SOCIO-ECONOMIC VIABILITY OF SAFESPOT COOPERATIVE SAFETY SYSTEMS

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ABSTRACT: This paper describes the results of a socio-economic assessment of two co-operative safety systems. One of the systems is based on V2V communication, the other one is based on V2I communication. Both systems are composed of a bundle of applications which have been designed to provide road safety information to the driver. An integrated assessment approach was applied in this study using cost-benefit analysis and stakeholder analysis. The results of the impact assessment show a considerable increase of road safety for both systems. Benefit-cost ratios calculated for the V2V based system are acceptable from a society point of view, whereas the efficiency of the V2I system could not be proved in case of a large-scale equipment of infrastructure. The findings lead to the conclusion that added value can be achieved, if a combined solution (V2V plus V2I) is implemented and low-scale equipment of infrastructure concentrates on accident black spots.

1 BACKGROUND AND OBJECTIVES OF THE STUDY

Cooperative safety systems promise a large potential to reduce the negative societal impacts with regard to road safety, traffic flow, energy consumption and emissions. In contrast to their potential, cooperative systems are not yet widely deployed due to the novelty of the technologies used. Therefore, the development of proper deployment strategies leading to a good market take-up is one of the challenging issues in order to make use of the expected benefits. This makes it necessary to evaluate the impact of these systems in order to provide a basis for rational decisions.

The socio-economic assessment described in this paper was performed within BLADE, a sub-project of the integrated project SAFESPOT funded by the European commission. The main goal of the study was to prove, whether the SAFESPOT systems under consideration are profitable from a society point of view. The results received from the assessment contributed to the selection of appropriate business models and the development of a deployment program within BLADE. The two co-operative systems considered in the socio-economic assessment were based on vehicle-to-vehicle communication (V2V) and vehicle-to-infrastructure communication (V2I). A special question of SAFESPOT is how to distribute the intelligence between V2V and V2I technologies in order to achieve the objective of a well balanced system regarding benefits and costs. For this, it had to be investigated which way is both effective in terms of improving road safety and efficient in terms of benefits and costs to society at large as well as to particular stakeholders. This paper focuses on the results from the society point of view provided by a cost-benefit analysis and a sensitivity analysis.

2 ASSESSMENT FRAMEWORK AND METHODOLOGY

The methodology was based on knowledge gained from previous projects. The fundaments for socio-economic impact assessment of intelligent vehicle safety systems on European level were laid in the SEiSS study (Exploratory Study on the potential Socio-Economic impact of the introduction of Intelligent Safety Systems in Road Vehicles) [1] which addressed one of the recommendations of the eSafety Working Group on road safety. It explored the methodological basis for socio-economic impact assessment of intelligent vehicle safety systems and demonstrated the workability of the approach by some cost-benefit case studies. The follow-up assessment project eIMPACT was the first study which covered a wide range of systems. It analysed the socio-economic impacts of twelve stand-alone and co-operative systems with the help of full-fledged cost-benefit analyses [2]. From eImpact, especially analytical foundations [3], data base [4] and empirical findings [5] have been used in this study. More recently, the CODIA study (Co-operative systems Deployment Impact Assessment) has been published which concentrated exclusively on the assessment of cooperative systems [6]. The thus derived state-of-the-art assessment framework was then adapted to specific research questions of SAFESPOT [7].

