* Corresponding author - PO Box 49, 2600 AA Delft, The Netherlands; Tel: +31 88 866 8498; E-mail: martijn.vannoort@tno.nl

Safety impact assessment for time-continuous ITS in EuroFOT

Martijn van Noort*, Taoufik Bakri, Freek Faber,
TNO, The Netherlands

ABSTRACT

The EuroFOT project executes a large scale FOT that puts more than five hundred instrumented vehicles on the road all over Europe. Most of these vehicles have one or more ITS applications on board and the purpose of the test is to evaluate the societal and individual effects of these ITS, among other on traffic safety.

This paper describes the approach taken in EuroFOT to assess the safety impacts of ITS that operate continuously rather than event driven. This approach has some similarities to existing methods but includes some novel aspects to handle the fact that the ITS are continuously active. The paper further describes the first results of the method applied to sample data from the first phase of the FOT.

Keywords: *safety impact, ITS, FOT*

INTRODUCTION

The EuroFOT project is a project in the 7th Framework Programme that aims to assess the impacts of ITS by conducting a large field trial (Field Operational Test, FOT). The field trial involves hundreds of vehicles with data logging equipment and different combinations of ITS functions on board. Objective data will be recorded at high frequency for an extended period varying from 6 months to one year. This includes CAN data and for some of the vehicles additional data from video cameras and from sensors like a forward looking radar. Subjective data will be recorded in several rounds of questionnaires. More details on the project can be found in [1].

The ITS functions that are present in the test are:

- Adaptive Cruise Control (ACC)
- Forward Collision Warning (FCW)
- Speed Regulation System (SRS).
- Lane Departure Warning (LDW)
- Impairment Warning (IW)
- Blind Spot Information System (BLIS).
- Curve Speed Warning (CSW)
- Fuel Efficiency Advisor (FEA)
- Safe Human-Machine Interaction for Navigation Systems (SafeHMI).

One of the aspects to be investigated is the safety impact of the ITS applications under test, if they were deployed in large numbers. Safety will be assessed in terms of the number of accidents, fatalities and injuries saved by the ITS application if it is installed in a certain fraction of the European vehicle fleet. This can not be done by direct measurements because the number of accidents occurring in the FOT is not expected to be significant. This is typically the case with FOTs, and thus in recent years several approaches have been developed to estimate the safety impact. Some of these methods estimate the impact in terms on fatalities and injuries saved, while others provide a more qualitative estimate. Many use both CAN data and video data. All methods base their estimates on the number and severity of accident related events, and are therefore most applicable to ITS acting on discrete events. For ITS that work in a time-continuous mode these methods are less applicable because their operation induces a time-continuous change in the state of the vehicle (and possibly in the behavior of the driver). Moreover, for time-continuous ITS there is no natural dichotomy of the vehicle states into events and non-events, and therefore it is more appropriate to assess risk continuously over time.

For these reasons this paper introduces a method for *aggregation based safety impact assessment* that is applicable to time-continuous ITS. It estimates the number of accidents as the product of *accident probability*, *accident severity* and *exposure*, following established practice [2]. The first two factors together are called *accident risk* (per kilometer). The third factor measures the number of kilometers driven. The method can be seen as an adaptation of existing methods. In EuroFOT this method will be applied to the functions ACC and SRS. Additional requirements on this method are that it should be usable without video data, because most of the EuroFOT vehicles do not have video data, that it should be usable without in-depth accident statistics, because on the EU level there is only a high level accident database, and that it should run (almost) automatic after initial preparation. The latter requirement is motivated by the huge amount of data being produced in EuroFOT which makes an interactive form of analysis practically impossible. Another motivation is that due to the size of project, the experts working with the data are typically not the safety experts involved in modeling safety impacts. The assessment method is set up such that users of the method merely need to provide the number of kilometers driven under various circumstances, from which the safety impact is determined automatically.

The remainder of this paper is structured as follows. The next section provides an overview of relevant literature on safety impact assessment methods for FOTs. This is followed by a section explaining the aggregation based assessment, and illustrating the approach with the case of rear end crashes. The following section applies the method to a data sample from the EuroFOT project and describes the results. The paper ends with a section on conclusions.

LITERATURE REVIEW

There is an extensive body of literature on assessing safety impacts based on crash counts, see e.g. [3, 12].

