehicles. On this basis, the EPICS algorithm decides whether in a particular case of a public transport vehicle the green signal should be extended or the time of arrival of the vehicle to the stop line is sufficiently distant that it is possible to handle movement of other vehicles in the meantime.

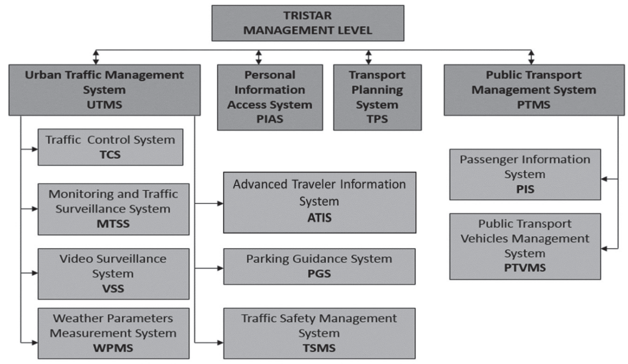

Fig. 1. TRISTAR system Architecture [10]

The data from traffic monitoring devices used by the Monitoring and Traffic Surveillance System (MTSS) are necessary for operational and planning purposes. Current data from detection in the form of the most common induction loops are used in TCS, while data from Automated Number-Plate Recognition Cameras (ANPR) and Bluetooth / WiFi scanners are necessary for the operation of the Advanced Traveller Information System and incident detection. Thanks to the openness of the system, it is possible to link data from ANPR cameras and BlueTooth / WiFi scanners to the TCS. As a result, it was possible to develop decision-making tools that would implement appropriate control strategies depending on the data collected. The usefulness of the data was already indicated in publications on traffic modelling and incident detection at junctions [11, 13].

In the case of Video Surveillance System (VSS), the analogue camera technology used is now obsolete and records unsatisfactory image quality in relation to the disk space occupied. Currently existing technologies allow the use of other types of cameras. They can be rotary cameras, with a 360-degree lens or a combination of a rotating camera with several faces constantly pointing in different directions within one device housing.

The Weather Parameters Measurement System (WPMS) works well within the scope of the assumed functions. There are possibilities to expand and modify the system allowing for the provision of C-ITS services.

Parking Guidance System (PGS) in terms of its basic functionality, that is, informing about the number of free parking spaces fulfils its tasks. In case of using information about parking places from parking lots of external operators, there is no possibility of interference with their indications, which determines the reliance on their correctness. There are possibilities of extension and some kind of system modification that allow for the provision of C-ITS services.

Advanced Traveller Information System (ATIS) enables to freely define sections and routes to measure travel times within the range of installed devices. In terms of incident detection, the

Bluetooth / Wi-Fi scanners used for this purpose are arranged at a certain distance, which in specific cases is the reason for detecting the changes in traffic parameters slightly later. The system was described in [14]. The system is open and provides the possibility of expansion and modification. This is evidenced by the connecting Variable Message Board and mobile Variable Message Signs of other manufacturers. Operators have tools to create new messages based on the development of the road network covered by the calculation of flow times along sections of the network.

The Traffic Safety Management System (TSMS) has not been fully activated due to changed legal regulations. Appropriate statistics of offenses are currently being developed. The infrastructure dedicated to this system (ANPR cameras) is used to estimate travel times that are used by ATIS. Another function performed by the ANPR cameras is the so-called "Black list" used by authorized search services. The opposite to this solution is the so-called "White list", enabling to detect unauthorized vehicles appearing in a given place. The solution can be successfully used in the case of limiting access to dedicated bus lanes, restricted access zones or to count vehicles entering the paid parking zone.

The basic function of the Public Transport Management System is to inform passengers about the actual situation in the public transport network. For this purpose, three ways of providing information are used: Internet portal, Passenger Information Terminals (TRIP) and Passenger Information Boards (TIPA) at bus stops. The location of the vehicle is carried out using GPS satellite navigation, which is transmitted to the Transport Management Centre (TCM) at a frequency of 20 seconds on sections between stops and every 10 seconds within a bus stop. It is a sufficient frequency for operators. In practice, from the point of view of estimating the travel time, it also seems sufficient, although if increasing the frequency, e.g. up to 5 seconds at any moment of the route, this would not disturb the system, and could increase the accuracy of estimation of travel time. Such data were used in the paper [10] indicating their suitability for more advanced analyses. A good example of the further development of the system is the availability in 2017 of open data of information on the current timetable and related data containing real-time departure times from stops of all public transport vehicles connected to the TRISTAR system. This allowed the use of information about actual departures from all stops (not only those with actual TIPA boards) in applications for mobile devices, disseminating such information in a widely available manner. This is an exemplary example that should be reproduced in the further development of the system with regard to the remaining transferable range of data.

