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Impact of Intelligent Transport Systems Services on the Level of Safety and Improvement of Traffic Conditions

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Abstract. The positive effects of the services of Intelligent Transport Systems (ITS) on the level of transport systems operation was confirmed by long-term studies conducted, inter alia, in the USA, Japan and Europe. Benefits resulting from the application of ITS services can be presented through performance indicators. The indicators represent in a numerical or qualitative manner to what extent ITS services can contribute to improving the safety of travellers and the quality of travel, upgrading the efficiency and reliability of the transport system, the efficiency of transport services providers, energy saving and environmental protection. The paper presents the impact of selected ITS services on the safety and efficiency of traffic, as well as indicators describing that impact. ITS services were specified according to the standard classification of services, prepared within the framework of the RID 4D research project "The impact of the use of Intelligent Transport Systems services on the road safety level," funded by the National Centre for Research and Development and the General Directorate for National Roads and Motorways (GDDKiA).

Keywords: Intelligent Transportation Systems, ITS service, road safety

1 Introduction

The purpose of ITS services is to improve the efficiency, effectiveness, reliability and safety of the transport system. Effective implementation of ITS measures depends in part on the knowledge which of them most effectively solve problems related to road congestion and safety. Therefore, it is important to understand the real benefits of operation of existing and implementation of new technologies. Based on documented experiences gathered from available literature the paper presents the results of studies on the effects of selected ITS services in European countries, the USA and Japan. This paper presents the indicators that enable an assessment of the impact of the proposed solutions of Intelligent Transport Systems on road safety and improvement of traffic conditions. Additionally, the authors analysed - based on the diagnosis of the traffic status - the possibility of the impact of existing and planned ITS services on improving the safety and efficiency of traffic in the area of the National Road Traffic Management System (Krajowy System Zarządzania Ruchem, - KSZR). This impact is presented on the basis of a benchmark classification of ITS services developed within the framework of the RID 4D research project "The impact of the use of Intelligent Transport Systems services on the road safety level."

2 Effects of ITS services application

Advantages of using ITS systems are defined by various performance indicators. These indicators represent the way in which ITS systems can improve safety and mobility of the traveller, efficiency of the transport system, performance of providers of transport services, energy saving and environmental protection. These measures include:

- Safety: direct safety measures may include the number of accidents and changes in their number, the number of injuries and fatalities (absolute measurements). Direct relative measures can be analysed as micro indicators (automotive, transportation, severity) specifying the number of events in relation to the volume of traffic (miles travelled), the number of trips or proportion of involved fatalities or seriously injured persons in the total number of traffic incidents; and macro indicators (e.g. the density of accidents in the defined area or road section). Safety analyses also apply indirect measures which include traffic parameters and their dynamic range (e.g. vehicle speed, speed variation, changes in numbers of infringements of road safety traffic rules, rescue operation time, as well as drivers' and pedestrians' behaviour measures). Safety can also be examined by defining social or individual risks [1];
- Mobility: these measures may include travel time, variability of travel times (travel time reliability), variable speed (traffic flow), time to restore normal/typical traffic conditions (from the point of view of the user and efficiency of the transport system), miles travelled;

- Capacity: measured by the maximum number of people, goods or vehicles passing a point in the road (junction, perimeter or the reference point of the road network per unit of time), as well as traffic conditions (e.g. number of stops, number of vehicles/persons in the queues, time lost);
- Satisfaction of a service user (traveller, supplier of goods): related to the choice of means of transport and the quality of service measured by the level of satisfaction. Typical results of satisfaction with services provided include: assessment of professionalism of the service provided, meeting the traveller's expectations, quality of use, as well as the level of service efficiency and reliability;
- Productivity: activities related to sufficient operational performance and security of the service costs [2];
- Energy and environment: measures include changes in the level of pollutant emissions (carbon dioxide and carbon monoxide, nitrogen oxides, hydrocarbons and volatile organic compounds) and energy consumption [2].

