Testing a framework for the efficiency assessment of road safety measures

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Abstract

The objective of this research is to develop and test a framework for efficiency assessment of road safety measures and evaluate its use in decision-making. An exhaustive review of standard methodologies and practices related to cost-effectiveness and cost-benefit analyses is carried out for that purpose. Moreover, a number of case-studies are performed, concerning the efficiency assessment of various road safety measures in different countries, covering different types of road safety measures (user-, vehicle- or infrastructure-oriented, policy or enforcement and so on), ranging from national to local levels of implementation and including both ex ante and ex post evaluations. From the results conclusions are drawn on the efficiency of different road

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safety measures and the related determinants. Furthermore, the case-studies reveal a number of methodology and data issues, for which further research is required. The procedures and barriers involved in the use of efficiency assessment techniques at different levels of decision-making are also highlighted, by means of feedback received during and after the various case-studies. On the basis of these results, a framework for the promotion, implementation and evaluation of efficiency assessment in road safety decision-making is proposed. A particular set of recommendations is also presented regarding the treatment of barriers (fundamental, institutional or technical) within the efficiency assessment itself and the related decision-making process.

Key words: efficiency assessment; road safety measures; decision-making

1. Introduction

In order to reach the overall EU objective of halving the number of fatalities by 2010 (European Commission, 2001), it is necessary to implement effective road safety measures. A prerequisite for this task is reliable knowledge about the effectiveness and efficiency of road safety measures. It is believed that better knowledge of safety effects will stimulate more efficient priorities for road safety measures and will enable to employ available resources in such a way as to achieve the greatest possible benefits for society (Baum and Hoehnscheid 2001).

Efficiency Assessment (EA) tools can assist policy-makers to identify the most cost-effective and profitable road safety measures. The major advantages of the EA tools are that they: (a) provide input to complex decision-making based on clear rational-choice models, which is compatible with basic democratic principles; (b) follow the principle of getting the most out of typically limited resources; (c) provide a systematic and transparent structuring of the objectives considered (Elvik and Veisten 2005). Recent evaluations of road safety priorities for Norway and Sweden demonstrated (Elvik 2003; Elvik and Amundsen 2000) that alternative strategies for road safety policies, which are strictly based on cost-benefit analysis of road safety measures, would be 4-5 times more effective in terms of saved accident casualties than the business-as-usual strategies.

EA tools typically comprise cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA). CEA sets out from given road safety targets or road safety budgets and ranks measures according to the lowest monetary costs for, e.g. one casualty saved (Tengs et al 1995), whereas CBA involves monetary assessment of both costs and effects/benefits (safety, mobility, environment) of a measure. In fact, CBA can handle monetary comparisons of safety goals with other societal goals (Elvik and Veisten 2005; Layard and Glaister 1994).

A recent literature survey (BASt 2003) demonstrated that there exist many cases of both CBA and CEA of road safety measures which were performed in European and other countries. The report, which is referred to as 'An Inventory of road safety measures', contains the description of 68 groups of measures with about 200 assessment examples. The categorisation of road safety measures applied by the screening study (BASt 2003) is presented in figure 1. The findings demonstrate that over the last decade, efficiency analyses of large numbers of road safety measures were carried out in the USA, Switzerland and Scandinavian countries. For the USA, Tengs et al (1995) assessed the cost-effectiveness of five-hundred life-saving interventions, based on a comprehensive search in publicly available economic analyses. In Switzerland, the development of a road traffic safety policy was based on a background study which assessed the efficiency of 77 road safety measures (VESIPO 2002). Recent analyses of cost-effective road safety policies for Norway and Sweden considered 132 and 139 road safety measures, respectively (Elvik 2001a).

Figure 1 to be inserted here

However, close consideration of decision-making practices revealed that in most countries the EA is not regularly used in the assessment of road safety priorities (Elvik and Veisten 2005). CBA is usually applied when large infrastructure investments are considered, which does not necessarily imply that the safety effects of such projects are assessed monetarily. For example, in the Netherlands, simplified CBA or 'mini CBA' is compulsory for large national infrastructure, regional projects costing more than 225 million Euro and local projects over 121.5 million Euro; for other projects CBA is only recommended (Elvik and Veisten 2005).

Considering the reasons obstructing a wide application of the EA tools for road safety measures, three major groups of barriers may be identified (BASt 2003):

- fundamental barriers, e.g. rejecting the principles of welfare economics, rejecting efficiency as the most relevant criterion for priority setting, rejecting the idea of monetary valuation of risk reductions, etc;
- institutional barriers – related to the organisation of policy making;
- technical barriers – relation to the quality of the evaluation tools.

