Methodology of research on the impact of ITS services on the safety and efficiency of road traffic using transport models

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Abstract. The current assessment of the impact of Intelligent Transport System (ITS) services on the level of traffic safety and efficiency is based mainly on expert assessments, statistical surveys or several traffic safety models requiring development. There is no structured, uniform assessment method that would give the opportunity to compare the impact of ITS services and their different configurations. The paper presents the methodology for researching the effectiveness of ITS services implementation using transport models and key indicators allowing such an assessment. An approach was used in which the impact of ITS services is analysed using macro, meso and microscopic models. Macro and mesoscopic models allow estimation of the impact of ITS services on the efficiency of transport network operation and constitute the basis of analyses at the microscopic level, which takes into account the behaviour of drivers through the use of car following and lane change models. As part of the analyses, road network test models (for motorways and expressways along with an alternative route) were developed. Test models include road class, network topology, and different traffic intensity. The models were calibrated using real data (data from the traffic measurement station, data measured in the field, traffic distribution data from the VIATOLL charging system) and data from the vehicle simulator.

1 Introduction

Intelligent Transport System (ITS) services in many long-term studies have been identified as a factor that can improve road safety level. Many of them have been successfully implemented on expressways and motorways improving the efficiency and reliability of the transport system, the efficiency of transport service providers, energy saving and environmental protection. The most direct way to assess the level of traffic safety is the statistical analysis of road accidents., It is possible to calculate direct or risk measures taking into account the number of accidents per road length and traffic volumes on different types/classes of roads using data from accident statistics. However, accident statistics are only available for existing roads with or without ITS services and in other status quo road

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characteristics and conditions. Such reliable analyses can be carried out if the status quo persists for several years. In the case of new or planned roads and implementations of new measures to improve road safety (including ITS services), safety levels cannot be assessed in terms of the number of accidents due to short time, small sample or lack of data [1]. In such cases, it is advisable to use other safety measures. One of the options is to use forecasting models to predict the number of accidents taking into account the road characteristics (e.g. road class) and anticipated traffic [2–4]. Other safety measures are based on more indirect indicators, such as the estimation of the number of traffic conflicts, sometimes supported by microsimulation models [5–8]. We have observed the development of the National Traffic Management System on Polish expressways and motorways in recent years. The project of the National Traffic Management System was divided into implementation modules corresponding to ITS services. The number of devices and the functional structure of ITS services on individual road sections differ from each other. The first part of the paper presents selected analysis of road sections where the scope of ITS services and equipment implementation is wider especially in the field of information provision to drivers, e.g. about adverse road surface conditions with introduction of variable speed limits (via Variable Message Signs), and those for whom ITS services have been implemented to a lesser extent or have not been implemented at all. In general, on roads where the ITS implementation status is at a higher level, the individual risk associated with an accident is lower. However, many factors influence the level of road safety, e.g.: road class, road geometry, road surroundings, number and geometry of interchanges, speed limits and driver behaviour. The second part of the article presents the methodology and selected results of analyses using transport models.

2 Individual risk analysis

In order to determine the impact of Intelligent Transport Systems on the level of safety on motorways in Poland, the authors identified motorways coverage with ITS services based on data received from the national road administration (GDDKiA). The inventory included the different ITS services [9]. In many cases, it is not currently possible to directly analyse the impact of ITS services on improving motorway traffic safety. Many ITS systems were built together with the construction of roads, therefore it is impossible to determine the state before ITS deployment. However, as part of the development of the National Traffic Management System on existing roads without ITS, such research is possible. Therefore, sections of the highways with ITS infrastructure and sections without ITS were selected for the analysis. A road safety analysis for these sections was conducted based on data on accidents and traffic volumes in the period from 2013-2015. The map (Fig. 1) shows national roads in Poland. Developed ITS infrastructure was identified on motorways sections marked in green (including traffic data collection, VMS, data collection on weather and surface conditions). For the purposes of the paper, the results of risk analyses of individual participation in an accident or becoming a victim of an accident were presented.

Fig. 2 shows the number of accidents and victims of these accidents per million driven vehicle kilometres (VKT) on sections with and without ITS. 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), and the number of fatalities is reduced by 49%. These results may suggest a positive effect of ITS services on the level of traffic safety. However, the analysis does not take into account the use of ITS by road traffic services and emergency services. The traffic management strategy (including information quality for drivers) using ITS devices has not been assessed. Most accidents per VKT were recorded on sections of motorways without ITS, as well as on sections equipped with ITS in the vicinity of urban areas (Fig. 3). The numbers show that the sections of highways located