The efficiency of road traffic is closely related to the aforementioned indicators. Traffic performance is upgraded by increasing safety, improving mobility (reduction of travel time), increasing road capacity and use of public transport vehicles, reducing the cost of freight, reducing the negative impact of road traffic on the environment, as well as satisfaction of the road user (ITS services are to make, among other things, the journey more pleasurable and less tiresome).

The result of the implementation of ITS services can be a balance between all the indicators, e.g. improvement of the level of safety in such a way as not to cause a significant increase in travel time which translates directly into user satisfaction. On the other hand, the capacity should improve along with shortened travel time (taking into account all travellers, including cyclists and pedestrians) - but not at the expense of safety. In conclusion, the implementation of a new ITS service should consider comprehensively all aspects of traffic, so that the overall balance of such implementation was favourable, which requires developing methods defining such balance.

Currently, In Poland there are not methods allowing for a comprehensive assessment of the implementation of individual ITS services which significantly hinders the development planning of ITS services on transport networks and makes it impossible to make optimal decisions take into account the costs of implementation and maintenance of these services. The planned development of multi-method within the RID-4D project can improve decision-making processes in the field of ITS services location and development, taking into account the potential benefits of their use.

3 Efficiency of selected ITS services

The following are examples of ITS services that can improve safety and efficiency of transport systems to the greatest extent.

3.1. Electronic tolling systems

The literature review indicates that in its early years the introduction of intelligent systems of road tolling resulted in an increase in the number of accidents caused by drivers' confusion and ignorance concerning these services. Currently, due to the greater availability of these systems and greater awareness of drivers, smart tolling leads to increased safety and reduced number of accidents in the areas of their application. However, the presence of road charges leads to migration of traffic onto lower standard roads, which in turn involves the risk of increasing the number of accidents on such alternative roads [3].

Implementation of the Open Road Tolling (ORT) may provide better performance with respect to charges collection than a conventional construction of a toll site. The technology of Automatic Vehicle Identification (AVI) for electronic toll collection system (ETC) is a concept that has revolutionised the way of tolling, and the ever increasing volume of traffic on the tolled roads results in more frequent application of such innovative methods as ORT. For example, following the introduction of ORT at the University Toll Plaza they observed [4]:

- reduction of the average time losses for cash paying customers by 49.8%, while in case of customers using the automatic toll collection - by 55.3%;
- increase in the average speed of vehicles by 57%;
- decrease in the number of accidents by 22% at the place of tolling, and by 26% in the impact area.

A high-occupancy vehicle lane (HOV) is a lane reserved for vehicles carrying a driver and one or more passengers. HOV lanes are designed to reduce road traffic when many persons travel in a single vehicle. But foreign experience (mostly from the USA) shows that HOV lines do not always meet their objectives and under-utilise their potential, which is why more and more often HOV lanes are converted into High-Occupancy Toll (HOT) lines, which are available both for vehicles with a large number of passengers and not tolled, as well as other vehicles with road charges paid [5]. The fees depend on the time of day and number of people in a vehicle. There are also differences in tariffs depending on the day of the week. Pricing strategies are selected in such a way as to improve traffic conditions in a given traffic corridor as much as possible.

Charges also apply for entry points to the central areas of cities. The introduction of fees for driving into the city centre in London in 2007 reduced the number of vehicles entering that zone by 14%; travel time was shortened by 14%; and the average speed increased by approximately 30%. The charges resulted in an increase in the use of public transport by about 40%, which in turn reduced traffic congestion in the centre. In London it was observed that a 10% increase in travel costs for a car user (without parking) reduced the number of car trips by 4-5% [6].

3.2. Speed management

Variable Speed Limits (VSL) are displayed by Variable Message Signs (VMS).