As to the first group of barriers, Elvik (2001b) concluded that there is no perfect argument to rule them out. Whereas some people regard the provision of road safety mainly as a technical and economic issue, others regard it as a matter of justice and fairness. Neither opinion is more correct than the other, but the first group may accept the use of CBA of road safety measures more easily. However, policy decisions have to be made and some basis for making them has to be provided. Considering the different formal techniques available, which can support policy-making, it becomes obvious that they all rely on the same basic principles as CBA, i.e. individual freedom of choice and norms of rationality. Moreover, it is also possible to construct a formal basis for making decisions in terms of justice and fairness e.g. by requiring that the adopted set of measures would be expected to prevent the same percentage of casualties for each of a range of road user categories. Consequently, the first group of barriers may be addressed within the evaluation basis. Therefore, the most complex issues among the barriers to the application of the EA tools are those relating to the quality of evaluation as such (i.e. overcoming 'technical barriers') and of performing the evaluation (i.e. removing 'institutional barriers').

Moreover, the screening of safety evaluation studies (BASt 2003) demonstrated that:

- the EA methods are applicable for different groups of road safety measures, i.e. infrastructure-, vehicle- and user-related measures;
- the tools can be applied on different scales, e.g. international, national, regional or local, and at different stages of transport projects, e.g. design, maintenance or rehabilitation;
- the assessment results can provide the decision-makers with: (a) a comparison and prioritization between several alternatives for safety investment within a defined safety budget; (b) support for regular work, e.g. comparisons of options for treatment of high-risk sites; (c) quantified answers to specific questions concerning interventions in the system, e.g. introducing a new traffic regulation, initiating an enforcement campaign (d) a general framework of actions towards achieving given road safety targets at the lowest cost.

However, for the EA to be applied, several prerequisites are required, such as the values of safety effects associated with various measures, the monetary valuations of accident prevention, as well as the basic assumptions with respect to implementation of the evaluation techniques (e.g. typical project life, annual traffic growth, relation between accident numbers and traffic volumes). The lack of these prerequisites results in technical barriers, which deter the EA application in some countries (BASt 2003).

Thus, the objective of the present research is twofold: first, to explore and test an efficiency assessment framework for road safety measures and second, to evaluate its usefulness in decision making and to identify and address the various barriers in the implementation of EA. In particular, the research aims to define a common framework for the EA in road safety, to test the suggested framework on a range of practical examples and to examine the experience gained from the viewpoint of further development and the requirements of the evaluation framework, in terms of methodologies, data and EA components. Through the practical examples, the use of standardized procedures and the treatment of related barriers are demonstrated. The assessment framework should be simple in order to be applicable in different countries and enable further comparisons of the results among the European countries (Hakkert and Wesemann 2005).

2. Cases selected for assessment

As the research aims to test the EA on a number of road safety measures, a representative list of cases was selected. The cases had to be real, i.e. consider actual road safety measures which were applied or are planned to be applied in participating countries: Austria, Finland, France, Greece, Israel and the Czech Republic (and also Germany, Sweden and the Netherlands for which the data were available).

Various considerations were taken into account before a safety measure was considered as a test case. These criteria included:

- Consideration of different categories of safety-related measures, i.e. user-related, vehicle-related or infrastructure-related measures (see figure 1).
- Consideration of different levels of implementation (national, regional and local), which influences the effect of the treatment on its environment. Moreover, the problems faced in decision-making as well as in implementation are different, and may become more (or less) complicated as measures leave the local level and advance to the regional and national level.
- Consideration of measures included in different national road safety programmes. Such programmes are characterized through long-term and clearly worked-out methods and they are guaranteed by having passed legislation and having all the necessary financing. Moreover, cooperation of decision-makers is most likely in such measures.
- Consideration of both ex post and ex ante evaluations. A CBA is sometimes conducted for measures that have already been implemented (ex post evaluation), in order to assess if a certain measure made sense from an economic point of view. However, decision-makers are most frequently interested in an ex ante analysis, to compare potential costs and benefits of certain road safety measures that have not yet been

implemented, in order to avoid injudicious investments in measures of limited usefulness. However, ex post studies are also very useful to collect data for further ex ante studies.

According to the above, eleven test cases were selected covering as many types of road safety measures as possible (Table 1).

