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EFFECT OF INTELLIGENT TRANSPORT SYSTEMS ON TRAFFIC SAFETY

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Abstract. One of the biggest problems of constantly growing transport sector is traffic safety. Innovative technologies are an effective tool to deal with the following issue. In order to ensure efficient and coordinated development of intelligent transport systems, it is essential to know their individual performance and impact on traffic safety. This article gives the summary of the effect of intelligent transport systems on road traffic safety. The aim of the research is to highlight intelligent transport systems and intelligent transport systems applications which have the greatest positive impact on traffic safety. To achieve this aim, meta-analysis of previous studies and analysis of experts interviews was carried out. The research consider the following thirteen driver support and control systems regarding their potentials to reduce the number of fatalities: average speed control system, stationary speed cameras, "Alcolock" ‑ application of drunk driver detection, "eCall" system, variable speed limit sign, red light violation detection cameras, forbidden maneuver detection system, vehicle identification system, variable message boards, intelligent road studs, incident detection system, weigh-in-motion system and seat belt control system.

Keywords: intelligent transport systems (ITS), road accidents, road fatalities, Analytical Hierarchy Process (AHP) method.

1. Introduction

Transport sector is one of the most important area in today's economy and society. According Eurostat data, the transport industry in European Union (EU) directly employs around 10 million people and accounts for about 5% of gross domestic product (GDP). From 2012 to 2015, there has been a 16% increase in the number of vehicles on the roads all over the world. Furthermore, transport sector still receives great attention in EU. In 2015, the record €13.1 billion investment plan for the transport sector was adopted by the European Commission. It is important to ensure the smooth, efficient, safe, and free movement of people and goods across the EU by using all modes of transport. One of the main objectives of the European Union's transport policy is to improve traffic safety.

Road accidents are one of the major cause of death all over the world. According to the World Health Organization (WHO), more than 1.2 million people die each year on the world's roads. In the European Union almost 25 700 road fatalities were reported in 2014. According to the WHO (2015), the main factors influencing fatalities and injuries is speeding, drink-driving, the failure to use helmets, seat-belts and child restraints properly. Speeding accounts for 30% of the fatal accidents and alcohol about 25%.

The problem of traffic safety has been recognized by the United Nations and its Member States in 2010, when the global ministerial conference on road safety released declaration for a period 2011–2020 as the "Decade of Action for Road Safety". The main target was to stabilize and then reduce road fatalities by increasing activities at the national, regional and global levels. Respectively, the European Commission approved the target to halve the overall number of road deaths in the European Union by 2020 starting from 2010. From 2010 to 2014, deaths on the road decreased by only 18%, therefore it is necessary to develop more effective mechanisms to achieve the main target.

One of the ways to significantly reduce road accidents is application of innovative technologies in transport sector. Such concept of traffic safety measures exists for already more than 25 years. From the beginning they had several names: Road Transport Informatics (RTI), Advanced Telematics in Transport (ATT) and Intelligent Vehicle-Highway Systems (IVHS). Nowadays it has an agreed term – Intelligent Transport Systems (ITS).

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ITS are integrated telecommunications, electronics, information technologies and its applications in transport engineering in order to plan, design, operate, maintain and manage transport systems. ITS can receive and transmit information between road users, roads and vehicles.

ITS have been often deployed on a fragmented, uncoordinated basis and also implementation of ITS in road transport sector has been much slower than in other modes of transport (Concerning the adoption…2011). To achieve effective development of ITS, common regulation across the EU was necessary. On 16 December 2008, an Action Plan for the Deployment of Intelligent Transport Systems in Europe was adopted. On 7 July 2010, Directive 2010/40/EU was adopted as a new legal framework. This Directive controls interoperable and seamless establish of ITS in EU, but it leaves the freedom for Member States to decide which systems to invest in. To comply with this Directive, all Member States has brought into force the laws, regulations and administrative provisions. As well as most of Member States have the functioning national ITS associations, which helps to coordinate the activities of the ITS sector for relevant public authorities.

The purpose of this paper is to compare the different ITS as traffic safety measures, and identify the best, intended to be implemented on EU roads. To achieve this aim determination of ITS individual performances, impacts on road safety and review of best practice was carried out. In order to identify the impacts on road safety, the research of expert interviews was carried out. The expert questionnaire was created and results were evaluated by the method of Analytic Hierarchy Process (AHP) through the pairwise comparisons.

