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Influence of Intelligent Transport Systems services on motorways road safety

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Abstract

The positive effects of Intelligent Transport Systems (ITS) services on road safety 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 paper presents analysis results of the influence of existing ITS services on road safety on motorways in Poland and indicators describing that impact. For the purpose of the analysis data of accidents (years 2013-2015) are used to describe safety level for motorways with different number and scope of ITS services. Additionally, the authors analyzed - based on the diagnosis of the traffic status - the possibility of the impact of existing and planned ITS services on improving the road safety in the area of the National Road Traffic Management System (Krajowy System Zarządzania Ruchem, - KSZR). Current level of ITS services on Polish motorways within the architecture of KSZR System and state of its development will be presented as well.

Keywords: Intelligent Transport System; road safety; motorways; ITS services.

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1. Introduction

Intelligent Transport Systems (ITS) services in many long-term studies was identified as factor which can improve road safety level. Many of them was successfully implemented in cities, expressways and motorways where improved safety of travelers 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. Road safety can be assessed in various ways. The most direct way to evaluate is the statistical analysis of road accidents. On the basis of accident statistics, it is possible to calculate direct measures and risk measures for hazards by taking into account the number of incidents with the length of the road or the intensity of traffic on the different types/ classes of roads. Accident statistics are however only available for existing roads and in the presence of the existence or absence of ITS services and other status quo conditions. Reliable analyzes can be conducted if the status quo lasts for several years. For new or planned roads and new road traffic safety improvement measures (including ITS services), safety levels or safety effects cannot be assessed for the number of accidents due to short duration of time, small sample or no data (Dijkstra A. et al. 2005). In such cases it is advisable to use other safety indicators. One option is to use prognostic models to predict the number of incidents taking into account road characteristics (e.g. class of road) or predicted traffic (FHWA 2005 and Reurings M. et al. 2006). Other safety measures are based on more indirect indicators, such as the number of traffic conflicts evaluation sometimes supported by micro simulation models (Bevrani K. and Chung E. 2011, Bonsall R. et al. 2005, Minderhoud M. and Bovy P. 2001, Cafiso S. et al. 2016). Another type of safety score may be derived from expert knowledge, such as a traffic safety auditor, assessing the safety of a new project based on its experience and knowledge. One way to estimate benefits from the implementation of ITS services is to present them through key performance indicators e.g. changes in number of accidents, number of injuries and fatalities, number of events (accidents, injuries) in relation to the volume of traffic or friction of involved fatalities or seriously injured persons in the total number of traffic accidents. In this article, the traffic safety assessment was based on the measures estimated on Polish motorways with and without ITS services.

In recent years we can observe the development of National Road Management System (KSZR) on Polish expressways and motorways. KSZR design was based on ITS FRAME architecture and was divided into implementation modules which corresponding to ITS services (Kasprzak W. and Olszewski P., 2011). 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 (and drivers behaviours), interchange entries and exits areas (their number and geometry within the interchange, geometry form of interchange).

2. Status quo of the ITS system in Poland

In order to determine the impact of Intelligent Transport Systems on the level of road safety on motorways in Poland, the authors identified coverage of motorways with ITS services based on data received from the national road administration (GDDKiA). An update of the inventory of ITS devices on national roads was taken at the beginning of 2015. The inventory was taken according to the classification of the implementation modules within the framework of the KSZR's physical architecture. It included the following items (Kamiński T. et al. 2016):

- collecting traffic data (traffic parameter measurement devices),
- road lighting management
- traffic signals,
- speed and lane control,
- providing information and instructions for drivers (Variable Message Signs - VMS),
- providing information and instructions for drivers in tunnels (VMS),
- detecting incidents with the available data resources (incident detection),
- collecting weather and road surface data (meteorological stations),
- air pollution measurement,
- collecting vehicle data (devices that identify the features of individual vehicles, including weight in motion preselection systems - WIM),
- collecting video data (video monitoring).

In recent years, many ITS devices have been implemented on motorways in Poland. Table 1 shows the KSZR modules that were implemented on Polish motorways. Most of these ITS devices have been implemented along with new sections of motorways (mainly years 2010-2012).

Table 1. ITS devices on Polish motorways in 2010-2015.