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For instance, the implementation of measures for particular and vulnerable road user categories (A - stimulating ABS for motorcycles, K - compulsory helmets for bicyclists), or for all user categories (C - daytime running lights), was assessed in different countries. Moreover, enforcement measures were examined in several countries, ranging from local implementation of more advanced methods (B - automatic speed section control) to nationwide implementation of more routine methods (I - intensification of police enforcement). Various infrastructure improvements were also tested, including the implementation of guardrails or removal of trees (G), grade-separation of rail-road crossings (F), the improvement of rural road sites (H) , constructing 2+1 roads (J) and the implementation of different types of traffic calming measures in urban areas (E).

In total, user-, vehicle-, enforcement- and infrastructure-oriented measures were assessed, these categories not always being mutually exclusive. Moreover, the evaluations were balanced between national and regional/local level of implementation and between ex ante and ex post evaluations. In most cases, two or more countries were comparatively examined with respect to the implementation of a measure.

The applicability of the EA techniques was tested in light of both the limitations of available methods data and the restrictions of decision-making procedures in different countries. In all cases, later feedback from the decision makers was recorded and discussed (Winkelbauer and Stefan 2005).

Moreover, standardized EA techniques were used in all cases. In the following section the basic issues involved in CBA/CEA evaluations are briefly summarized. The description refers to: basic formulae, safety effects, implementation units, target accidents, accident costs, implementation costs and side-effects.

3. The assessment framework

3.1. Basic formulae

The cost-effectiveness of a road safety measure is defined as the number of adverse outcomes (accidents, or fatalities, injuries) prevented per unit cost of implementing the measure, as follows:

[Cost-effectiveness] = [Number of accidents prevented by a given measure] / [Unit costs of implementation of measure]

Discussion here will be in terms of accidents whereas, depending on safety measures considered, the interpretation can be in different forms of adverse outcomes units, e.g. injuries, drivers involved, vehicles involved, etc.
The accidents that are affected by a safety measure are referred to as target accidents. Depending on the type of safety measure it can also be a target injury group, target driver population, etc. In order to estimate the number of accidents that the measure can be expected to prevent (or has prevented) per unit implementation of a safety measure, it is necessary to identify target accidents, estimate the number of target accidents expected to occur per year for a typical unit of implementation, and estimate the safety effect of the measure as the typical proportion of target accidents prevented. The numerator of the cost-effectiveness ratio is then estimated as follows:

[Number of accidents prevented per year by a measure] = [The number of accidents expected to occur per year without the measure in place] × [The safety effect of the measure]

The benefit cost ratio is defined as:

[Benefit-cost ratio] = [Present value of all benefits] / [Present value of implementation costs]

When a CBA is applied, then, besides the above components of CEA, the monetary values of the benefits of applying the measure are also required. The monetary values imply, first of all, the valuation accidents prevented and, depending on the range of other effects considered, may also require values of travel time, vehicle operating costs, costs of air pollution, costs of traffic noise, etc.

In order to make the costs and benefits comparable, a conversion of the values to a certain time reference is required (in most cases, the 'present value' is calculated). Such an action needs a definition of the economic frame, i.e. the duration of the effect (length of service life of the project) and the discount rate, which are those commonly used for the performance of economic evaluations in the country.

In a basic case, where the benefits come from the accidents saved only (and no influences on travel expenses and the environment are expected), the numerator of the benefit-cost ratio will be estimated as:

[Present value of benefits] = [Number of accidents prevented by the measure] × [Average accident cost] × [Present worth factor],

where the present worth factor depends on the discount rate, and the estimated distribution of the prevented accidents over the lifetime of the measure.

<u>3.2. Safety effects</u>

The most common form of a safety effect is the percentage of accident reduction following the treatment (Ogden 1996, Elvik and Vaa 2004). The main source of evidence on safety effects are observational before-after studies; however, other methods for quantifying safety effects are also possible. Those, mostly, provide theoretical values of the effects based on known relationships between risk factors and accidents..

The safety effect of a measure is considered available if the estimates of both the average value and the confidence interval of the effect are known. Typically, it is desirable to apply the local values of safety effects, i.e. those attained by the evaluation studies performed in the country. When the local values do not exist, the summaries of international experience can alternatively be used, preferably the values received by means of a meta-analysis, which provides both the weighted estimate of the mean effect and a confidence interval for the estimate (a 95% confidence interval is common). Both the techniques and the results of meta-analyses of road safety measures are presented in Elvik and Vaa (2004) and in TRB (2005).