2. Intelligent transport systems as traffic safety measure

ITS are irreplaceable tool to make transportation more efficient, more sustainable and finally to increase traffic safety. ITS help to increase the safety by minimizing the consequences of crashes or to prevent them altogether. The fact is that 85–90% of road accidents are caused by human factors (Häkkinen 1978). Numerous ITS can contribute to a possible solution by the advanced driver assistance systems. Such applications support the driver to maintain safe speed and distance, keep the right lane, avoid overtaking in critical situations, safely pass intersections, etc.

The greatest effect on traffic safety could be achieved if all the systems and applications are integrated and cooperated. Communication, information, data processing and electronic technologies cooperation of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and mode-to-mode (V2X) could significantly increase transport safety and mobility, improve the sustainability of travel, reduce congestion, and improve the performance of all modes of transport. According to Austroads (2011) estimations the current total of approx 29 000 annual fatalities and serious injuries could be reduced by 25–35% in case that a 100% market uptake of the technology in vehicles would be achieved across Australian jurisdictions.

This paper presents the following thirteen driver support and control systems:

Average speed control system. Selection of a safe speed is a main traffic safety influencing factor and in the "driver – vehicle – road – environment" model specifically the driver takes responsibility for selecting safe driving speed.

Speed effects to road safety in two ways: 1) the risk of being involved in an accident; 2) the severity of an accident.

Based on work done by Nilsson (1981) in Sweden, a change in average speed of 1 km/h will result a change in accident numbers ranging between 2% for a 120 km/h road and 4% for a 50 km/h road. This result has been confirmed by number of before and after studies of different speed reduction measures. Later Nilson (2004) estimated that 1% increase in speed results approximately 2% change in injury crash rate, 3% change in severe crash rate, and 4% change in fatal crash rate. A similar relationship was found in Britain (Taylor 2000), empirical studies have shown that changes in accident numbers associated with a 1 km/h change in speed vary 1–4% on urban roads and 2.5–5.5% on rural roads, where the lower value reflect good quality roads and the higher value poor quality roads. An average speed control system is used to measure the vehicle's average speed on a certain road section. The first camera is installed at the beginning of the road section and the second one at the end of the section. The cameras detect a number plate of the approaching vehicle, take an image of a driver and measure the time when the vehicle enters or leaves the road section. If the calculated average speed of the vehicle exceeds the speed limit the recorded data is sent to the Traffic Police. Based on the results of previous studies, the number of fatalities and injuries was reduced by 37–66% after installation of this system (Stefan *et al.* 2005; Wiman *et al.* 2008). Average speed control is however also intended to homogenise traffic flows, reduce traffic congestion and environmental and noise pollution (De Pauw *et al.* 2014; Soole *et al.* 2013).

Stationary speed cameras. High driving speeds increase accident risk and cause more severe consequences. For the grown-up pedestrian a fatality risk is less than 20% if he is crashed by the vehicle moving at a 50 km/h speed. Though if the vehicle moves at a 80 km/h speed the fatality risk increases up to 60% (Rosén *et al.* 2011). Stationary speed cameras are effective in high accident concentration locations where local speed control is needed (intersection, pedestrian crossing, etc.). Installation of a stationary speed camera is quite cheap, though the largest disadvantage of is that it cannot ensure speed control on the whole road section. Nevertheless, having evaluated 14 different studies on stationary speed cameras Pilkington (2005) found out that they helped to reduce the number of fatalities from 17% to 71%.

"Alcolock" – application of drunk driver detection. In the EU drunk drivers constitute almost 25% of the total number of fatalities. From 70% to 80% drunk drivers are captured for the second time. To solve this problem many world-wide countries implement the "Alcolock" programs. The drunk driving offenders can choose to participate in this program for two years or to pay a penalty and to lose their licence for a two-year period. During this programme the "Alcolock" device is installed into the participant's vehicle. The "Alcolock" is a device which is installed into the vehicle to prevent the driver from starting his vehicle without passing the alcohol test. The data of tests is stored in the device which is checked once per two months by appropriate institutions. The data analysis was carried out and recommendations were given on the driver's ability to choose between driving and drinking. The "Alcolock" program, implemented in the United States and Canada in 1980, indicated that the number of repetitive cases of drunk driving decreased from 40% to 95% (Drevet *et al.* 2004). The studies carried out in Netherlands, Czech Republic, Norway and Spain have determined that the number of fatalities on roads after introduction of this program had decreased by 1–6.2% (Vlakveld *et al.* 2005).