near cities where roads often serve as a part of ring road or bypass of the city (Wrocław, Kraków - around 600,000 inhabitants, Katowice, Szczecin - around 300,000 inhabitants, Gliwice, Opole with a population of over 100,000 residents). Similar dependencies can be found in the case of serious injuries and fatalities. A high concentration of accidents on these sections (high individual risk related to an accident) may be the result of mixing local traffic with a through traffic (different characteristics of transport behaviour of drivers) and the greater traffic volumes at the merging points at the interchanges
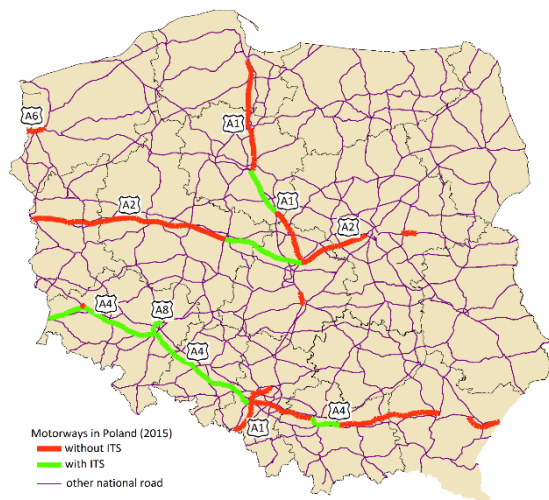

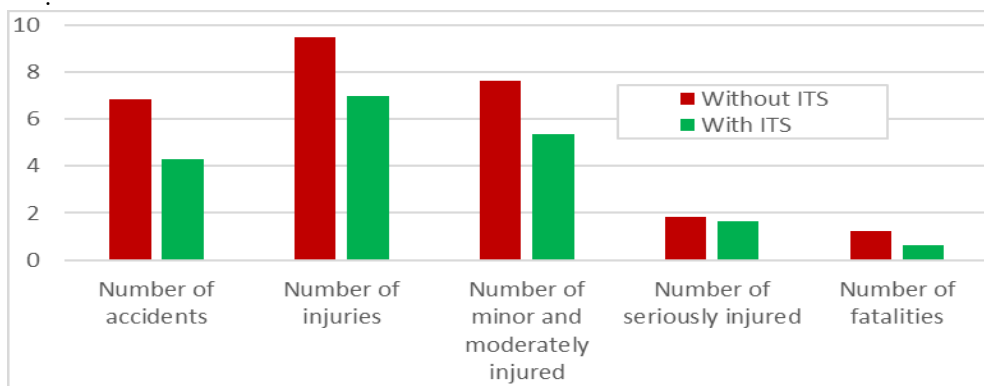
Fig. 1. ITS on Polish motorways in 2015 [10].

Fig. 2. Number of accidents and casualties per million VKT on Polish motorways in 2013-2015 [10].
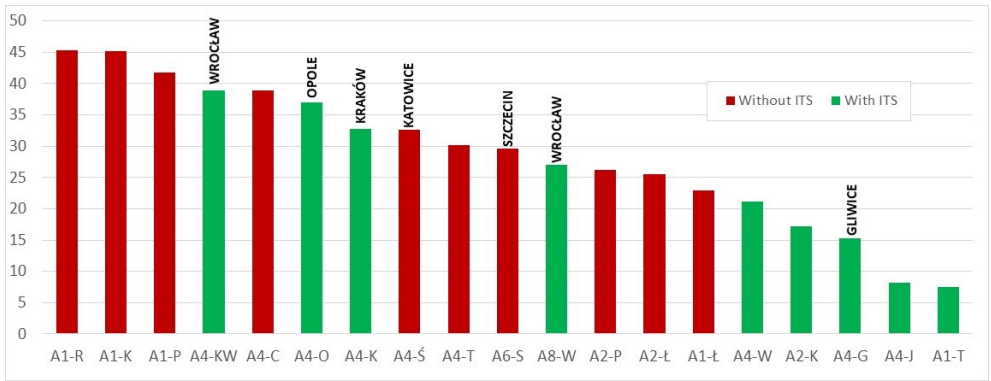
Fig. 3. Number of accidents per bln VKT on sections of Polish motorways in 2013-2015 [10].

The results of research conducted in Europe and United States confirm the effectiveness of ITS services in improving the level of traffic safety and efficiency [11–13]. On the basis of the common indicators presented in this paper, 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 with use of transport models. Based on preliminary studies pilot road sections were selected, which are analysed in detail with the use of transport models and surrogate safety measures.