The main element of the Personal Information Access System is a web portal used to provide the information to the inhabitants. The main advantage of the portal is the provision of information about actual departures from all stops, even those that do not have a physical Passenger Information Boards. The portal also provides information about traffic incidents and roadworks. Data from meteorological stations are transferred to the portal and after logging in, information about all the parameters collected by the stations are available for road services, including winter maintenance.

The Transport Planning System consists of software used to perform transport analyses and traffic analyses. As part of the TRISTAR system, road managers were provided with tools allowing to perform traffic simulation with regard to TCS. Thanks to such a solution, it is possible to verify the developed control algorithms and boundary settings for local and area optimization. Such analyses are performed for various types of studies on the impact of control systems on road traffic [7, 9].

4. TRISTAR system development concept in the field of C-ITS

For the purpose of adapting the TRISTAR system to the C-ITS services, the concept of development was proposed.

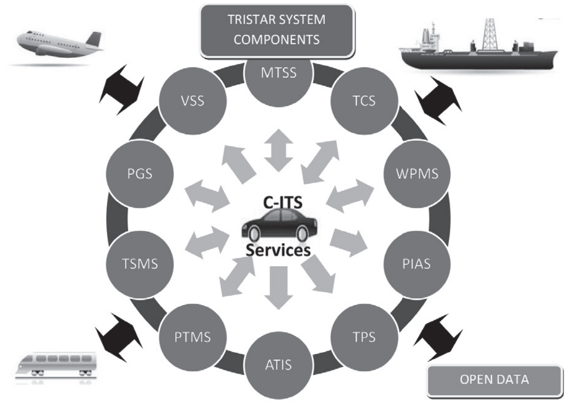

Fig. 2. Possible C-ITS services in TRISTAR system [own study]

The Fig. 2 shows the concept of data exchange between existing TRISTAR subsystems and the C-ITS services or use of data from C-ITS. C-ITS services would take information from other transport modes to increase transport effectiveness and safety. In order to achieve secure data exchange, it is important to develop an OPEN DATA platform. The current possibilities for including C-ITS services to TRISTAR system are described below.

As part of TCS, it is necessary to ensure access to updates of the implemented solutions in the field of control and programming of traffic signal controllers. The Tri-City currently has advanced tools for traffic engineering designing and signal programming that allow for efficient traffic management and the development of advanced algorithms and control strategies. The current development of C-ITS services and autonomous vehicles determines the need to provide high-quality services to transport users. An example of a service that can be easily implemented in the TRISTAR system is the GLOSA (Green light optimal speed advisory) service. TCS could receive information about the location of individual vehicles using this solution. It enables to manage and control traffic more efficiently. The TRISTAR system infrastructure allows to start providing this service after installing an application responsible for transmitting information to vehicles. Implementation of this solution is possible in the TRISTAR system due to the fact of using the OTS2 protocol. The possibility of developing C-ITS in the Tri-City will require the use of a more modern OCIT protocol ensuring compatibility with the infrastructure necessary to perform functions fulfilled by C-ITS services in the future, e.g. Roadside Unit - RSU (infrastructure used to transfer information to passing vehicles, ultimately dedicated for autonomous vehicles). The development of the TRENDS KERNEL (necessary to interpret the control logic) would allow for delivery of traffic data to the controller based on information such as traffic volumes, queue lengths, travel times, delays, number of stops, average speed from Floating Car Data (FCD) to improve traffic control process. In the case of emergency vehicles, it will be possible to use the so-called "Hurry Call" which is an element of traffic signal priority request by designated vehicles. It is a function that allows immediate activating of the desired signal phase. Increasing the frequency of locating all public transport and emergency vehicles would enable faster response to changes in traffic and restore traffic conditions after giving priority.