"eCall" system. This is the in-vehicle emergency call system which in the event of an accident automatically dials emergency number 112, transmits information about the accident location and activates a direct connection between the vehicle occupants and the emergency operator. The main objective of the system is to speed up the arrival of emergency services. Based on the estimations, implementation of eCall system could reduce the emergency response time by 50% on rural roads and by 40% on urban roads (Francsics *et al.* 2009). A faster response to the traffic accident on high-volume roads would help to avoid traffic jams and secondary accidents. Data of various studies indicated that the implementation of this system could reduce the number of fatalities by 5–10% (Abele 2006; Geels 2004), 4–8% (Virtanen *et al.* 2005), 3.5–6% (Baum 2008), 1–6 %.

Variable speed limit signs. About 13% of fatalities on the roads of European Union occurred under poor traffic conditions (fog, rain, snow, heavy wind). Dynamic (variable) speed limit signs are significantly more effective than the stationary since they are promptly adapted to the changing traffic conditions (traffic volume, weather conditions, road accidents, road works, etc.). The Lee *et al.* (2006) study results indicated that variable speed limits could reduce risk of accident by 5–17%, by temporarily reducing speed limits during risky traffic conditions when accident potential exceeded the pre-specified threshold. The study of German researcher showed that after implementation of this system the number of road accidents in a certain road section was reduced by about 30% (Kuhn 2006). The EasyWay project has indicated that with the assistance of this system the number of fatalities and injuries could be reduced by 15–40% (Holmgren 2012).

Red light violation detection system. The red light running violations still cause severe accidents at the intersections. About 20% of fatalities on the roads of European Union occurred at the intersections. Many researches (Kloeden *et al.* 2001; Polders *et al.* 2015; Shin, Washington, 2007) reported, that red light running at signalized intersections has a significant impact on road safety since this leads to more serious collisions (side collisions or collisions with vulnerable road users). The red light violation detection system continuously observes traffic at intersections and automatically registers vehicles running the red light. The study carried out in United Kingdom (UK), Glasgow City has indicated that after installation of red light violation detection system the number of accidents at signalized intersection has decreased by 25%. The number of fatalities was reduced by 67%, severe injury accidents – 40%, light injury accidents – 28%, and the number of technical accidents – by 22%. Installation of this system in 254 UK cities resulted the reduction of fatal and injury accidents by 18% (Traffic Technology Today 2009). The study in the United States has determined that after installation of this system the number of accidents at the intersections has decreased by 44% (Fitzsimmons *et al.* 2007).

The present research also studies seven additional intelligent transport systems the impact of which on traffic safety has not been studied in literature sources. These are: forbidden maneuver detection system, vehicle identification system, variable message boards, intelligent road studs, incident detection system, weigh-in-motion system and seat belt control system.

3. Experimental research

Many ITS and their applications are innovative solutions, yet it is difficult to assess their impact on traffic safety due to the short operational time and majority of other factors influencing traffic safety simultaneously. Due to these reasons an unbiased comparison of different ITS solutions becomes complicated. To ensure reliability of evaluation results this research compared the meta-analysis data and results of expert interviews.

In the first stage of research the meta-analysis was performed using data of various previous studies. In the course of analysis information about the impact of six ITS on traffic safety was systematized. The basic criterion selected for the analysis of the systems' impact was a reduction of road fatalities.

In the second stage the expert interviews were carried out and its results were analyzed. In total, 18 specialists working in the transport sector of different EU countries were interviewed. The interview consisted of two parts: evaluation of traffic safety influencing factors, and of ITS and their applications. The questioner was compiled and the data was analyzed using the Analytical Hierarchy Process (AHP) method.

AHP method is one of the most popular methods in analyzing multi-criteria decisions that was developed by Saaty (1980). AHP assists in analyzing complex decisions which need human experience and intuition more than mathematical calculations. The required data is obtained using a pairwise comparison. A pairwise comparison is used to obtain the weight of criteria. The essence of this comparison is to assign a relative preference to one criterion against another.