VSL systems have been implemented in many countries, particularly in Europe, as a method of improving traffic flow and safety. VSL systems through sensors collect data on current road and/or weather conditions, and then send the recommended speed limits that are dynamically updated in order to impact the drivers' behaviour. Passing onto drivers speed limits that are appropriate for the current conditions can reduce vehicle speed and speed variations in the overall traffic stream. Properly designed VSL systems result in reducing the number of accidents, travel time and exhaust emissions thanks to harmonised traffic speed [7].

In 2008, during the implementation of the VSL system on the I-495 road in Virginia, an analysis of some operating VSL systems was carried out. The results of that analysis are presented in the table 1 [8].

VSL signs are useful in the implementation of various strategies, such as Hard Shoulder Running (HSR) which allows for periodic increase in the number of traffic lanes by means of ITS equipment. Implementation of variable obligatory speed limits on four lanes with the possibility of using shoulder to keep ongoing traffic led to a 55.7% decline in the number of collisions on the main motorway in England (M42) [9]. VSL signs are also useful in roadwork areas. The research in Lansing showed that VSL helped to reduce travel time and increase the average speed of vehicles in the area of such works [10].

Table 1. VSL applications throughout the world [8].

Test type	Location	Results
Real conditions	Germany, Autobahn 5	Reduction of accidents involving injury by 30%
	UK, M25	10-15% reduction of accidents
	the Netherlands	16% reduction of accidents, capacity increase by 3-5%
	Germany, Autobahn 9	Free traffic flow during increased congestion, 20–30% reduction of accidents
	Finland, Motorway E19	Increase of an average speed, reduction of speed variability, expected 8-25% reduction of accidents
	Utah, I-80	Reduction of speed variability in the area of VSL impact
	Minnesota, I-494	Capacity increase by 7% at rush hours, no changes at other hours, compliance with speed limits increased by 20% -60%
Simulation	North Virginia	VSL minimises the dangerous imbalances in speed and length of queues, it was less effective in case of long queues

3.3. Detection of traffic violations and support for law enforcement

Systems for automatic recording of traffic violations are used both in urban and rural areas. In the UK in 2003 the research results were presented, aimed at determining the impact of such systems on direct and indirect traffic safety measures in each city covered by the study. The results obtained were compared to those obtained in the adjacent areas (with no enforcement systems), also, the long-term trends were forecasted. A pilot study was conducted in the period from April 2000 to March 2002 at 599 locations in eight regions (Cleveland, Essex, Lincolnshire, Northamptonshire, Nottingham, South Wales, Strathclyde and Thames Valley). The following elements were researched: changes of speed, a change in the KSI (killed or seriously injured) indicator, and a change in the PIA (personal injury accidents) indicator. The KSI rate has been reduced by 31-67%, while the PIA – by about 14-64%. In most of the areas the researchers noted the decrease in the number of vehicles exceeding the speed limit (about 61-81% for fixed speed cameras and 24-46% for mobile speed cameras) [11].

In Scottsdale, Arizona, speed cameras registering speeding on the highway caused a reduction in the number of accidents by 44-54%, the number of injured by 28-48%, and accident costs by 46-56%. Whereas in Chicago there was a 65% reduction in the number of vehicles exceeding speed in three weeks after installation of the surveillance system. Implementation of the system to detect vehicles passing a red light in Texas contributed to reducing by 11% the number of road accidents occurring within the junctions [11,12].

3.4. Providing traffic information to drivers

Advanced communication technologies allow for fast transmission of information to travellers. Drivers can now receive important information about the current traffic situation, including specific road conditions, in many ways, both before travelling - via websites or smartphone applications, as well as during the journey by means of Variable Message Signs or information systems in the vehicle.

Providing road users with accurate and timely information about travel conditions is very important because it can affect the choice of route and in case of obtaining information before the trip - the choice of means of transport or the time of departure. Studies show that information about road events (e.g. the occurrence of queues or roadworks) and recommended alternative routes displayed on a VMS leads to traffic dispersion among routes covered by those systems. However, the percentage of drivers who change their route rarely exceeds 40%. In the Swedish study, from 6% to 41% of drivers chose the recommended alternative route in order to avoid traffic jams, while the research in Houston showed that as much as 85% of drivers changed their route following the information displayed on a VMS [13].