These methods are typically used to assess safety as a function of macroscopic traffic characteristics and infrastructure arrangements, and are not applicable to the current situation because significant numbers of crashes are not to be expected in EuroFOT. Here a method is needed that will estimate safety based on some surrogate measures. This literature review discusses some established methods in detail. This will help to understand the differences with the aggregation based method that will be presented in the next section. The methods generally assess the probability and optionally the severity of crashes, and ignore the exposure.

NHTSA developed a method that estimates for a certain crash type the number of fatalities saved by an ITS from data recorded in a FOT, see e.g. [4, 5, 6]. The method assumes that there is data from travels where the ITS is not present (or not turned on), and data from travels where the ITS is present. It further assumes that for this crash type one can identify so-called conflict types S_1, …, S_n. These conflict types are thought to be the events that potentially lead to crashes, but they occur much more often and can be identified from the FOT data. (Despite the name "conflict", they do not necessary involve another vehicle.) It should also be possible to determine from an accident database the incidence of these conflicts in crash situations. The method calculates the number of avoided crashes N_a as follows:

$$N_a = N_{wo}(C) * \sum_i P_{wo}(S_i \mid C) * \left(1 - \frac{P_w(C \mid S_i)}{P_{wo}(C \mid S_i)} \frac{P_w(S_i)}{P_{wo}(S_i)} \right).$$

Here the event of a crash is denoted by C, and $N_{wo}(C)$ is the number of applicable crashes without the application, which is obtained from an accident database. The probability $P_{wo}(S_i|C)$ is the fraction of crashes preceded by conflict type S_i and has to be obtained from the accident database. The ratio $P_w(S_i) / P_{wo}(S_i)$ is called the exposure ratio and is the frequency with which conflicts occur with the system ("w") compared to without ("wo"). This can be measured from the FOT, using CAN and video data. The ratio $P_w(C|S_i) / P_{wo}(C|S_i)$ is called the prevention ratio and measures the ability of the system to prevent crashes after a conflict has occurred, relative to the case without the ITS. This ratio is determined using simulation of simple traffic scenarios.

The relation between the number of avoided crashes and the corresponding reduction in fatalities is obtained by estimating the severity of each conflict type, possibly depending on a further subdivision, for example by the impact of the associated crash.

The NHTSA method produces the kind of results that this paper is after. It is however event based and relies on the use of an accident database that records conflicts and on the use of video data.

Tarko et al. have developed a similar method that calculates safety benefits in terms of avoided crashes using extreme value theory, see e.g. [7]. It is based on measured data regarding conflicts of various types and on the assumption that the probability distribution of conflict severity is a Pareto distribution, including crashes as the most severe conflicts. By matching this distribution to the data one obtains the estimated number of crashes as a function of the measured number of conflicts of varying severity.

This method therefore produces an estimate of the number of expected crashes without use of an accident database, and in an absolute setting, that is, not as a comparison between "with" and "without" cases. It is event based although severity is taken into account, and it relies on the assumption that the severity parameter is Pareto distributed.

Similar methods have been developed and used by other researchers, see e.g. [8, 9, 17]. Furthermore, the use of surrogate safety measures or more subjective measures has been advocated, sometimes in conjunction with microscopic simulation, although validity and reliability remains a serious problem [18, 19]. Pedestrian accidents are investigated in [20] using microscopic simulation and a physical risk model, similar to the one advocated in the present paper. In some of the cited sources the approach does not produce safety benefits in terms of avoided crashes or fatalities, but rather stops at estimates on the number of avoided conflicts. The research often relies heavily on the use of video data to identify conflicts after an initial automatic selection of the data set.

The section concludes with a short review of literature on other safety impact assessment methods that are not necessarily tailored for use with FOT data.

The TRACE project addressed traffic accident causation. A study of existing literature on the safety effects of a large number of ITS functions can be found in [10]. An a priori evaluation of the safety effects of future ITS functions can be found in [11]. It proposes several methods for evaluation, namely expert evaluation, scenario based modeling, in-depth analysis by hand of selected cases and block box modeling.

The eIMPACT project performed a safety impact analysis of 12 ITS safety functions, in terms of changes in the number of fatalities, severe and light injuries [2]. The analysis was based on literature review, expert judgment and accident databases, and considered nine behavioral mechanisms impacting safety.

The AIDE project aimed to develop a risk assessment methodology [12]. It identified vehicle and driver state variables that impact accident risk and attempted to determine associated risk factors.