In the system constituted by the AHP model there are 13 qualitative indexes illustrated in Table 1, and 13 alternatives illustrated in Table 2. Qualitative indexes and alternatives are compared pairwise in regard to traffic safety.

Five foreign experts took part in the interview representing Latvia, Estonia, Poland, Slovenia, Belgium and thirteen experts from Lithuania. The data of experts' interview was summed up with the use of the Expert Choice Comparion software and additional statistical methods. The Expert Choice Comparion software calculated the

Table 1. Pairwise comparison of traffic safety influencing factors

Traffic safety influencing factors	Traffic safety												
	Speeding	Drunk driving	Fatigue	Distracted driving	Lack of driving skills	Vehicle breakdown	Technical condition of vehicles	Lack of safety equipment on vehicles	Slippery road conditions	Rough road	Inadequate geometrical parameters	Animals	Meteorological conditions
Speeding													
Drunk driving													
Fatigue													
Distracted driving													
Lack of driving skills													
Vehicle breakdown													
Technical condition of vehicles													
Lack of safety equipment on vehicles													
Slippery road conditions													
Rough road													
Inadequate geometrical parameters													
Animals													
Meteorological conditions													

Table 2. Pairwise comparison of ITS and ITS applications

Technology for improving traffic safety	Traffic safety												
	Average speed control system	Drunk driver detection system "Alcolock"	Weigh-in-motion system	eCall system	Incident detection system	Intelligent road studs	Stationary speed cameras	Variable speed limit signs	Vehicle identification system	Seat belt control system	Red light violation detection cameras	Forbidden maneuver detection system	Variable message boards
Average speed control system													
Drunk driver detection system "Alcolock"													
Weight in motion system													
eCall system													
Incident detection system													
Intelligent road studs													
Stationary speed cameras													
Variable speed limit signs													
Vehicle identification system													
Seat belt control system													
Red light violation detection cameras													
Forbidden maneuver detection system													
Variable message boards													

significance of each expert's indices and presented their distribution of 100%.

Consistency of experts' opinions was tested by using the concordance coefficients W. The concordance coefficient W varies from 0 to 1, where 0 indicates complete inconsistency, 1 – complete consistency. A hypothesis is formulated: H_0 – the experts' opinions are contradictory (i. e. the concordance coefficient is equal to zero) and H_A – the experts' opinions are similar (i. e. the concordance coefficient is not equal to zero).

Calculations are performed according to the following algorithm:

1) the mean sum of ranks is calculated: $a = 0.5m\,(k+1)$;

2) the sample variance is calculated: $S^2 = \sum_{j=1}^{k}\left(\sum_{i=1}^{m} x_{ij} - a\right)^2$;

3) the concordance coefficient is calculated: $W = \dfrac{12S^2}{m^2\left(k^3 - k\right)}$, where m – number of experts; k – number of alternatives (objects).

Having made calculations of concordance coefficient for the results of interview on traffic safety influencing factors it was obtained that W = 0.52. The concordance coefficient for the results of interview on technologies for improving traffic safety was W = 0.43.

The H_0 hypothesis was tested to determine if the experts' opinions are not contradictory:

When the calculated statistical value $\chi^2_{(\alpha,f)} = wm(k-1) > \chi^2{}_{rit}$ under the chosen significance level α and the number of freedom degrees f, the hypothesis H_0 is rejected. Statistical value of the results of interview on traffic safety influencing factors was 112.7, whereas of the results of interview on technologies for improving traffic safety – 93.2.

It is known that the freedom degree $f = (k - 1) = 12$. An assumption was made that the significance level α = 0.05. Then $\chi^2_{krit}(0.05;\ 12) = 21.0$. Thus $\chi^2_{(\alpha,f)} = 112.7 > \chi^2{}_{rit} = 21.0$ and $\chi^2_{(\alpha,f)} = 93.2 > \chi^2{}_{rit} = 21.0$, therefore it can be stated that the consistency of experts' opinions was sufficient and statistically significant.

Methodological assumptions, formulated in a classical theory of tests, propose that reliability of interview results and the number of decision makers (in this case – the experts) are related by a fast-worsening indirect relation. Since 18 experts participated in the interview the reliability of decisions was 95%.