In 2012 in Minneapolis - St. Paul and Seattle-Tacoma they surveyed drivers' reaction to the information about the actual travel time displayed on variable message signs. The results indicate that drivers are more likely to alternate their route when the displayed travel time is almost two times longer than the typical travel time on a given route (sections with a regular travel time of 5-20 minutes were studied) [14, 15].

Crash reductions resulting from VMS to be 28% for injury related crashes in the UK, 35% for all crash types in Switzerland, and 10-30% for property damage and injury crashes in Germany. Weather monitoring VMS system was estimated to reduce crashes by 30-40% in various European countries; fatalities and injuries were conservatively estimated to reduce by 1.1% and 2.0% respectively [16]. The USDOT implemented a fog detection and warning system in December 1990. The system incorporated a VMS that alerted road users to the fog and slower traffic speeds, and a variable speed limit during foggy conditions. Following the introduction of this system, no fog-related crashes have been reported, compared with the 200 crashes that occurred between 1973 and 1990.

Messaging services are used among others in traffic incident (adverse event) management systems interconnected with Traveller Information Systems [17], [18].

3.5. Ramp metering

Ramp metering is an integral part of the Highway Management System, which outlines strategies to reduce congestion and increase safety on Highway. Traffic light together with a signal controller that regulates the flow of traffic entering freeways according to current traffic conditions. It is the use of traffic signals at freeway on-ramps to manage the rate of automobiles entering the freeway.

Kansas Department of Transportation (KDOT) and Missouri Department of Transportation (MoDOT) implemented a pilot ramp metering programme in Kansas City (KC) Scout in order to improve traffic safety and flow on the road I-435. The main objective of ramp metering is to reduce the number of sudden changes of lanes and braking in the vicinity of the motorway entry point, as well as to improve the flow of traffic on the main road by maintaining the stream of traffic in conditions of optimal traffic parameters. The conducted analyses indicated significant improvement in safety when entering the motorway (lower number of dangerous braking and too small spacing between vehicles) [19]. Preliminary conclusions of the evaluation were consistent with the data collected in Milwaukee, Portland, Detroit and Denver which show that installing ramp metering systems can reduce the number of accidents by 26 to 50%. The research carried out after one year of ramp metering systems introduction showed a decrease in the number of accidents by 64% in the study area, including an 81% reduction in accidents in the area of entering the main road. Before the implementation of the system, the average time to remove the effects of the incident on the I-435 was approx. 22 minutes, while after the implementation of the system - 18 minutes. Travel time and speed were maintained at the same level as before the implementation of the system, despite the increased traffic volume [19, 20].

In 2000, in response to drivers' dissatisfaction with the ramp metering system, Minnesota DOT conducted an experiment which excluded all 433 ramps in the area of Minneapolis-St. Paul, to test their effectiveness. The study was conducted by Cambridge Systematics and it showed that after disabling the system the motorway capacity decreased by 9%, travel time increased by 22%, the average speed on the motorway fell by 7% and the number of road accidents increased by 26% [21].

3.6. Incidents management and support for rescue operations

Studies conducted in USA in the 1990s showed that the use of priorities for emergency vehicles allowed to shorten their travel time to victims by 14-23% (surveys were carried out in the cities of, inter alia, Colorado and Texas) [22].

In 2007, the city of Savannah implemented the wireless GPS system for prioritising rescue vehicles along the Derenne Avenue corridor. The system was installed at key junctions with which rescue vehicles communicated. The travel time of emergency vehicles along Derenne Avenue was reduced from seven minutes before the implementation of the system to about 1 minute [23].

Integration of systems of dispatching emergency vehicles and the Traffic Management Center in Utah allowed for more effective incident management. Observations carried out in the first months of implementation indicated that the process of detection, verification and reporting of events was shortened by 35-105 seconds. Accuracy of events location was improved through the direct import of information from CAD systems to the incident management system in TMC [24].