3 Methodology of research with use of transport models

3.1 Macro, meso and microscopic approach

One of the methods of assessing the effectiveness of implementing ITS services is the use of laboratory simulation models. Simulation to study safety is more accessible than the traditional safety studies. Simulation can help to reduce field work and is a useful way to evaluate ITS resources. Traffic simulation models, according to the level of detail they can provide, are divided into three parts: micro, meso and macroscopic models. The macro and mesoscopic approach makes it possible to estimate typical transport network indicators (total travel time of vehicles in the network, VKT, average speed, traffic volumes resulting from the assignment). Macroscopic models enable, among others, defining the type and cross-section of the road, defining capacity for various types of roads, free flow speed and the resistance functions (curves describing the speed decrease with the increase of traffic) for specific sections of the transport network. Mesoscopic models additionally allow to reflect the influence of elements, such as types of intersections, the organization of traffic at intersections and traffic control, thanks to which queues at intersections and the resulting delays are taken into account. The microscopic approach means that every vehicle in the network is constantly modelled during simulation while traveling through a designated road network. The movement of the vehicle from its beginning to the destination is followed by reactions to stimuli, such as traffic signals and the movements of other vehicles [14]. The main advantage of the microscopic simulation is that each driver is analysed on an individual level. However, to obtain results at the microscopic level, input data must also be provided at the microscopic level. The quality of the input data not only takes into account the integrity of the data, but also the appropriate physical care when entering data into the system [15]. Microscopic traffic simulators aim to realistically emulate the flow of individual vehicles in

the road network. Each microscopic model includes three behavioural sub-models which are responsible for vehicle movement inside the network: Car Following, Lane Changing and Gap Acceptance. Each sub-model has different influencing parameters which mean it is necessary to modify and improve these parameters to ensure they emulate more realistic traffic measures [5].

3.2 Methodology

Methodology of the research includes the following steps:
- collection of available data from the traffic measurement stations (traffic parameters) and the ViaToll system (routes of heavy vehicles) and analysis of traffic volumes in the road network using the National Traffic Model, General Traffic Surveys and traffic volume data from the traffic measurement stations),
- analysis of road network topology for motorways and expressways,
- development of test models of the road network for road classes (S 2/2, A 2/2, A 2/3)
- estimation of network Key Performance Indicators (KPI) to analyse the impact of ITS services on the traffic efficiency and safety based on the analysis of test models and selection KPI to power the model using the AHP method to identify the services that have the greatest impact on the traffic efficiency and safety,
- verification of correctness of results obtained from test models and correctness of AHP model using real road network models

The studies used a multi-level approach presented, among others, in the article [16]. Macroscopic simulation models (PTV VISUM software), mesoscopic models (SATURN software) and microscopic models (PTV VISSIM) were used to assess the impact of ITS services on safety and efficiency of traffic. The macroscopic model was used to obtain data on the distribution of traffic for meso and microscopic models. The basic analyses were carried out in meso and microscopic models.

3.2.1 Test model

The mesoscopic model was used primarily to analyse the service of the incident management system, while the microscopic model to analyse the services of ramp metering and speed control with use of Variable Message Signs, including scenarios with the occurrence of incidents. An example of a test network is shown in Figure 4. Network topology scenarios differ in distance between interchanges on the major road, type of interchanges on individual road classes, location of alternative roads and types of intersections within interchanges and on alternative roads as well as roads connecting alternative roads with a motorway or expressway that reflect the location with respect to intensively urbanized areas. Test models include scenarios in which the occurrence of incidents was assumed (blocking of 1 or 2 lanes during an incident, an incident without blocking of lanes).
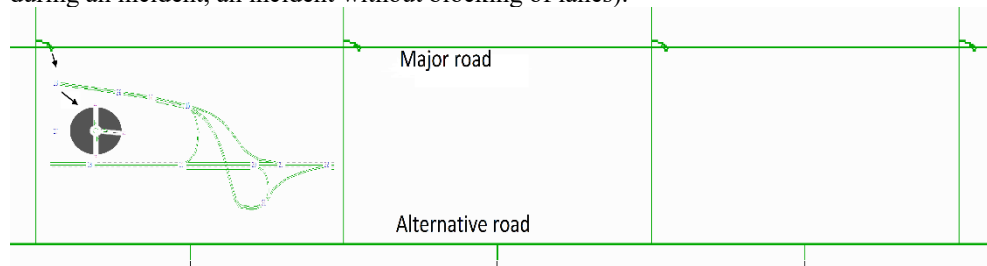

Fig. 4. Test network for A 2/2 motorway with roundabouts at alternative and connecting routes.

The limitation of road capacity during an incident including rubbernecking was adopted on the basis of research [17,18]. The analyses included providing drivers with information about the incident occurrence and the issues relating to the dynamic traffic assignment [19,20]. 3 scenarios of the duration of the difficulties were defined based on the data on the duration of incidents obtained from national road administration and Regional Fire Departments. The data obtained from the ViaToll system complemented the results of US research [21] allowing to determine the share of vehicles choosing an alternative route in the case of an incident (tab. 1). Representative hourly traffic can be classified as cohorts. Cohort sets can be defined depending on the road class. The division into cohorts presented in Table 2 was assumed for the purposes of the research. The adoption of the cohort sets aims at determining the frequency of occurrence of particular types of incidents on individual road classes in the total time of road functioning.