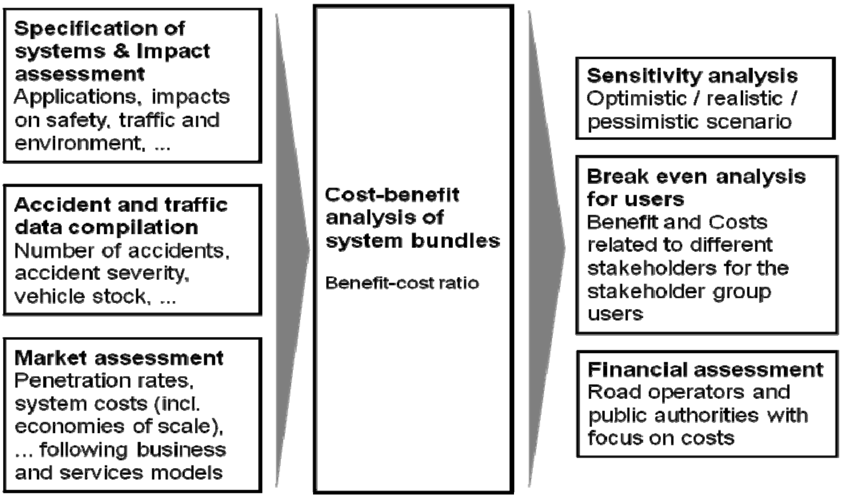

Fig.1. Methodological approach

In this study an integrated assessment framework was used which consisted of cost-benefit analysis (CBA), sensitivity analysis, and complementary stakeholder analyses. The core of the comprehensive methodology was the CBA on society level. The CBA valued the impacts of each system on safety, traffic flow and environmental indicators, quantified the impacts in monetary units, and compared them to the system costs by calculating the benefit-cost ratio. Benefits are the money value of the resulting of savings calculated from the impacts. In contrast, costs are generated by investments in the in-vehicle devices and the complementary infrastructure equipment, and operating and maintenance of the systems.

In the sensitivity analysis variations of important parameters were calculated in order to reveal the real drivers for the result. The sensitivity analysis also included a scenario analysis which discussed some conceptual scenarios depending on different rates of infrastructure equipment and provides the possible effects on costs and safety benefits. Additionally, stakeholder analyses checking the profitability of the cooperative systems from the point of view of vehicle drivers, road operators and public authorities were undertaken.

3 APPLICATIONS AND DEDICATED ACCIDENT SCENARIOS

The two SAFESPOT co-operative systems under consideration address major areas of road safety: accidents at intersections, accidents due to hazardous road and weather conditions, and accidents due to speeding and inappropriate distance. By providing warnings and giving advice to the driver the systems aim at increasing both the driver perception of near danger and the driver perception of safe driving behaviour. For each of the two systems a bundle of applications was defined in collaboration with the technical subprojects of SAFESPOT (Figure 2).

Applications of the V2V bundle

1. Lateral Collision Warning – LATC: Road intersection safety
2. Road Departure Warning – RODP: Road condition status - Slippery Road
3. Longitudinal Collision Warning – LONC: Speed limitation and safe distance

Applications of the V2I bundle

1. Co-operative Intersection Collision Prevention – IRIS: Basic application
2. Hazard and Incident Warning – H&IW: Reduced friction or visibility

Fig.2. Bundles of safety applications considered in the assessment

The corresponding applications of the V2V based system and the V2I based system feature nearly the same use cases and services. This analogy was the prerequisite for comparing both systems with regard to communication technology. Both the "V2V Lateral Collision warning" and the "V2I Co-operative Intersection Collision Prevention" are applications which aim at preventing dangerous situations at intersections. The “V2V Road Departure Warning” and the “V2I Hazard and Incident Warning” applications provide safety relevant information to the driver regarding hazardous road and weather conditions. Safety relevant information concerning speed is provided by the “V2V Longitudinal Collision Warning” application and the “V2I Speed alert” application.

The specification of the general human machine interface for the SAFESPOT applications envisages the use of suitable earcons (audio sample) in order to draw the driver’s attention to the warnings immediately. The earcons will be combined with visual and haptic attractors where necessary and suitable. In addition, visual information can be gathered from the central display of the vehicle.

4 INPUT DATA USED FOR SOCIO-ECONOMIC ASSESSMENT

In order to perform a socio-economic assessment of safety systems the impacts on safety, traffic flow and the environment have to be thoroughly analyzed. But this information, for instance the effectiveness to prevent an accident or to mitigate at least its impact, has to be combined with realistic data on road safety and traffic environment. The assessment must also reflect realistic market conditions for the deployment of the new systems which affect the achievable market penetration rates. Finally, the system costs have to be determined.