As part of the MTSS adjustment to the provision of C-ITS services, it will be necessary to create mechanisms for sharing information in Open Data allowing for the transmission of data and statistics on road traffic. In addition, it may be useful to implement solutions that allow to obtain information on pedestrian and bicycle traffic in terms of traffic and travel distribution. The use of "white" and "black lists" could be the basis for the implementation of zone access control for urban areas. Due to the implementation of the National Access Point for data exchange between providers and recipients of data on traffic conditions by the National Road Administration, existing data on incidents and traffic conditions should be integrated using the Datex II traffic information standard.

During the further extension of the VSS system, consideration could be given to using a different type of device than rotating cameras. These can be cameras with a 360-degree lens or a combination of a rotating camera with several faces constantly pointing in different directions within one housing. This solution will allow to increase the area covered by monitoring, which is often used by authorized services to investigate road accidents and as an element supporting operational activities related to combating crime. It is possible to provide information exchange with vehicles, e.g. about the occurrence of an accident and automatic targeting of the camera in incident location to identify the effects and the potential number of victims as well as accelerate the detection of incident. In addition, images from cameras that are constantly observing the same area can be analysed by intelligent image analytics. This can be useful for completing the "Hazardous location notification" service.

As part of the WPMS, it is advisable to supplement existing meteorological stations with noise measurement sensors and sensors measuring the level of air pollution. A warning about exceeding pollution or noise standards can be provided as a warning for city inhabitants by mobile technologies, and warnings about dangerous weather conditions for vehicles as a C-ITS service "Weather Conditions". Data from meteorological stations can be used to develop control strategies aimed at achieving performance indicators related to measured parameters, e.g. minimization of noise or minimization of exhaust emissions. Information on the level of traffic impact on the environment can be used to develop a dynamic parking policy, which includes, among others, dynamic parking fees aimed at discouraging drivers to travel to the most polluted areas of the city.

The main element developed in ATIS will probably still be Variable Message Boards in order to provide drivers with information, among others, about traveling times between important places in the Tri-City. It is reasonable to increase the number of sensors measuring the travel time (ANPR cameras or Bluetooth / WiFi scanners). It is also important to integrate this system with "probe vehicle data" to fill gaps with data on travel times. Emphasis should be placed on the development of technologies and information services directly to vehicles. Due to the extension of the scope of travel time measurements and obtaining information from road users, it will be possible to implement services such as "traffic information and smart routing" and those from the scope of Day 1 services - location notifications. An example of existing technology that is successfully used in the world today is TMC (Traffic Message Channel) which is based on delivering information about events on the road network to a vehicle using dedicated radio waves. The software implemented within the TRISTAR system is adapted to provide information in accordance with the Alert-C standard. Due to the implementation by the National Road Administration of the National Access Point, work is underway to adapt the TRISTAR system to transfer and download road information from the above-mentioned application. Thanks to this, it will also be possible to use information from the National Access Point, also from external suppliers, for example to identify the causes of road network traffic disturbances outside the area of operation of the TRISTAR system.

As part of PGS, it is reasonable to include new parking areas in the system along with providing information on free parking spots. It will also be reasonable to increase the number of boards with information on free parking spots, while the costs should be covered by private managers of parking lots included in the system. It is reasonable to implement a solution that allows drivers to navigate to free parking spaces, e.g. in a paid parking zone. It is worth considering connecting the parking meters to the system to provide information from the parking meters to the TRISTAR system (e.g. to estimate the number of free spots in the vicinity of the parking meter). Parking information as much as possible can be helpful in shaping the city's dynamic parking policy based on supply and demand (dynamic adjustment of parking fees). The openness of such data should be ensured in order to develop innovative solutions by the private sector and C-ITS services related to parking information.

One of the elements of TSMS are the ANPR cameras, which could be expanded due to the "black list" mechanism used by authorized services. The use of "white and black lists" can be the basis for the implementation of "zone access control for urban areas". It would be useful to incorporate intelligent urban lighting located in the city into the TRISTAR system. Modern lighting equipped with controllers and sensors that allow automatic adjustment of the lighting level to the actual needs, ongoing supervision of lighting thanks to which it is possible to minimize the period in which lighting does not work, thus worsening both traffic safety and public security. A very important element is the system of automatic detection of road incidents, which has been implemented to a limited extent. In the current solution, the analysis of changes in the travel time trends between successive measurement points are used. It is reasonable to increase the concentration of these points in order to more accurately identify the street section on which an incident occurred. To complement the existing solution, focusing on intersections is considered, because of numerous collision points. It is possible to use algorithms based on induction loop excitations, taking into account the traffic signals parameters [12] or use video image analysis. The use of feedback from vehicles may also contribute to limiting the development of infrastructure elements, as vehicles can transfer, among others, information about the travel time and about the detected traffic incident from, e.g. the E-Call system. Information about detected incidents may be transferred to vehicles as part of the C-ITS service, among others, as "in vehicle signage" and "in vehicle speed limit" warning the driver about the danger and issuing instructions for speed restrictions in the incident area.