Table 1. Percentage of drivers choosing an alternative route in the case of an incident.

Road class	Variable Message Signs	incidents 0-45'		incidents 45'-90'		incidents > 90'	
		1lane	2 lanes	1lane	2 lanes	1lane	2 lanes
S 2/2	NO	4%	-	8%	-	12%	-
A 2/2	NO	3%	-	7%	-	11%	-
A 2/3	YES	9%	50%	13%	60%	18%	70%

Table 2. Cohorts defined for traffic intensity scenarios.

Cohort	Traffic volumes in the cohort q [veh/h /lane]	Volume-to-Capacity Ratio q/C	The intensity of traffic assumed for the load of the major road lane in test models	Representative Volume-to-Capacity Ratio q/C
0	q>2100	0,95-1	2150	0,98
1	1300-2099	0,59-0,95	1700	0,77
2	720-1299	0,33-0,59	1010	0,46
3	0-719	0-0,33	360	0,16

Microscopic models were calibrated, among others, with time headways between vehicles and vehicle speed distribution. Using data from the traffic measurement station and the driving simulator. Parameters of road traffic and the behaviour of road users, which allow identification and assessment of changes affecting road safety are referred to as surrogate safety measures. Surrogate safety measures have their origin in traffic conflicts. The traffic conflicts technique is a methodology for field observers to identify conflict events at intersections by watching for strong braking and evasive manoeuvres. The model developed in VISSIM enabled to obtain information on the trajectory of each vehicle in traffic flow as well as location and number of traffic conflicts. Data are stored in the form of x, y coordinates and a time marker. Trajectories analyses were carried out using the Surrogate Safety Assessment Model [22].

3.2.2 Sample results of the application of incident management service

In order to obtain more reliable results in the process of deterministic and stochastic traffic assignment in the network, a quasi-dynamic model was used in which over-capacity queues are passed between time periods. Thus, the model takes into account the dynamics of changes in blocking lanes in particular places (30 minute periods were assumed during 210 minutes of simulations) and traffic parameters changes are spreading over time periods. Sample calculations of some indicators values at 30 min intervals are shown in Figure 5 (incident lasts from 30 to 90 minutes of simulation). Assignment models were calibrated with use of results presented in section 3.2.1. Stochastic model (STOCH) assumes lack of information provided to drivers, in the deterministic model (DETER) knowledge of drivers about the occurrence of the incident was established. The model makes it possible to estimate the difference between selected network indicators in the case of an incident occurrence or without incident, including providing the driver with information about the incident or lack of information.
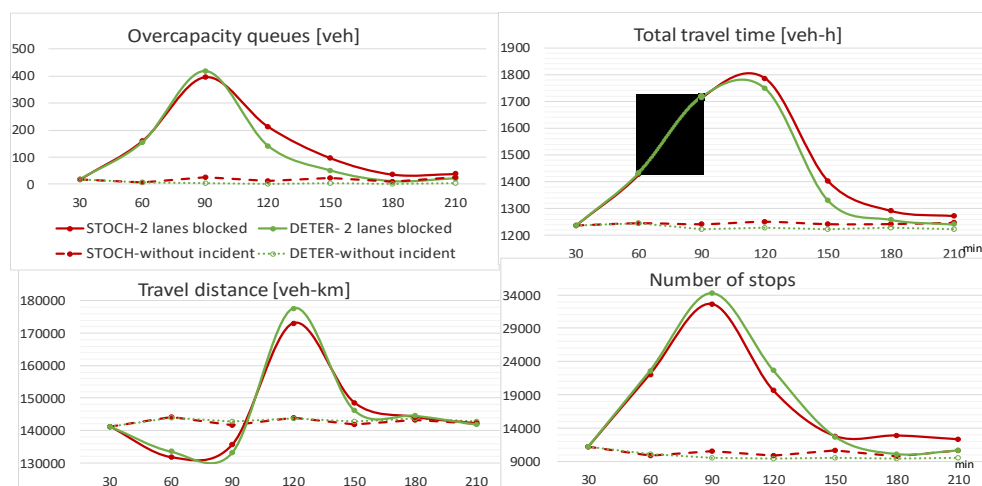

Fig. 5. Examples of traffic network efficiency indicators (A 2/2, scenario including intersections with traffic signals, cohort 2, 2 lanes blocked).

4 Conclusion

The obtained results will allow to develop and supply the model developed using Analytic Hierarchy Process (AHP) method, which will enable the road administrator to choose optimal ITS solutions and decide on the appropriateness of implementing individual ITS services on designed or existing motorways and expressways. The effectiveness of the method will also be verified using the developed models of real transport networks in the corridor of motorways and expressways.

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