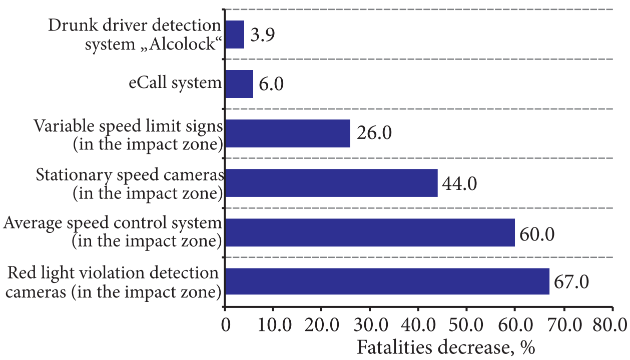

Fig. 1. ITS effect on a decrease in road fatalities criterion evaluated by meta-analysis method

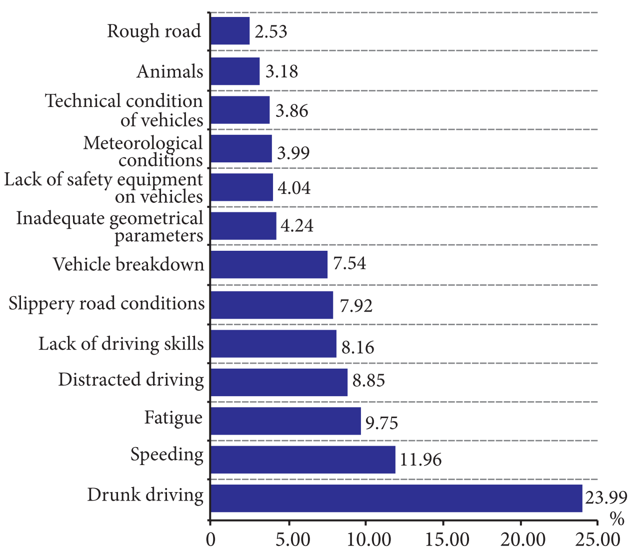

Fig. 2. Distribution results of summed up experts' opinion on road accident causes

4. Results analysis

In the first stage of research, the effect of six different ITS measures on traffic safety were determined. For this purpose a meta-analysis was used. The results obtained show the effectiveness of the system within the zone of its impact (at the location where it is installed). The effect of automatic emergency call system eCall and drunk driver detection system "Alcolock" on traffic safety was calculated based on the assumption that distribution of these systems is 100% (100% of vehicles are equipped with these systems).

ITS installed in motor vehicles and in road infrastructure were compared separately, since there were no possibilities to compare those systems unambiguously. For the evaluation the criterion of decrease of road fatalities was chosen. The results obtained are given in Fig. 1.

It has been determined that the largest effect of ITS installed in road infrastructure on a decrease of road fatalities (67%) was represented by red light violation detection systems. From ITS installed in motor vehicles the largest effect on a decrease of road fatalities (6%) was made by automatic emergency call system eCall.

In the second stage of research, the data of expert interviews was assessed which consisted of two parts. In the first part, evaluation of traffic safety influencing factors has indicated that in the experts' opinion the largest negative effect on traffic safety is made by drinking and driving. 16 from 18 experts have distinguished this factor as one of the most important and this makes 24%. In the experts' opinion the lowest negative effect on traffic safety is made by rough road pavement. This factor makes 2.53%. Fig. 2 gives the distribution of values of all factors considered by experts.