Module of KSZR	Number of ITS devices in						Change 2010-2015
	2010	2011	2012	2013	2014	2015	
Collecting Traffic Data	85	147	170	170	174	174	105%
VMS	144	274	299	300	308	308	114%
Collecting Weather and Road Surface Data	46	57	71	75	85	85	85%
Collecting Video Data	97	151	181	181	183	183	89%
Kilometers of motorways with ITS devices	218	416	489	490	553	553	153%

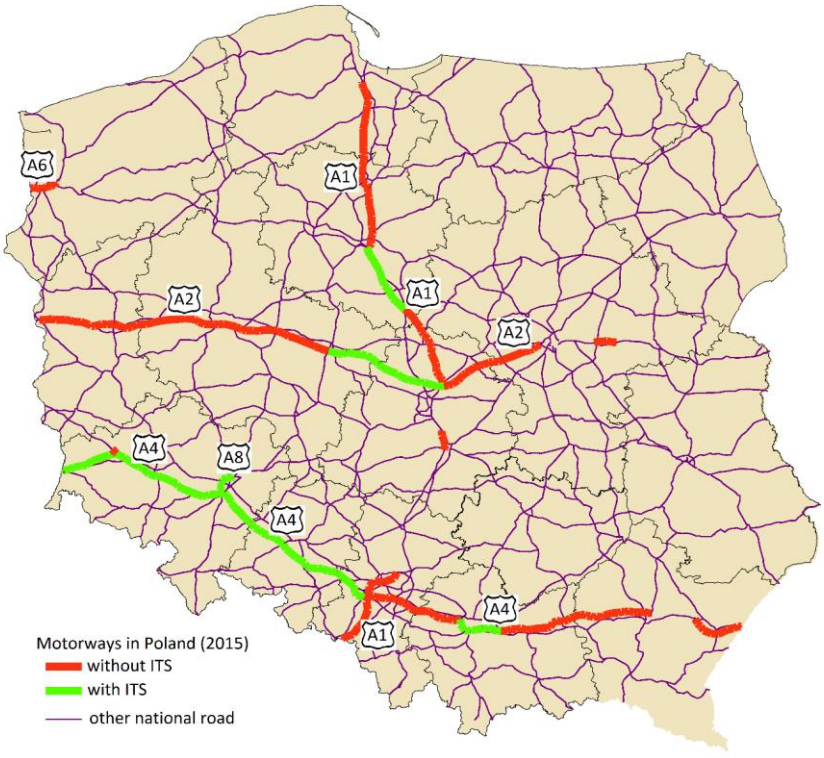

Fig. 1 ITS on Polish motorways (2015).

The map (Fig. 1) shows Polish national roads. On the sections of motorways marked in green, a comprehensive ITS infrastructure has been identified, meaning that modules from Table 1 have been deployed there. No ITS services have been deployed on the sections of motorways marked in red. Fig. 2 shows the number of accidents and victims of these accidents per million vehicle-kilometers travelled (VKT) on sections with and without ITS (eq. 1, 2).

$$N_a = \sum_{i=1}^{n} \frac{a_i}{PP_i} \tag{1}$$

$$PP_i = T_i \cdot 365 \cdot 3 \cdot L_i \cdot 10^{-6} \tag{2}$$

where:
N_a – number of accidents per mln VKT on section with or without ITS
i – section road with or without ITS
n – number of section road with or without ITS
a_i – number of accidents on section i in 2013 – 2015
PP_i – performance of road traffic on section i (in million vehicle-kilometers travelled)
T_i – average daily traffic volume on section i in 2013 – 2015
L_i – length of section i

The graph shows that the number of accidents per million VKT is 37% lower on motorways with ITS than on motorways without ITS. Similarly, the number of injuries is 26% lower (11% seriously injured), while the number of fatalities is lower by 49%. These results may suggest the positive impact of ITS services on the level of traffic safety. However, the analysis does not take into account the use of ITS by the road traffic services and emergency services. Traffic management strategies (including the quality of information for drivers) using ITS devices were also not evaluated.