Since cooperative systems are not yet on the market or installed only to a very little degree, the year 2020 was chosen as the time horizon for the socio-economic assessment. The target year 2020 is not too close after the market introduction which is expected for 2015. Due to the availability of accident data the geographical area of the EU-25 was considered.

4.1 Accident and traffic data

The accident categories used for the description of the applications and the safety impacts have to suit the accident classification of the accident data base. To get an adequate classification of accidents the accident categories of the CARE database (Community database on Accidents and Roads in Europe) were used. The reference year of the accident data compiled was 2005. But the CARE database provides only limited data. BLADE therefore made use of additional data which had been compiled in co-operation between the projects eIMPACT and TRACE in order to get current data for the EU-25. For efficiency reasons, the countries of the EU-25 were grouped into three country clusters which differed in the level of road safety performance based on the number of fatalities in 2005.

The accident data compilation for the year 2005 provided shares of accidents, fatalities and injured for different accident categories thus giving insight into the potential of safety measures targeting those types of accidents. For instance, if a safety system targets side-by-side collisions, the potential of the system in avoiding fatalities can not exceed 2 %, even at high penetration rates and high effectiveness of the system.

The future trend of total numbers of fatalities and injured was forecasted for the target year 2020 by using time series analysis. Being based on accident data for the period 1991 to 2005, the forecast of fatalities took into account the effects of all measures taken for the improvement of road safety at any level in the EU within this time period. Hence, it is presumed for the road safety prediction that the already implemented measures will still be effective in the future – however, with decreasing effectiveness – and that no additional efforts are made to reduce the number of accidents and casualties. Based on a total of 41,304 fatalities in 2005 the forecast resulted in a total of 20,791 fatalities in 2020.

The traffic data on vehicle stock, vehicle mileage and distribution of level of road services used in this study were the same as used in the eIMPACT project [3, 5].

4.2 Penetration rates

The estimation of the penetrations rates of the SAFESPOT cooperative system is based on an experts´ survey about the market potential of the systems in new vehicles (Table 2). This estimation was made with respect to different business and service models concerning the financing of the systems and services provided. The basic distinction between business and service models can be found in charging. In a business model the system is partially or completely funded by public authority, whereas in a service model the system is completely financed by private investors and thus finally paid by the end user. In the service model „plus" the SAFESPOT system and additional service features are included.

Table 1: Estimated fleet penetration rates for selected Business and Service models

Model	V2V system	V2I system
Business model – Public	6.7 %	7.9 %
Business model – Public/Private	8.7 %	9.5 %
Service model – Private	4.2 %	5.4 %
Service model plus – Private	6.1 %	7.7 %

As suggested by eIMPACT [4] the estimates for the penetration rate of new vehicles were concerted to fleet penetration rates in the year 2020. It was assumed that the vehicle age distribution would remain the same in 2020 as in 2005.

4.3 System costs

System costs consist of investment costs as well as operating costs and maintenance costs which are due to the implementation of the technology. The investment costs in case of the V2V solution are given by the sum of the component costs for the in-vehicle systems, in case of V2I the investment costs are the sum of costs for equipping the vehicles and the infrastructure.

It had to be taken into account that each SAFESPOT system is made of a bundle of applications. If a component is needed by two or more applications, the applications can share access to this component, so that the component is needed only once. This results in bundle costs which are lower than the sum of costs needed for systems with accordant stand-alone applications. The synergies help the bundle to achieve a higher profitability [8].

The costs of the single components were estimated by technical experts of the SAFESPOT project from a project internal expert enquiry. For confidentiality reasons an iterative estimation process was used which took the fleet penetration rates shown above into account. The implementation costs were calculated using a 5 % mark-up to the sum of component costs [5].

The system costs were distributed over the lifetime of the systems. It was assumed that the lifetime of the systems equals the average lifetime of the vehicles. For calculation of the yearly costs a discount rate of 3 % and a lifetime of 12 years were assumed.