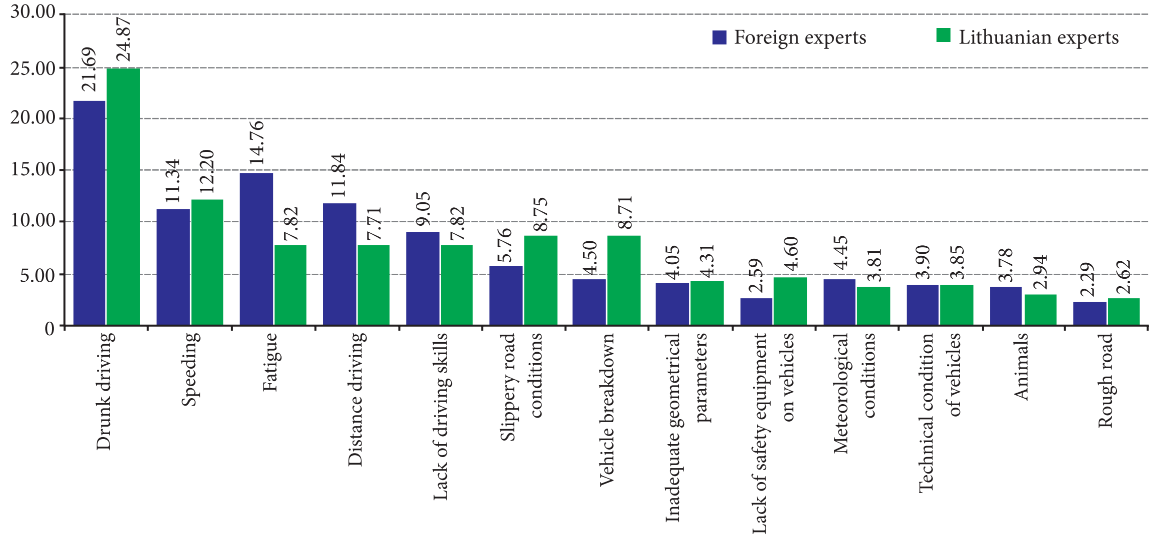

Fig. 3. Distribution of foreign and Lithuanian experts' opinion on the causes of road accidents

The results of interviews of Lithuanian and foreign experts in the first part of research showed that the opinion of foreign and Lithuanian experts is similar – the main accident-causing factor is drinking and driving. By common agreement of the experts from all countries it was decided that the lowest negative effect on traffic safety is represented by rough road pavement. Distribution of experts' opinions is given in Fig. 3.

In the second part, evaluation of the effect of ITS and their applications on traffic safety has indicated that the largest positive effect in the experts' opinion is made by the average speed control systems. This makes 13.4%. The lowest effect on traffic safety is represented by variable message boards. This factor makes 2.3%. Fig. 4 gives the distribution of values of all factors considered by experts. Analysis of interviews of Lithuanian and foreign experts in the second part of research showed that in the opinion of foreign experts the largest positive effect on traffic safety is represented by seat belt control system and in the opinion of Lithuanian experts – average speed system. Distribution of opinions of Lithuanian and foreign experts is given in Fig. 5.

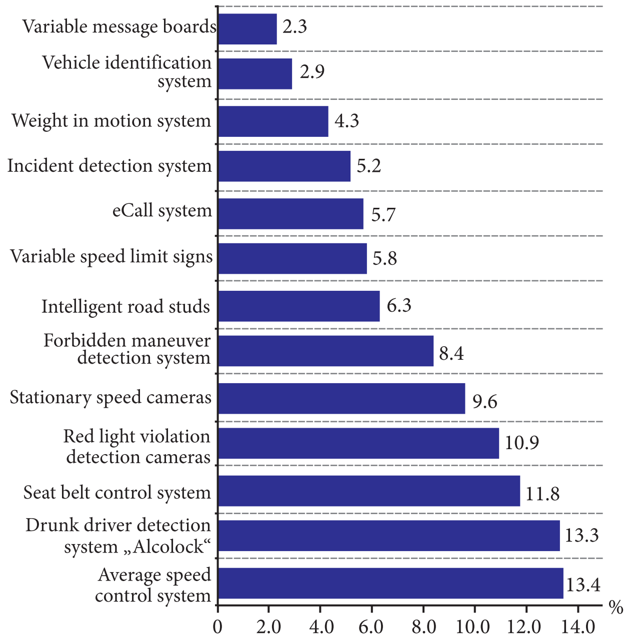

Fig. 4. Distribution results of summed up experts opinion on the effectiveness of ITS measures