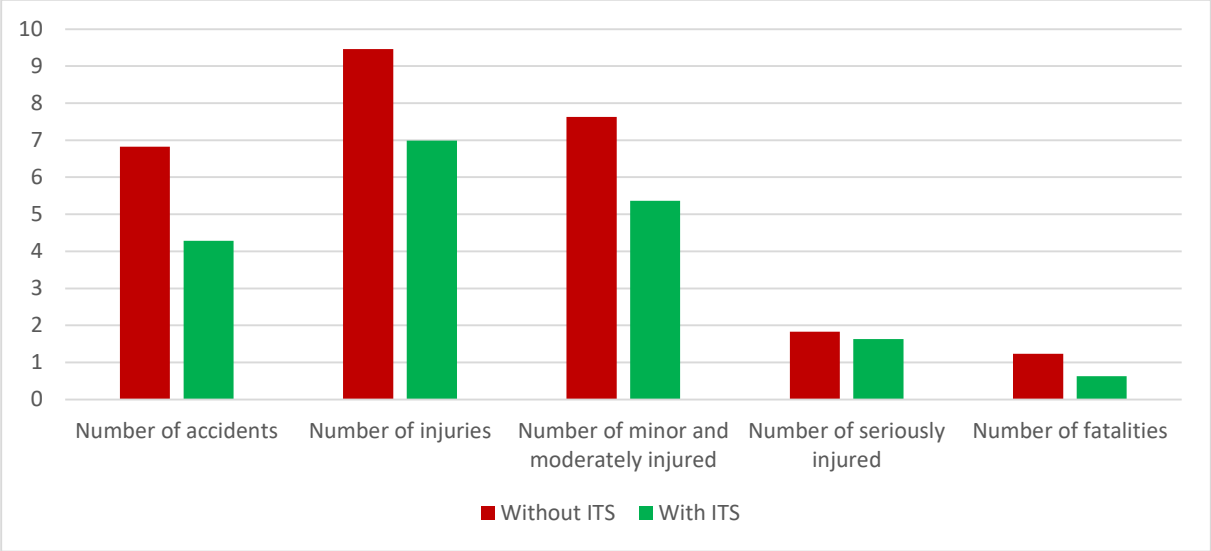

Fig. 2 Number of accidents and casualties per million VKT on Polish motorways in 2013-2015.

3. Impact of ITS services on road traffic safety in Europe

Advanced communication technologies allow for fast transmission of information to travellers. Drivers can 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.

On-trip information has the potential to effect traffic safety positively, especially when drivers get support on the appropriate choice of speed. Öörni, R. and Kulmala, R. (2012) predicate that real-time information on slipperiness and other road weather related problems has been estimated to reduce the risk of injury accidents in adverse conditions by 8 % on main roads and 5 % on minor roads and decrease mean speeds by around 10 km/h in Nordic conditions. The system was also shown to affect the direction of attention to find cues showing potential hazards, and to make passing behaviour of drivers more careful indicating an even larger positive impact on safety than that due to lower speeds. In addition, by e.g. getting incident related information on-trip, drivers can by changing their route avoid the affected area and therefore reduce the risk of secondary accidents.

Studies show that information about road events (e.g. the occurrence of queues or roadworks) accompanied by recommended alternative routes information displayed on a VMS leads to traffic dispersion among routes covered by ITS. However, the percentage of drivers who change their route rarely exceeds 40%. In the Swedish study, from 6% to 41% of drivers choose the recommended alternative route in order to avoid traffic jams (Elvik R. 2009)

Tignor S. et al. (1999) states that in Amsterdam, dynamic lane management reportedly reduced the "overall accident rate" by 23 percent, reduced the "serious accident rate" by 35 percent, and reduced the "secondary accident rate" by 46 percent. In Germany, the accident rate fell by 20 percent in areas where variable speed limit signs and lane control signals were used to warn drivers of congested conditions on the A5 autobahn between Bad Homburg and Frankfurt/West. On a comparable section of autobahn without control, accidents increased by 10 percent in the same time period. Even though some of the studies might suffer from the bias-by-selection or regression-to-the-mean effect, the accident reduction may be more than 10%.

Studies indicate positive safety effects from on-trip traffic information via VMS. These are due to the fact that real-time information and warnings make the drivers better prepared for the problem ahead and encourage them to approach the incident location with lower speeds, longer headways and better situation awareness. The probable effect of these systems on the number of injury accidents is estimated to be in the in range of -3 to -10% (Nygårdhs S. and Helmers G. 2007). Concerning incident warnings, the whole range of the effect on the total number of injury accidents is from 45% to 9%, where the largest reductions may include bias caused by the regression-to-the-mean effect (Nygårdhs S. and Helmers G. 2007). The effects are more beneficial on secondary accidents. Other sources report that rear-end injury accidents have decreased as a result of queue warning systems on motorways whereas the number of rear-end accidents resulting in property damage only have increased. Rämä P. (2001) writes in his publication that the automatic fog-warning system on the M25 motorway in England showed that the mean vehicle speed reduction was around 3 km/h, when the signals were switched on as a result of the formation of fog. Variable weather-controlled speed limits have been shown to improve safety by 10-20%, traffic controlled speed limits also indicate similar accident reductions. The magnitude of the safety impacts depends on whether safety has been taken as the primary aim of the system or not.