The components of the SAFESPOT V2V application bundle contain a communication tool (including antenna and cables) and a display. These components were assumed to be standard equipment in 2020 and thus will not lead to extra costs. Further, the V2V system needs a dual frequency GPS, digital maps including intersections, a warning module and a long-range radar at the front end. Component costs depend on penetration rate, because market penetration is interrelated to production output. Therefore a degression rate of 16 % was used thus taking into account the cost reduction when doubling the penetration rate. To determine the complete costs for the equipped vehicles, the component costs have to be multiplied with the number of equipped vehicles, i.e. expected vehicle stock of the year 2020 multiplied by the penetration rate. The costs of the V2V system are shown in Table 3.

Table 2: Estimated costs of the V2V system for the considered penetration rates

Fleet penetration rate	Equipped vehicles [Mill.]	Costs per system [EUR]	Operating costs per system [EUR p.a.]	Total costs [Mill. EUR p.a.]
4.2 %	13.0	151.20	6.00	276
6.1 %	18.6	140.71	5.15	359
6.7 %	20.5	138.19	4.96	386
8.7 %	26.7	131.41	4.45	471

The V2I in-vehicle system uses the same basic equipment as the V2V in-vehicle system. In addition to the in-vehicle system, the V2I system needs components for the infrastructure equipment. Besides CCTV video cameras which are assumed to be standard equipment in 2020 roadside units and dedicated antenna systems, automatic ice detection systems, laser scanners, and digital maps including intersections were considered. The present study firstly assumed that an infrastructure equipment rate of 50% will cover almost all of the accidents in the EU-25. This assumption was relaxed in a later stage where the effects on costs of lower infrastructure equipment rates were assessed.

Table 3: Estimated costs of the V2I system for the considered penetration rates and an infrastructure equipment of 50 %

Fleet penetration rate	Equipped vehicles [Mill.]	Total vehicle costs [Mill. EUR p.a.]	Infra-structure equipment rate	Infra-structure costs [Mill. EUR p.a.]	Total costs [Mill. EUR p.a.]
5.4%	16.6	190.0	50%	4,902	5,092
7.7%	23.6	231.0	50%	4,902	5,133
7.9%	24.3	234.2	50%	4,902	5,136
9.5%	29.2	257.9	50%	4,902	5,160

5 RESULTS

5.1 Impact assessment

The main goal of the SAFESPOT safety systems is to reduce the number of accidents and road fatalities. Avoiding accidents respectively achieving mitigation by reducing the numbers of fatalities and heavily injured, represent the direct benefits of road safety technologies. Beneath improvement of road safety further effects may occur, e.g. effects on traffic efficiency and on environment, and have to be taken into account. Avoided accidents and harmonized traffic flow can result in reduced fuel consumption and less exhaust emissions.

The impact analysis showed considerable safety effects resulting in 7.1 % less fatalities for the V2V case, and 8.9 % for the V2I case, assuming a 100 %-penetration rate of cooperative systems into the vehicle fleet. (see Table 5).

Table 4: Estimates for behavioural mechanism effects of the SAFESPOT systems

System	Fleet penetration rate [%]	Safety Impact	
		Fatalities [%]	Injured [%]
V2V system	100	-7.1	-7.3
V2I system	100	-8.9	-8.5

The approach used for safety impact assessment was based on work that has been performed in eIMPACT [4]. This approach aims to capture all possible effects of cooperative systems on driving behaviour and on accidents in a systematic manner. Human performance was taken into account by basing the safety impact of each application on empirical studies, behaviour-accident risk models and theoretical insights in driver performance. Furthermore, the eIMPACT methodology account for behavioural effects, such as adaptation, change of modality etc. Since in SAFESPOT bundles of applications were assessed the safety impacts of the bundles were derived by aggregating the impacts of the individual applications.

The reliability of the technology (i.e. communication, sensing, positioning etc.) was assumed to be sufficient robust and accurate. However, we took into account that not all potential traffic conflicts can be predicted on time. In order to avoid double counting of safety effects in case that applications aim at the same accident type the approach had to be extended. Thus, only one application per specified accident type was considered in those cases where an overlapping of safety effects occurred, and no additional effect on human performance was assumed. In this respect our impact estimation was cautious, and safety effects achievable in real traffic may be higher.