Carsten and Fowkes describe a method that relates accident risk to speed, based on a literature review [13].

The iCars Network project and the In-Safety project have created overviews of assessment methods [14, 21], listing some of the methods discussed above.

AGGREGATION BASED ASSESSMENT

The safety impact of an ITS is the difference between the expected number of fatalities and injuries with and without the ITS. The expected number of fatalities and injuries is calculated as the product of the accident probability, the accident severity and the exposure. The accident probability is the probability per kilometer that the vehicle will have an accident. The accident severity is the probability that this accident will lead to a fatality or injury. The exposure is the number of kilometers driven.

Fig. 1 shows an overview of the safety impact assessment method that will be used in EuroFOT. The top of the diagram shows the input data that will be available, namely the number of equipped vehicles (the penetration rate), the data logged from sensors (objective FOT data), questionnaires (subjective FOT data) and other sources.

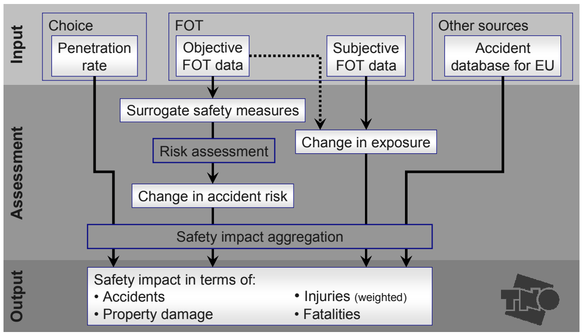

Fig. 1: overview of the safety impact method.

Accident probabilities and severities are estimated in the step "Risk assessment" in the centre of the diagram, based on indicators computed from the FOT data. A change in exposure between the "with" and "without" cases is hard to determine because the effect of the ITS function will be hard to separate from other influences such as the season, the participant's characteristics etc. Therefore, a change in exposure will be taken into account only if both objective and subjective data clearly indicate an effect.

Changes in risk and exposure due to the ITS will be estimated for various accident types and situations. Table 1 shows the accident types under consideration. Situations are distinguished by parameters called situational variables (SV), such as road type, speed limit, lighting and weather. On the one hand, SV's can be used to detail the analysis of risk changes. On the other hand, they are used to resolve unwanted bias in the data by accounting for the distribution of data over the various situations in aggregating the risk, as follows. In the step "Safety impact aggregation" changes in risk per accident type and situation are aggregated by matching these accident types and situations with the accident circumstances recorded in an EU wide accident database, similar to the process used in eIMPACT [2]. The outcome of this calculation can be the expected number of fatalities and injuries separately, where injuries are for example those from certain MAIS categories [15]. Another possibility is to aggregate injuries and fatalities into a single fatal equivalent value, which is obtained by weighting the various injury levels. To fix thoughts this paper considers the expected number of fatalities only.

Table 1: accident types and their share of fatalities and injuries for EU-25 in 2005 (source [2]).

Accident type	**Fatalities**	**Injuries**
Collision on road with pedestrian	13%	11%
Collision on road with other obstacle	7%	6%
Collision off road with pedestrian or obstacle, or single vehicle	22%	13%
Frontal collision	18%	8%
Side-by-side collision	2%	5%
Angle collision	15%	25%
Rear end collision	5%	13%
Other accidents with two vehicles	3%	6%
All other collisions	14%	13%

The focus of this paper is to describe the "Risk assessment" step. It will not go into detail on the other aspects of the method. The risk assessment method can be seen as an adaptation and extension of the methods found in the literature. In short, it considers a *state space* consisting of all possible vehicle and driver states. Of course, the complete state of the driver and vehicle will not be measured, hence the state space is restricted to those variables that can be measured, or can be determined or modeled in another way. Each FOT data point then corresponds to a point in this state space. In principle, one could associate a risk to each point, and then aggregate the risk over all data points measured in the FOT to obtain a total risk. Because of the large number of FOT points, the calculation is eased by dividing the entire state space into rectangular boxes or *cells*, and associating a *risk factor* to each cell. The idea is to choose the cells such that the risk does not vary much within a cell. Then the total risk can be estimated by determining the fraction of FOT data points in each risk cell. The method consists of the following steps:

1. Select an accident type and identify corresponding risk indicators
2. Create a risk matrix and fill it with risk factors
3. Collect the FOT data with and without the ITS in the risk matrix
4. Aggregate the data in the risk matrix to produce a *risk reduction factor* for the ITS for the selected accident type.