Crash reductions resulting from VMS were 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 (OECD 2003).

Variable Speed Limits (VSL) are displayed by 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. Introducing 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 harmonisation of traffic speed (Randolph L. 2015) . Table 2 on based on publications Fudala N. (2010) shows the impact of selected VSL applications in Europe on traffic safety and efficiency.

Table 2. Impact of selected VSL applications on motorways in Europe on road safety.

Road	Impact of VSL applications
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

4. Analysis of the possible impact of ITS services on road traffic safety in Poland

The purpose of ITS services is to improve the efficiency, effectiveness, reliability and safety of the transport system. The effective implementation of ITS depends on the knowledge that can effectively reduce the problems of congestion and road safety. Therefore it is important to understand the true benefits of using existing and implementing new technologies. Within the RID 4D research project, analyzes were conducted to identify the most important ITS services in Poland.

4.1. Survey research

Surveys described in the publication (Oskarbski J., Marcinkowski T., Mowiński K., Gumińska L., Oskarbska I., 2017) has been conducted to diagnose the status and manner of implementation of ITS services in Poland. In addition, relevant plans and needs were analyzed. A database of services currently provided and planned was developed, as well as of services identified by the stakeholders as required. Road administrators, public transport managers, police, emergency services, Road Transport Inspectorate, mobile operators, car navigation system operators and other private sector operators participated in the study. The analysis of surveys helped to define current and future participation of stakeholders in the services and to 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 KSZR (Oskarbski J., Marcinkowski T., Mowiński K., Żarski K., 2017).

Table 3. ITS services having the most positive impact on road safety according to surveys.

ITS service	Percentage of responses indicating a positive effect on road safety
Incident management: Detection of incidents (93%), Response to incident (95%), Reducing negative effects of incidents (91%), Informing drivers about the incident (87%))	95%
Management of inter-urban traffic strategies	94%
Weather monitoring (94%) and weather information (88%)	94%
Traffic management in tunnels	91%
ITS systems in vehicle (cooperative ITS): Detection for the vehicle surroundings 86%), Monitoring of status of driver (85%), Warning driver (90%), Road information & dynamic commands and warnings (83%)	90%
Detect and identify traffic violations (88%), and violation notifications (84%)	88%
Providing road information to drivers	87%
Speed management	87%
Support for winter maintenance of roads	87%
Manage emergencies: Identify and classify emergencies (80%), Plan emergency operation (85%), Providing information for emergency operation (84%))	85%

According to the respondents, the most efficient in improving of road safety services are the ITS group of incident management services. Early detection of the accidents contributes to shortening the duration and shortening the time needed to assist the victim, resulting in reduced accident severity, minimized exposure to the risk of secondary accidents, and minimized travel time losses. Moreover, the important service indicated by respondents is the providing road information to drivers. Effectively informing drivers can influence on the improvement of road safety (e.g. by speed harmonization) and traffic performance (e.g. by routing alternative routes) (Kamiński T. et al. 2017). This service is associated with other services affecting the level of road safety, such as speed management, lane management, providing of weather information, traffic management in tunnels. The key element of these services are VMS, which allow to influence on the behavior of drivers. Currently, traffic information for drivers is transmitted mainly via radio and VMS, but after deployment the National Access Point (the element of KSZR), traffic information will also be transmitted through, inter alia, in-vehicle navigation systems. An important service according to respondents is also ramp metering, which facilitates the improvement of traffic conditions within the road interchanges, which directly contributes to the improvement of safety (mainly at merge points but also along the road). Table 3 (Oskarbski J., Marcinkowski T., Mowiński K., Gumińska L., Oskarbska I., 2017) shows the services that, according to respondents, have the most positive impact on improving road safety.