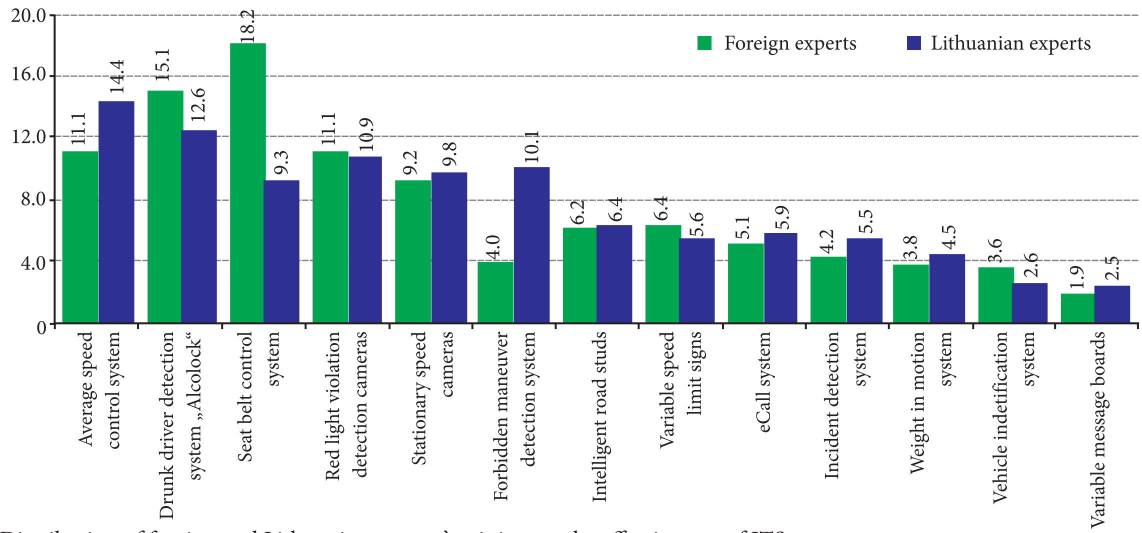

Fig. 5. Distribution of foreign and Lithuanian experts' opinion on the effectiveness of ITS measures

When the results of expert interviews and meta-analysis were compared, it was obvious that the 5 main ITS making the largest positive effect on traffic safety are dominating (Table 3). Two of them (drunk driver detection system "Alcolock" and average speed control system) were determined to be the best in both research stages.

To sum up the research results it can be concluded that the two main accident-causing factors, i.e. speeding and drunk driving, correspond to the statistical accident data of the EU member states. Also, technologies designed for reducing the effect of these factors, i.e average speed control system and drunk driver detection system "Alcolock", were evaluated to be the best systems fortraffic safety improvement.

5. Conclusions

1. The main factors affecting traffic safety in European Union Member States are speeding and drunk driving. These factors are responsible for more than 55% of all road accidents. As the road network and traffic volumes grow rapidly, the new and more effective traffic regulation and control measures should be considered such as intelligent transport systems.

2. According to the expert interviews data the drunk driving is a significant issue for traffic safety. More than 21% of foreign experts and more than 24% of Lithuanian experts highlighted drunk driving as the primary reason for road accidents and deaths. Vehicle breakdown, slippery road conditions, lack of driving skills, fatigue and speeding were determined as next very important aspects with experts' opinion distribution from 7.54% to 11.96%.

3. The meta-analysis evaluation showed that red light violation detection cameras and average speed control systems are the most effective intelligent transport systems regarding the traffic deaths reduction criteria. The effectiveness criterion of red light violation detection cameras is 67% and 60% for average speed control systems. Stationary speed camera is also a very effective intelligent transport system measure with the effectiveness criterion of 44%.

4. According to the expert interviews data the average speed control system and drunk driver detection system "Alcolock" are the most effective intelligent transport systems with regards to the traffic safety criteria. Average speed system is 13.4% and drunk driver detection system "Alcolock" – 13.3%. Forbidden maneuver detection system, stationary speed cameras, red light violation detection system and seat belt control system are also very effective intelligent transport system measures with the effectiveness criterion from 8.4% to 11.8%.

5. Finally, it should be stated that each individual intelligent transport system measure could provide reasonable effect on traffic safety. However, seeking to reach the highest results the effect of individual measures combination should be evaluated. Of course, individual measures could be applied on specific sections where particular problem (e.g. speeding) occurs.

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Table 3. Comparison of experts' interview and meta-analysis results

Importance	Meta-analysis results		Experts' interview results		
	in vehicles	in road network	General	Lithuanian	Foreign
1	eCall system	Red light violation detection system	Average speed control system	Average speed control system	Seat belt control system
2	Drunk driver detection system "Alcolock"	Average speed control system	Drunk driver detection system "Alcolock"	Drunk driver detection system "Alcolock"	Drunk driver detection system "Alcolock"

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