The steps will be explained in more detail below, and will be illustrated by the example of rear end collisions.

Risk indicators

The method is applied separately for each accident type. For a chosen accident type, one first selects risk indicators, that is, state variables of the vehicle or the driver that are presumed to be indicative of the risk for this accident type. For the case of a rear end collision the following six risk indicators are selected: speed, time headway, reaction time and acceleration of the ego vehicle[1], speed and acceleration of the predecessor.

Risk matrix

The n risk indicators span an n-dimensional space. This space is partitioned into rectangular cells by dividing the value range of each risk indicator into a finite set of intervals. A cell is the set obtained as a product of intervals, one interval per indicator. In two dimensions this yields a matrix like structure, like in Fig. 2. In general it will be a higher dimensional structure. This will be called the risk matrix (in any dimension). The cells in the risk matrix will be indexed by $C_{i_1,i_2,\ldots,i_n}$, as illustrated in the figure, where i_k indexes the interval of the k-th risk indicator. Each cell of the matrix will hold a risk factor $R_{i_1,i_2,\ldots,i_n}$, which is the accident risk per unit travel distance of a vehicle and driver in the state determined by the cell, relative to some user-defined default risk. The default risk can be chosen arbitrarily, but should be the same with and without the ITS – for example, the average accident risk per unit distance over all driver states without the ITS, as obtained from accident and mobility statistics. A risk factor greater than one means that travel in that cell is riskier than the default risk; a factor less than one means that it is safer than the default risk. These risk factors can be obtained in various ways, for example with the *physical risk model* described at the end of this section. In this way, risks are associated to vectors of parameter values, allowing for non-trivial dependencies between the variables. In other words, the risk is a multivariate function of the risk indicators. This is a much more versatile model than a multiplication of univariate probability functions, which is the model in case the risk indicators are modeled as independent factors. This versatility allows for a non-trivial dependence of risk on speed and time headway.

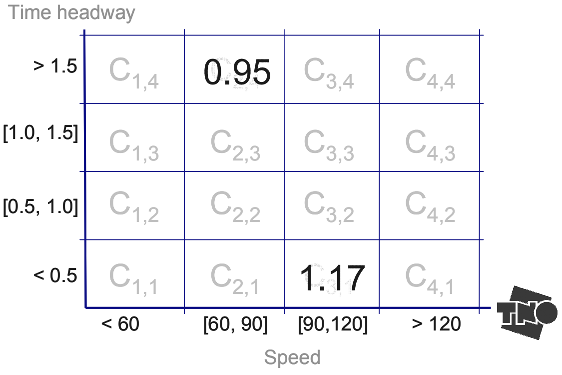

Fig. 2: Example risk matrix in two dimensions, showing the cell indexing and some example risk factors. The numbers are hypothetical and for illustration only.

Fig. 2 shows an example for the case of a rear end collision, where for ease of viewing only two of the six dimensions of the risk matrix are displayed. In the simplest setting one constructs a single risk matrix for an accident type, but it is also possible to create separate matrices for the cases with and without the ITS, or for various situations, if there is reason to do so.

FOT data

Each FOT data point belongs to a cell of the risk matrix. This is used merely to calculate the total distance travelled in that cell, as illustrated in Fig. 3. Let $D_{w;i_1,i_2,\ldots,i_n}$ and $D_{wo;i_1,i_2,\ldots,i_n}$ denote the total distance travelled in cell $C_{i_1,i_2,\ldots,i_n}$ with and without the ITS, respectively.

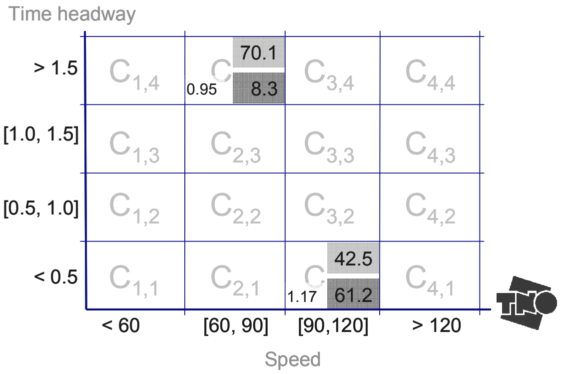

Fig. 3: Example risk matrix in two dimensions, showing for two cells the hypothetical risk factors and distance travelled without the ITS (light shading) and with the ITS (heavy shading).