Analysis of the survey allowed to identify the necessary directions of development of ITS services in Poland:

- It is necessary to standardize the period and manner of data archiving, which would require legislative or central regulation. It is also advisable to develop guidelines on the possibility of transferring different types of data to individual stakeholders and the legal basis for their transmission.
- It is necessary to set standards for database structures and data storage locations in order to be able to use data from different stakeholders for operational, planning and research purposes.
- Development of legislative indications of opportunities for cooperation between stakeholders.
- Development of legal basis for sharing services (hardware and functional)

4.2. Analysis of accidents and ITS deployment

Unfortunately in many cases it is currently not possible to analyze directly the impact of ITS services on improving road safety on motorways. Many of ITS systems were built together with the road construction, so it is impossible to determine the state before ITS was implemented. However within the extension of the KSZR on existing roads without ITS such research are possible. Therefore sections of motorways with ITS infrastructure and sections without ITS were selected for the analysis. Road safety analysis was conducted for these sections based on accident and traffic data for period 2013-2015. Table 4 shows sections selected for analysis. The A1 motorway runs from north to south, while A2 and A4 from west to east of Poland.

The highest number of accidents per VKT was recorded on sections of motorways without ITS and also on sections equipped with ITS near urban areas (Fig. 3). The figures show i.a. sections of motorways located close to cities, where roads often serve as a bypass or ring road of the city (Wroclaw, Cracow - about 600 000 inhabitants, Katowice, Szczecin - about 300 000 inhabitants, Gliwice, Opole with a population of over 100 000 inhabitants) . Similar dependencies can be found in case of accidents with seriously injured and fatalities. The high concentration of accidents on these sections (high individual risk to be involved in accident) may be due to the mixing of local traffic with the through traffic (different characteristics of the drivers transport behavior) and the greater traffic volumes at the merging points at the interchanges. Confirmation of this finding can be found in Fig. 4, which shows the concentration of accidents per the number of interchanges.

Table 4. Motorway sections selected for analysis.

Road	Section	Section length (km)	Lanes	Implemented ITS	Symbol
A1	Rusocin-Pelplin	37,4	2x2	No	A1-R
A1	Pelplin - Warlubie	33,3	2x2	No	A1-P
A1	Toruń Południe - Włocławek Północ	34,8	2x2	Yes	A1-T
A1	Kowal-Kutno Północ	27,6	2x2	No	A1-K
A1	Kutno Północ - Łódź Północ	49,5	2x2	No	A1-Ł
A2	Nowy Tomyśl - Poznań Zachód	46,5	2x2	No	A2-P
A2	Konin (Modła)-Dąbie	45,4	2x2	Yes	A2-K
A2	Łowicz - Wiskitki	29,7	2x2	No	A2-Ł
A4	Jędrzychowice (granica p.) - Bolesławiec	44,7	2x2	Yes	A4-J
A4	Kąty Wrocł. - Wrocław Wschód	27,1	2x2	Yes	A4-KW
A4	Wrocław Wschód-Przylesie(Brzeg)	29,3	2x2	Yes	A4-W
A4	Brzeg - Opole Południe	50,6	2x2	Yes	A4-O
A4	Strzelce Opolskie - Gliwice Sośnica	42,7	2x2	Yes	A4-G
A4	Ruda Śląska - Mysłowice	20,9	2x3	No	A4-Ś
A4	Chrzanów- Balice I (Kraków)	29,8	2x2	No	A4-C
A4	Balice I (Kraków) - Szarów (Targowisko)	43,6	2x2	Yes	A4-K
A4	Targowisko - Tarnów Zachód	43,6	2x2	No	A4-T
A6	Kołbaskowo - Szczecin Dąbie	25,3	2x2	No	A6-S
A8	Wrocław Południe-Przylesie(Brzeg)	22,7	2x3	Yes	A8-W