Based on an estimation of the trend in fatalities and injured for 2020 in the EU-25 region, an estimation of the maximum number of avoidable fatalities and injured was made assuming that 100 % of the vehicle fleet are equipped with the systems. From this forecast it can be expected that the V2V based SAFESPOT system has a safety potential of avoiding up to 1,470 fatalities and 63,000 injured. The V2I based system can avoid up to 1,850 fatalities and 74,000 injured.

Besides safety impacts, no direct effects on traffic flow, fuel consumption and resulting emissions could be shown. In accordance with former studies these effects are assumed to be marginal because the applications in the bundles considered were primarily designed for safety purposes.

5.2 Cost-Benefit Analysis

The distinction between V2V and V2I communication applications is important for the CBA because the attainable benefits depend on the communication strategy of the system application. Vehicles using V2V communication have to meet other equipped vehicles in order to transmit data. The probability of meeting other vehicles increases with fleet penetration rate. But a critical number of equipped vehicles have to be reached in order to generate benefits of the V2V communication at all. Former Studies show that V2V systems can only work properly for penetration rates above 5 % [9]. For V2I communication the efficiency also increases with fleet penetration rate, because an increasing number of vehicles can make use of the installed infrastructure devices. But a critical mass of equipped vehicles does not exist for V2I communication. Once the infrastructure has been implemented every vehicle equipped with a V2I in-vehicle device can communicate with infrastructure devices independent from the fleet penetration rate.

Benefit-cost ratios (BCR) were derived using the safety effects, the accident trend data, cost estimations, and forecasted market penetration rates for the SAFESPOT systems. For the V2V based SAFESPOT system, BCR values ranging from 1.0 to 1.1 were found for the estimated fleet penetration rates in 2020 (Figure 3). From a society point of view, the BCR results achieved for the V2V based system are acceptable.