In Georgia, the program for adverse events management, Navigator, reduced the average duration of the incident from 67 minutes to 21 minutes [24].

With the implementation of the Washington State DOT Incident Response Team, 98% of traffic disruptions caused by incidents are removed in less than an hour, and 75% in less than 15 minutes. Whereas the Bay Area Incident Response System (BAIRS) allows to shorten the duration of the incident by approx. 15%. In Utah, the service of event management in the area of Salt Lake Valley made it possible to shorten the duration of an incident by an average of 20 minutes. In 2009 the Miami-Dade Traffic Incident Management (TIM) allowed to reduce the average duration of an incident by 11% as compared with the previous year, while in Maryland - by 28.6%. TIM in Atlanta helped to reduce the average duration of an incident by 46 minutes and it lowered the number of secondary accidents by 69%.

4 Analysis of the possible impact of ITS services on road safety and traffic efficiency

On the basis of obtained data a preliminary analysis was made of the possible impact on current and planned ITS services on the safety of traffic. The impact was analysed through surveys and comparison of selected measures of safety and efficiency of traffic.

Surveys were conducted in order to diagnose the status and manner of implementation of ITS services in Poland. In addition, relevant plans and needs were analysed. A database of services currently provided and planned was developed, as well as of services identified by the stakeholders as required. The analysis of surveys helped to define current and future participation of stakeholders in the services and identify cases of shared services (logical connections). The main conclusion of the surveys is that currently there is no sustainable plan for the implementation of ITS services and systems in Poland. The authorities that implement or plan to implement some ITS services operate independently of one another. Respondents highlighted the lack of a common ITS architecture for the whole country. Currently, each administrator performs its tasks for the city or the region and does not have a coherent policy of implementing new technologies. The exchange of data is also problematic. A good first step towards the development of Polish ITS architecture was to develop guidelines for the National Traffic Management System (KSZR).

Regarding the links between various institutions, such cooperation results mainly from statutory requirements or regulations. Road operators provide data concerning violations of traffic rules, as well as ensure exchange of information on road traffic safety. However, some of the respondents were willing to widen the scope of cooperation in the area of ITS services, *inter alia* those related with the management of road incidents (including rescue operations), Variable Message Signs and information displayed on those signs.

In the survey respondents were asked about the impact of ITS services on traffic safety and flow. Services were analysed according to the standard classification of ITS services developed under the RID-4D project. The impact was evaluated according to a five-point scale, where 1 equals strongly negative impact; 3 - no impact; 5 - definitely positive impact. Among ITS services regarded by respondents as having the most positive impact on the safety and efficiency of traffic are (in parentheses the percentage of responders who pointed to the positive impact of the ITS service on road safety and traffic flow):

- Speed management (87% on road safety, 84% on traffic flow);
- Lanes management (78% on road safety, 83% on traffic flow);
- Detection of potential traffic violations (86% on road safety, 49% on traffic flow);
- Traffic control strategies management (94% on road safety in cities and 70% on road safety in non-urban area, 73% on traffic flow);
- Providing traffic information to drivers (87% on road safety, 89% on traffic flow);
- Traffic control at entry points (ramp metering) (79% on road safety, 81% on traffic flow);
- Traffic management at bridges (84% on road safety, 75% on traffic flow) and tunnels (91% on road safety, 82% on traffic flow);
- Incident management services (95% on road safety, 90% on traffic flow);
- Monitoring and sharing environmental information (weather) (88% on road safety, 80% on traffic flow);
- Support for maintenance of roads in winter (87% on road safety, 80% on traffic flow);
- Rescue operations management services (85% on road safety, 76% on traffic flow).

The above selection was made based on a number of responses indicating a positive impact of a given service (4 or 5 points) in relation to the total number of answers to a given question.