Aggregation

The total relative risk is aggregated by multiplying the distance travelled in a cell by the risk factor of that cell, and adding the result for all cells. For the example of Fig. 3 this means that the total relative risk without the ITS is $\mathrm{R}_{\mathrm{wo}} = 0.95 * 70.1 + 1.17 * 42.5 + \cdots$ and with the ITS it is $\mathrm{R}_{\mathrm{w}} = 0.95 * 8.3 + 1.17 * 61.2 + \cdots$. These numbers have no absolute meaning and can only be interpreted relative to each other as a risk reduction factor R_w/R_{wo}, as follows. The number of fatalities for this crash type (and situation, if the risk matrix is created for a specific situation) without the ITS can be obtained from an accident database. If this number is N_{wo} then the number of fatalities avoided by the ITS equals

$$\mathrm{N_a} = \mathrm{N_{wo}} * \left(1 - \frac{\mathrm{R_w}}{\mathrm{R_{wo}}}\right) = \mathrm{N_{wo}} * \left(1 - \frac{\sum_{i_1,i_2,\ldots,i_n} D_{w;i_1,i_2,\ldots,i_n} R_{i_1,i_2,\ldots,i_n}}{\sum_{i_1,i_2,\ldots,i_n} D_{wo;i_1,i_2,\ldots,i_n} R_{i_1,i_2,\ldots,i_n}}\right).$$

Notice the similarity with the NHTSA formula.

Physical risk model

The risk factor $R_{i_1,i_2,\ldots,i_n}$ for a cell can be determined

---

[1] The ego vehicle is the vehicle participating in the FOT, while the predecessor does not necessarily participate.

with a physical risk model that models a hypothetical accident scenario starting from initial states from this cell. Each accident type has its own accident scenario(s) and therefore its own physical risk model. The accident scenarios attempt to determine a (relative) accident probability and fatality risk for their initial states.

The approach is illustrated for the case of rear end collisions, see Fig. 4. This is one of the easier accident types to model, because the dynamics is relatively straightforward and the required data can largely be obtained from the FOT. The ego vehicle is following another vehicle with a certain speed, speed difference and time headway. The scenario assumes that at this moment the predecessor suddenly brakes with a certain deceleration. The ego vehicle will then also brake with some deceleration, but only after an initial reaction time. The scenario assumes for simplicity that the braking is constant throughout the scenario. In this setting, the evolution of the vehicle dynamics can be calculated and it can be determined whether a collision will take place and if so, with what impact speed.

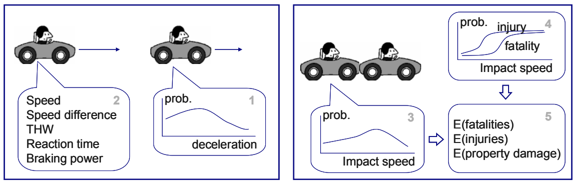

Fig. 4: rear end collision accident scenario. Left shows the situation before the collision, right after.

The impact speed can be translated into a fatality risk. This relation is e.g. defined by [16] with empirical crash data from the U.S. collected in the CDS accident database. In order to obtain the risk factor for a cell, one runs a large number of Monte Carlo simulations for initial conditions from this cell and calculates the average fatality risk.

A few remarks can be made on this method. Firstly, similar approaches can be found in the literature, see e.g. [4, 5, 6, 7].

Secondly, the starting condition of this accident scenario is comparable to the FOT data points in its risk cell and hence likely to occur in reality. However, the *evolution* of the scenario is highly unlikely in reality. Indeed, one expects that for many risk cells a significant proportion of starting conditions will lead to a crash in the scenario, while they will not lead to a crash in the FOT. Reasons for the difference are for example that the predecessor does not brake as hard as in the scenario, or that the ego vehicle executed some evasive maneuver. This means that in order to estimate the risk factor correctly, one needs to determine the probability p of the accident scenario, which may be difficult to do. However, assuming that this probability is the same for all risk cells, and that it is the same with and without the ITS[2], then all risk factors are wrong by a factor of p and hence this factor cancels out in the formula for the number of avoided fatalities.