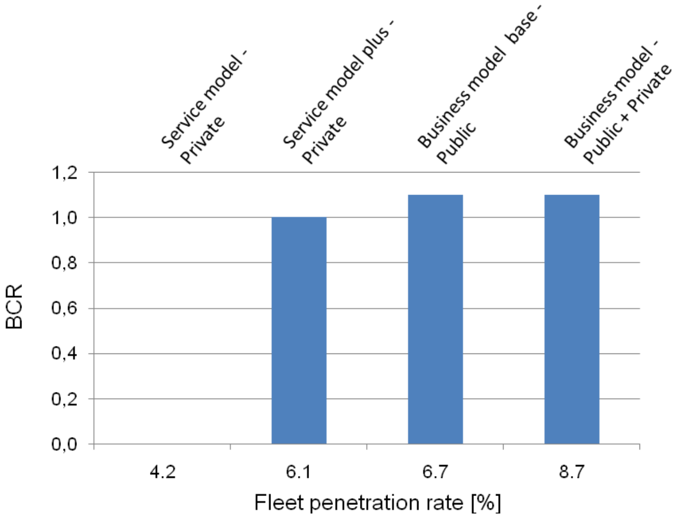

Fig.3. BCR of the V2V based system for different penetration rates

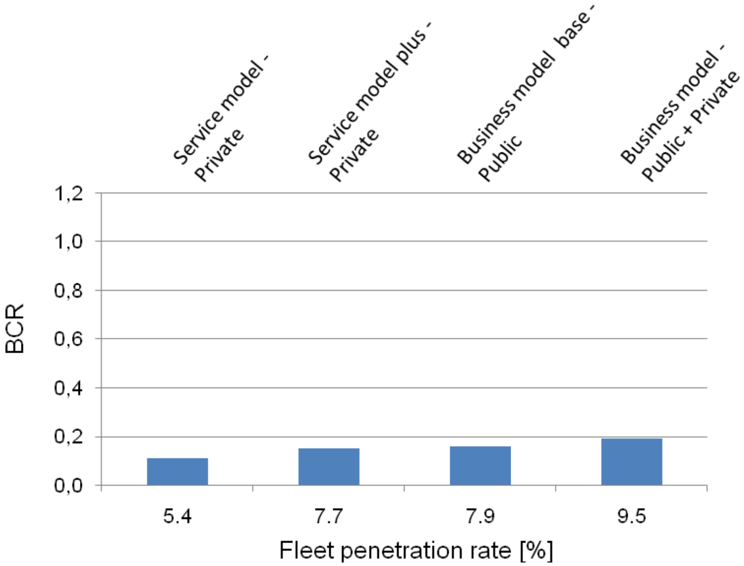

Fig.4. BCR of the V2I based system for different penetration rates (baseline scenario, large-scale infrastructure equipment)

In contrast to the V2V case, the benefit-cost ratios calculated for the V2I based SAFESPOT system are clearly lower than 1. The calculation is based on an infrastructure equipment rate of 50 %. The low BCR of the V2I system is mainly caused by the high costs resulting from the large-scale equipment of infrastructure. This result indicates that the V2I based SAFESPOT system is not efficient under the given assumptions from a society point of view.

5.3 Scenario analysis

The infrastructure cost of a large-scale infrastructure equipment outweighed the safety benefits of the V2I based SAFESPOT system. Scenarios with far lower infrastructure equipment rates have been also analyzed and point at options how to create larger benefits of the V2I system at limited costs. To get a better understanding of the necessary investment in infrastructure to capture the safety benefits of the V2I based system in a cost efficient way a case study focusing on the Netherlands was performed. The case study is based on the assumption that the location of black spots of accidents is perfectly predicted and that by equipping these locations with road side units all accidents could by avoided. Three scenarios have been considered assuming the (1) equipment of the accident black spots on highways and at intersections where an accident occurred in 2008, (2) equipment of the same accident black spots as in the year 2008, but now preventing accidents for a period of 20 years, (3) equipment of accident black spots at important roads and intersections of the past 20 years, and assuming preventing accidents for the next 20 years.

All scenarios show higher benefit-cost ratios than calculated for the baseline V2I case. However, the result we derived here is based on the assumption of perfectly predicting all black spots of accidents and preventing all these accidents. These assumptions are, of course, idealistic, but still show the impact of a smarter concept of equipping the infrastructure compared to large-scale equipment. The scenario analysis revealed, from a society point of view, that the profitability of the V2I based system could be increased, if the equipment of infrastructure is done on a smaller scale concentrating on accident black spots.

6 CONCLUSIONS

The overall results of the socio-economic impact assessment provide some indication for deployment strategies for the SAFESPOT cooperative systems. It seems that added value in terms of increased safety benefits can be achieved, if the V2V based SAFESPOT system and the V2I based SAFESPOT system are combined. Both the V2V system and the V2I system use the same hardware for the in-vehicle device. Once V2V is implemented, no additional costs for the in-vehicle device arise in order to put V2I into effect for the SAFESPOT applications.

It is a question, whether the deployment process should start with the V2V or the V2I based SAFESPOT system. The CBA indicates that it seems more successful to start deployment rather with the V2V solution than with the V2I solution. However, it needs to be realised that the first step for V2V is to overcome the barrier of 5% fleet penetration rate, before effects will arise. The V2I solution could be very important in this respect, because it shows not such a barrier. But the considered configuration of the V2I system, i.e. large-scale infrastructure equipment, is not efficient from a socio-economic point of view due to the high costs, although the system is an effective solution for improving road safety. The scenario analysis revealed, from a society point of view, that the profitability of the V2I based system could be increased, if the equipment of infrastructure is done on a smaller scale concentrating on accident black spots.

It seems to be beneficial 1) to start with the V2V system implementation after having some black spots of the infrastructure equipped, then 2) strengthen the market penetration of the V2V system in order to exceed the critical penetration rate as fast as possible, and 3), if needed, add further infrastructure equipment at other black spots.

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