Within the framework of the project an initial analysis of the possibility of impact of existing and planned ITS services on traffic safety and efficiency was made. In order to determine the effect of selected ITS services on the national road network in Poland, the analysis was performed taking into account the selected factors affecting traffic conditions on the roads. The following maps were developed:

- Traffic volumes on reference sections of national roads in 2010 and 2015 based on data from general traffic measurements GPR2010 and GPR2015;
- Changes in the level of road safety: the number of accidents, the number of injured, the number of seriously injured, the number of fatalities - in years 2010 - 2015 based on data on accidents on national roads in Poland received from GDDKiA;
- Changes in the level of road safety in relation to traffic volume: the number of accidents, the number of injured, the number of seriously injured, the number of fatalities - per 1 million vehicle kilometre consecutively for years 2010 and 2015 based on data on accidents on national roads in Poland in years 2010, 2015 received from GDDKiA;
- Accident severity – the number of fatalities per 1 accident and the number of fatalities and seriously injured per 1 accident;
- Level of service for 2010 and 2015 based on data on traffic volume, road class and vehicle structure [25].

Based on the aforementioned maps road sections were selected, for which an in-depth analysis were carried out . The table below (table 2) presents sample indicators for a few key road sections of motorways and expressways.

Table 2. ITS equipment and accidents per mln vehicle-kilometres on selected roads in 2015

Road no	Average daily traffic/weighted average	Section length	Lanes	Implemented KSZR modules	Accidents per mln veh-km
S6	29660 – 77141 /61672	36.54	2x2	VMS (2) Road data collection (3) Weather stations (3) Video data collection (2)	11.73
S8	26789 – 29252 /28003	37.39	2x2	VMS (27) Road data collection (28) Traffic lights (1) Weather stations (29) Video data collection (29) Vehicle data collection (15)	6.82
A1	19927 – 35683 /23960	37.41	2x2	None	19.98
A8	38925 – 59528 /50621	22.72	2x3	VMS (18) Road data collection (14) Traffic lights (1) Weather stations (11) Video data collection (30)	5.09

Among the implemented modules of KSZR, the largest group are devices associated with traffic parameters (speed, traffic volume, detector occupancy – road data collection) and vehicle data collection (devices that identify the features of individual vehicles), monitoring weather and road surface conditions, video monitoring and providing information to drivers (via VMS). The location of the selected devices is presented in Fig. 1. We can also mention ITS services relating to the detection of incidents and the management of speed, however, such services require the extension of implementation and functional development. The number of devices and functional structure of ITS services on individual road sections differ from each other. Table 2 shows examples of road sections where the range of the implementation of ITS services and equipment is more comprehensive (S8, A8) and those for which ITS services have been implemented to a smaller extent (S6) or sections without ITS equipment (A1). The concentration ratio of accidents (number of accidents per million vehicle-kilometer) were compared, which is a measure of individual risk. Individual risk is defined as the probability of involvement of a single participant in the process of road traffic in collision/accident or the probability of material or physical loss in such incident [1]. The examples (Table 2, Fig. 2) show that on the road sections where the state of implementation of ITS equipment is at a higher level (A8, S8), the concentration is lower. However comparison of intensity of traffic on individual road sections do not give a definite answer on the impact of traffic flows on road safety. There is relatively less traffic on the road S8 than on S6, which may affect the level of road safety. Analyses carried out for selected sections of motorways has shown that despite a higher level of service of traffic on the highway A1 (less traffic per lane) than on the A8, the concentration ratio has a lower value, providing a higher level of road safety in terms of individual risk. Note, however, that the level of road safety is influenced by many factors, among others: class of road, road geometry, road surrounding, speed limits, interchange entries and exits areas (their number and geometry within the interchange, form of interchange). On the basis of the common indicators, it cannot be unambiguously determined that the implementation of the ITS services will improve the level of road safety, since a number of other factors could adversely affect this level.