Finally, some of the starting parameters are not measured in the FOT. Deceleration of the predecessor and reaction time are not measured at all. Although decelerations of the FOT vehicle are measured, it is unlikely that hard braking scenarios will occur with sufficient frequency to be statistically significant. Therefore the parameters that are not measured are modeled in another way, for example by drawing their values from probability distributions, taking into account correlations.

APPLICATION AND RESULTS

The results presented below are based on a FOT data sample from the first German test site in EuroFOT. As the data collection is still on going, the sample is limited in size and not representative. Hence the results reported below are preliminary and not validated – they are merely meant to illustrate the method. Two sets of data were analyzed:

- A baseline set consisting of 10 trips of about 150 km each, where no ITS is present in the vehicle (but all data acquisition and logging systems are active).
- A treatment set consisting of 23 trips of around 200 km each, where an ACC system is available to the driver.

From these FOT data, the probability of a fatal rear end crash is estimated using the risk matrix and physical risk model of the previous section. This yields a relative fatality risk of 1.7 x 10^{-3} per km without ACC, and 4.7 x 10^{-4} per km with ACC, leading to a risk reduction factor of 0.28. From an accident database we know that the fatality risk for rear end crashes without ACC in Europe is 5.0 x 10^{-10} per km in 2005 [2]. Thus, based on this data sample, the fatality risk with 100% ACC would be 1.4 x 10^{-10} per km. This is the benefit of *having* ACC, not of actually *using* it.

Various situational variables were recorded, including road type, speed limit and traffic state. Fig. 6 shows that the treatment set was driven on motorways for 94% of the time, and the baseline for only 86%. This means that road type can be a confounding factor with some impact on risk. The risk reduction factor for motorways is 0.18, and for rural and urban roads it is 0.0080 and 0.0028 respectively (although the latter two are based on very little data and therefore highly unreliable). Thus, ACC is considerably more effective on each road type than the general estimate suggests, and road type needs to be accounted for as a confounding variable.

---

[2] This is a reasonable assumption, at least at low penetration rates of ACC. At high penetration rates, the character of the traffic flow may change and this assumption may no longer hold. For the moment and in the absence of solid evidence to the contrary, this secondary effect is ignored.

A similar analysis can be performed for the other SV's. Some further open issues, to be addressed in future work, are for example the sensitivity with respect to the reaction time, or the reliability of the outcomes.

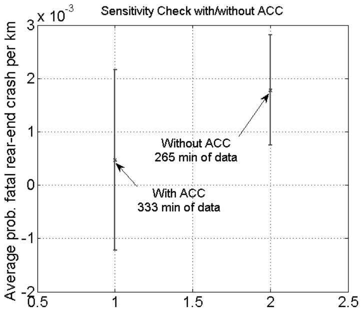

Fig. 5: Average probability of a fatal rear-end collision per kilometer, assuming the hypothetical hard braking scenario. The bars show the standard deviation

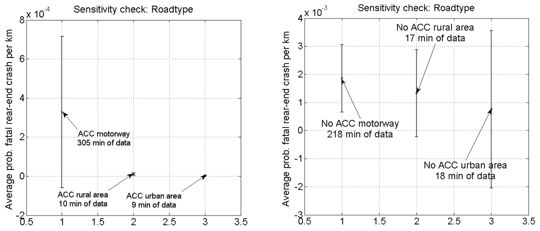

Fig. 6: Effect of road type on the risk

CONCLUSIONS

This paper has introduced a safety impact assessment method that will be used in EuroFOT to evaluate the safety effect of continuously operating ITS in terms of fatalities and injuries, based on data recorded in the FOT and external data sources such as accident statistics. Its strong points compared to many other existing methods are:

- Results are given in terms of societal impacts and can be used in a cost benefit analysis.
- Modular setup: one can easily replace the risk factors or the accident database by alternative values and redo the calculations.
- Limited data needs: no video data is needed.
- Ease of use: once the risks are precompiled, the FOT experimenters only need to record the distance travelled in each risk cell.

ACKNOWLEDGMENTS

The authors would like to thank the anonymous referees for helpful suggestions in the preparation of this paper.

REFERENCES

[1] Benmimoun A., Benmimoun M., Wilmink I., van Noort M. (2009). EuroFOT: Large scale field operational tests – impact assessment, ITS World Congress, Stockholm, 2009.