Under PTMS, the number of passenger information boards will increase that are positively perceived by residents and are a very useful tool for informing passengers about actual departure times, events and failures in the city's transport network. Independently, it will be necessary to increase the scope of cooperation with other modes of transport to increase the exchange of information about actual departures at public transport transfer nodes. The most important for C-ITS services such as "Traffic signal priority request by designated vehicles" is to increase the frequency of locating public transport vehicles. It may contribute to changes in the functioning of priorities in traffic signals and their extension to emergency vehicles as well as to the development of dynamically designated bus lanes. It will also help to increase the accuracy of the estimation of times on the passenger information boards. The next stage is the transmission of information about the location of public transport vehicles on the sections between stops to external users as part of Open Data. In the case of the development of passenger counting systems, it is also possible to process this information in real time, which can help passengers choose less crowded vehicles at the expense of a slight delay in travel. The presented data may still support planning of public transport lines and timetables

The main element of the implemented PIAS is the TRISTAR portal used to provide information relevant to the residents. The TRISTAR portal presents processed data (information on the status of public transport vehicles, timetables, stops, meteorological stations, information on Variable Message Boards and Variable Message Signs, cameras views) for further use by third parties. The use-value of viewing these data and traffic information on the portal (especially in its present form) is not competitive due to a number of alternative, free and generally available solutions that cover the whole country and even the world (such as map services, suppliers of navigation, etc.). While maintaining the current standards, it is necessary to allow for the re-use of data that are currently on the Portal as part of the application, which can then be used in an integrated and transparent manner to be used for information or advisory purposes to the benefit of all end users. It should be noted that due to the dynamics of changes of data appearing on the portal, they must be treated differently from the general "open data".

Ensuring the integration of TPS software with data collected in the TRISTAR system databases is one of the key issues. Data collected by devices such as measuring stations or equipment used to measure travel times or data transmitted by public transport vehicles can be used to supply models used in analyses carried out by Road Managers. The data collected in the TRISTAR system databases allow for the calibration of macro, meso and microscopic models, so that the analysis developed by transport and traffic engineers will be less error-prone and thus more reliable. The next stage in the development of TPS should be the use of data from C-ITS services which can develop analyses, and above all help the engineers with the results of these analyses in the form of e.g. parameters for traffic signals or optimization of public transport timetables. As part of this system, software should be provided to simulate pedestrian traffic. These simulations can be used when developing evacuation plans for large events. Analyses using such models allow for functional assessment of the existing and planned transport infrastructure in terms of pedestrian traffic (e.g. capacity of stop platforms).

5. Conclusion

As presented in the paper, it is possible to implement in the TRISTAR system the majority of C-ITS services planned for implementation in the first stages of development (day 1 and 1.5). Based on the example of the Tri-City, it can be concluded that it is also possible to implement such services in other urban ITS, but the key condition is the system's openness ensured at the time of its implementation.

One of the main problems determining the implementation of C-ITS services in Polish cities is the ITS architecture, which is not based on the FRAME architecture. It is worth foreseeing the adaptation of this architecture in existing systems during the work on FRAME NEXT in order to unify and ensure greater interoperability.

Most of the existing systems will require changes in the implementation of protocols and standards necessary to provide ITS and C-ITS services. Only such tailored systems will be prepared to provide high quality services and will be prepared for the service of autonomous vehicles.

It will be difficult to convince users to use the proposed solutions at least as regards the security of the information provided. For this purpose, it will be necessary to regulate the exchange of data and rules of responsibility for their processing. To increase interest in connected vehicles, it is very important to present advantages over existing ITS that do not preclude their further use. First of all, C-ITS can supplement current systems with feedback from users, improving the quality of messages.

The above-mentioned activities will enable the future adjustment of all existing and newly built road infrastructure to the less invasive introduction of autonomous traffic.

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