Fig. 1. Selected ITS devices on Polish national roads in 2015 [own study based on GDDKiA data]

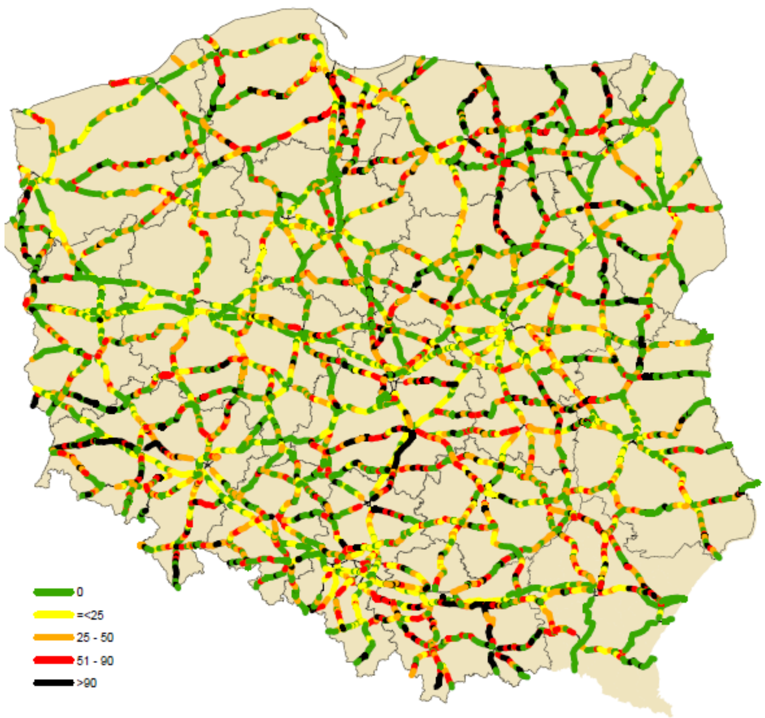

Fig. 2. Number of accidents per mln veh-km on Polish national roads in 2015 [own study based on GDDKiA data]

5 Conclusions

In-depth study of literature have demonstrated that providing ITS services can significantly influence both the improvement of road safety and efficiency of the transportation system. Among the services, which have the greatest impact on increasing the level of road safety, while also have a positive impact on the efficiency of traffic on motorways and express roads are ramp metering, traffic incident management (including providing information on speed limits, alternative routes and warnings to drivers), providing traffic information to drivers about weather and road surface conditions with associated speed limits, electronic tolling systems as well as detection of traffic violations and support for law enforcement. Literature studies were confirmed by surveys carried out as a part of the project RID 4D. Respondents indicated the ITS services that they think positively affect the level of safety and efficiency of traffic. Most respondents indicated ITS services (for the rural roads), such as incident management, monitoring and providing information to drivers (especially about weather conditions), speed management and detection of traffic violations (speed and red light enforcement).

A preliminary analysis of the impact of the application of ITS services on the level of traffic safety based on accident data and the location of ITS equipment were also carried out. The number of devices and functional structure of ITS services on individual road sections differ from each other. Selected road sections were analyzed where the range of the implementation of ITS services and equipment is more comprehensive, and those for which ITS services have been implemented to a smaller extent or sections without ITS equipment. Generally on the road sections where the state of implementation of ITS equipment is at a higher level the individual risk to be involved in accident is lower. However the level of road safety is influenced by many factors e.g.: class of road, road geometry, road surrounding, speed limits, interchange entries and exits areas (their number and geometry within the interchange, form of interchange). On the basis of the common indicators, it cannot be unambiguously determined that the implementation of the ITS services will improve the level of road safety, since a number of other factors could adversely affect this level. Due to the above, it is necessary to carry out more detailed studies, taking into account a variety of factors, which may affect the road safety. Based on preliminary studies pilot road sections were selected, which will be analyzed in detail with the use of traffic models (macro, micro and mesoscopic depending on particular ITS service or groups of services). Models of the impact of various factors on road safety will be also developed for selected sections in order to isolate the effect of ITS services.

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