[2] Wilmink I., Janssen W., Jonkers E., Malone K., van Noort M., Klunder G., Rämä P., Sihvola N., Kulmala R., Schirokoff A., Lind G., Benz T., Peters H., Schönebeck S. (2008). Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe, eIMPACT deliverable D4, http://www.eimpact.info

[3] Geedipally S.R., Patil S., Lord D. (2010). Examining Methods for Estimating Crash Counts, *Transportation Research Record* **2165**, pp. 12-20.

[4] Najm W.G., daSilva M.P., Wiacek C.J. (2000). Estimation of Crash Injury Severity Reduction for Intelligent Vehicle Safety Systems, SAE 2000 World Congress, Detroit (MI), March 6-9, 2000.

[5] Najm W.G. (2003). Alternative Methods for Safety Benefits Estimation, U.S. Department of Transportation National Highway Traffic Safety Administration, March 2003.

[6] Najm W.G., Stearns M.D., Howarth H., Koopmann J., Hitz J. (2006). Evaluation of an Automotive Rear-End Collision Avoidance System, NHTSA report, April 2006.

[7] Tarko A.P. (2011). Surrogate events in modeling traffic safety – a road departure case, TRB 2011, Washington DC, January 23 – 27, 2011.

[8] Batelle (2007). Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test, report for US DoT, January 5, 2007.

[9] Blanco M., Bocanegra J.L., Morgan J.F., Fitch G.M., Medina A., Olson R.L., Hanowski R.J., Daily B., Zimmermann R.P. (2009). Assessment of a Drowsy Driver Warning System for Heavy-Vehicle Drivers – Part I: Safety benefits and performance/capabilities, NHTSA report, April 2009.

[10] Bayly M., Fildes B., Regan M., Young K. (2007). Review of crash effectiveness of Intelligent Transport Systems, TRACE Deliverable D4.1.1 – D6.2, http://www.trace-project.org

[11] Karabatsou V., Pappas M., van Elslande P., Fouquet K., Stanzel M., Fildes B., de Lange R. (2007). A-priori evaluation of safety functions effectiveness - Methodologies, TRACE Deliverable D4.1.3, http://www.trace-project.org

[12] Janssen W., Nodari E., Brouwer R., Plaza J., Östlund J., Keinath A., Toffetti A., Alonso M., Rimini-Doering M., Portouli V., Horst D., Marberger C., Vega H., Cherri C. (2008). Specification of AIDE methodology, AIDE deliverable D2.1.4

[13] Carsten O., Fowkes M. (2000). External vehicle speed control – Executive summary of project results, report by University of Leeds and MIRA, July 2000, http://www.its.leeds.ac.uk

[14] Rämä P., Kulmala R., Lüdeke A., Blanco R., Sánchez D. (2009). Comparison of impact assessment methods for intelligent vehicle systems, iCars deliverable D3.2, http://www.icarsnetwork.eu

[15] Gennarelli T.A., Wodzin E. (2008). *The Abbreviated Injury Scale 2005 – Update 2008,* American Association for Automotive Medicine (AAAM), Des Plaines (IL).

[16] Nordhoff L.S. (2005) Motor vehicle collision injuries: biomechanics, diagnosis, and management, 2005

[17] Gordon, T., Sardar, H., Blower, D., Ljung Aust, M., Bareket, Z., Barnes, M., Blankespoor, A., Isaksson-Hellman, I., Ivarsson, J., Jurhas, B., Nobukawa, K., Theander, H. (2010). Advanced crash avoidance technologies (ACAT) program – Final report of the Volvo-Ford-UMTRI project: safety impact methodology for lane departure warning – Method development and estimation of benefits, U.S. Department of Transportation National Highway Traffic Safety Administration, October 2010.

[18] Archer, J. (2005). Indicators for traffic safety assessment and prediction and their application in micro-simulation modelling: A study of urban and suburban intersections, PhD Thesis, KTH, Stockholm, Sweden 2005.

[19] Gettman, D., Pu, L., Sayed, T., Shelby, S. (2008). Surrogate Safety Assessment Model and Validation: Final Report, FHWA report FHWA-HRT-08-051, June 2008.

[20] Ma, X., Andréasson, I. (2005).Predicting the effect of various ISA penetration grades on pedestrian safety by simulation, *Accident Analysis & Prevention* **37** (6), 2005.

[21] Dijkstra, A., Bald, S., Benz, Th., Gaitanidou, E. (2008). Overview of resulting tools, guidelines, and instruments, In-Safety DL3.4, February 2008.