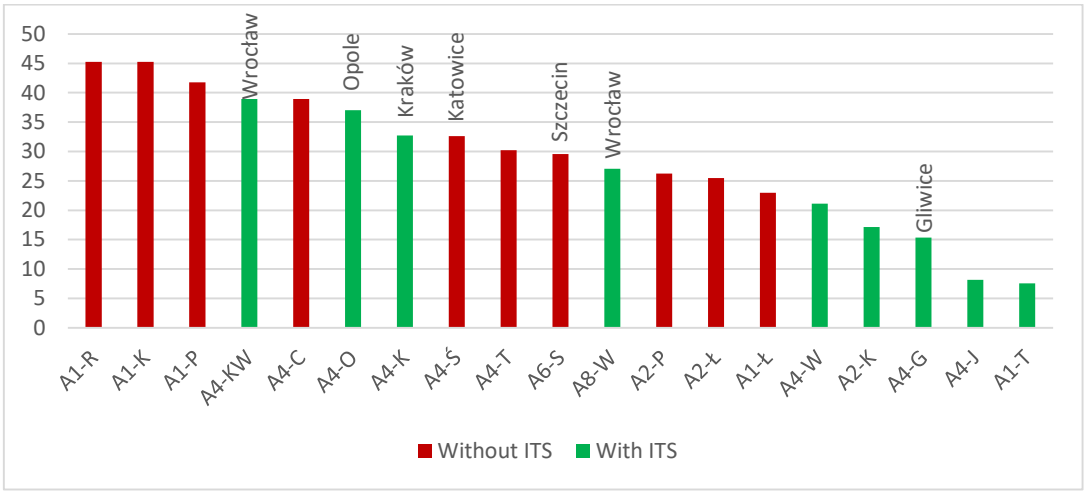

Fig. 3 Number of accidents per bln VKT on sections of polish motorways.

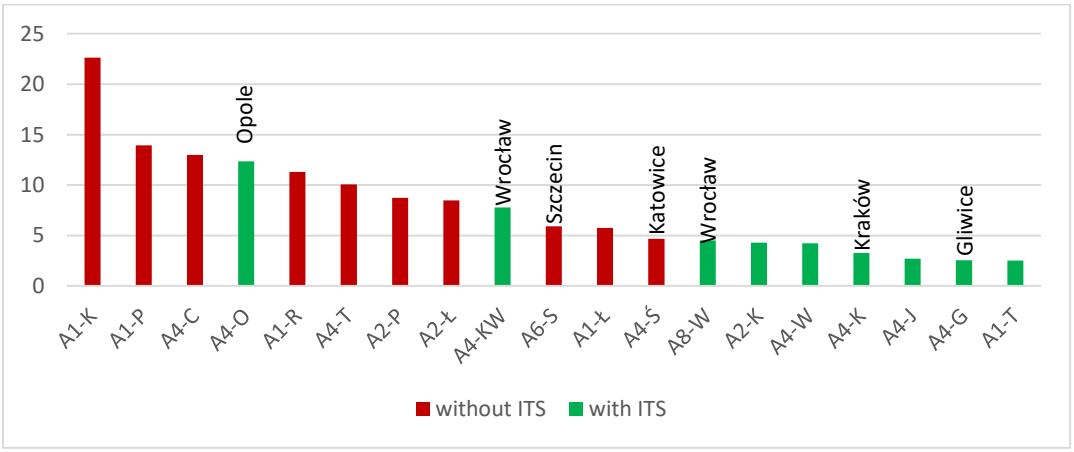

Fig. 4 Number of accidents per bln VKT per interchange on sections of polish motorways.

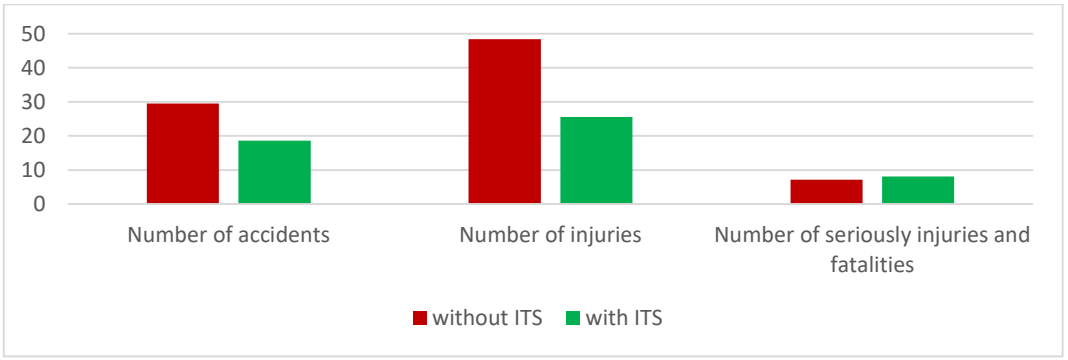

Fig. 5 Number of accidents and casualties per mld VKT on motorway A2

Figure 5 shows the comparison of accident rates on the A2 motorway (with length of approx. 100 km). The comparison covers the periods prior to ITS implementation (from January 2008 to June 2011) and after implementation (from July 2011 to December 2015). Indicators were normalized for comparable time periods (3 years). After the deployment of ITS, the number of accidents decreased by 37%, the number of minor injuries by 47%, while the severity of accidents increased slightly (13%). The increase in severity of accidents can be attributed to a significant increase in traffic volumes (20-30%) with a slight decrease in average speed. In the period after introduction of ITS more casualties were reported, with more victims being seriously injured or killed.

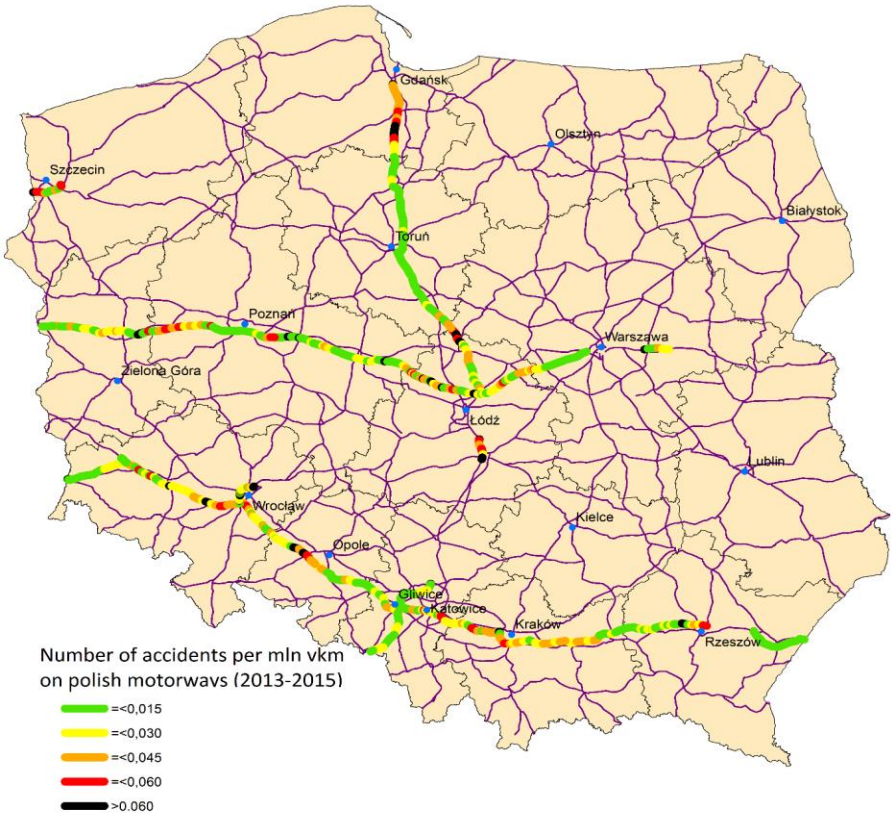

Fig. 6 Number of accidents per mln VKT on polish motorways (years 2013-2015).

Figure 6 shows the concentration of accidents on analyzed sections of motorways. Locations of the highest concentration of accidents occur mainly at the motorway entries to major road at interchanges and rest/service areas for drivers.

5. Conclusion

In-depth study of literature have demonstrated that providing ITS services can significantly influence the improvement of road safety 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 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, ramp metering, 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) (Oskarbski J., Marcinkowski T., Zawisza M., 2017). 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. 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. 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 also sections without ITS equipment. The results of analysis may suggest the positive impact of ITS services on the level of traffic safety (on the road sections with ITS services the individual risk to be involved in accident is lower). 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). The analysis does not take into account the use of ITS by the road traffic services and emergency services. Traffic management strategies (including the quality of information for drivers) using ITS devices were also not evaluated.

Some roads are covered with ITS equipment, however others require ITS implementation. The use of devices needs to be developed through the implementation of traffic management strategies. Many VMS provide information only on weather conditions while it would be reasonable to provide information related to, for example, incident or speed management, including support actions of rescue operations (e.g. emergency corridor). An important step towards improving the flow of information and notifying the services is the National Access Point deployed by the General Directorate for National Roads and Motorways. ITS resources can also be used to support cooperation between emergency and preventive services with traffic control. This, however, will require new procedural and equipment standards (to ensure equipment compatibility and communications) at the national level including the local specificity and stakeholders involved in incident management and inclusion in the system of Traffic Management Centers (Oskarbski J., 2017). 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. 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) and with use of surrogate safety measures.

Acknowledgements

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