If the value of a safety effect is provided by a study, for which the CBA is performed, the estimation of the safety effect should satisfy the criteria of correct safety evaluation. This implies that the evaluation should account for the uncontrolled environment, e.g. general accident trends, changes in traffic volumes, and for the selection bias if relevant. Due to the fact that safety studies are observational (non-experimental), there are confounding factors,

which influence the accident occurrences and, therefore, should be accounted for in the estimation of a real safety effect of the treatment.
The nature of confounding factors, which should be accounted for in the evaluation of safety effect, is explained in detail by Hauer (1997).

Therefore, to properly quantify the effects of a treatment, a simple before/after comparison is not correct. It is necessary to compare the situation with the treatment ('after') with the situation that would have existed had the treatment not been applied. The latter presents a corrected value of a previously observed ('before') situation.

The determination of what situation would have occurred without the treatment is a critical phase of the process and is performed in two steps:

- determination of the correct before value (of accidents).
- determination of the correct after value (of accidents) without the treatment.

The first point accounts for the selection bias; the second one – for the uncontrolled environment. The Empirical Bayes method constitutes an effective instrument for the first point. A correction of 'before' accident numbers is performed with the help of reference group statistics, for each site in the treatment group. Methods of controlling for regression to the mean can be found in Hauer (1997), Abess (2001), Gitelman, Hakkert et al (2001).

For the second point (the corrected value of accidents without the treatment), two basic approaches are possible:

- Using a comparison group; this approach relies on the assumption that the changes in the number of accidents in the comparison group correctly predict the changes that would have occurred at the treatment sites in the absence of treatment The evaluation of the treatment effect is performed by means of a odds-ratio (for details see Maycock and Summersgill 1995, Elvik 1997, Gitelman, Hakkert et al 2001).
- The use of multivariate models; this approach supplies the expected number of accidents as a function of a series of physical and traffic parameters of the treatment sites and of general accident trends. The technique of generalized linear models with a Poisson or Negative Binomial distribution for the frequency of accidents is the most widely accepted today for this purpose. Methods for the development of models can be found in Hauer (1997), Maher and Summersgill (1996), Hakkert, Gitelman et al (2001) and other papers.

The simplest way for estimating safety effect by using the first method is as follows. Let us designate X_a – the number of accidents observed at the treatment site in the 'after' period, X_m – the (adjusted, i.e. accounting for a selection bias if necessary) number of accidents at the treatment site in the 'before' period, C_a – the number of accidents in comparison group sites in the 'after' period, and C_b – the number of accidents in comparison group sites in the 'before' period. Then, the estimate of the safety effect observed at site i

(θ_i), is the odds-ratio of accident numbers observed at treated and comparison sites, in the before and after periods. It has the form:

Estimated effect (θ_i) = $[X_a / X_m]/[C_a / C_b]$

For a combined estimate of the effect at a number of sites, the logarithm of the estimate at each site i should be weighted by:

$$w_i = \frac{1}{\frac{1}{A_i} + \frac{1}{B_i} + \frac{1}{C_i} + \frac{1}{D_i}}$$

where A_i, B_i, C_i, D_i are the four numbers of the odds-ratio calculation at site i.

The weighted mean effect (WME) based on a set of sites is

$$WME = \exp\left(\frac{\sum_i w_i \ln(\theta_i)}{\sum_i w_i}\right)$$

with a confidence interval

$$WME \times \exp\left(\frac{z_{\frac{\alpha}{2}}}{\sqrt{\sum_i w_i}}\right),\ WME \times \exp\left(\frac{z_{1-\frac{\alpha}{2}}}{\sqrt{\sum_i w_i}}\right)$$

where (exp) is the exponential function, (ln) is the logarithm and 100(1 - α)% the confidence level (95% is usually accepted).

The applicable value of the safety effect, i.e. the best estimate of accident reduction associated with the treatment (in %), is calculated as (1-WME)*100. A reduction is significant when the whole WME confidence interval is below one. The above formulae are correct for any number of treatment sites, including the case of only one site, or for a widespread measure with no comparison group (e.g. the two numbers for the comparison group are just omitted from the expression for the weight).

3.3. Accident costs

A detailed survey of practice in estimating road accident costs in the EU and other countries was made by an international group of experts as part of the COST-research programme (Alfaro et al 1994). Five major cost items of accident costs were identified as follows:

- Medical costs
- Costs of lost productive capacity (lost output)
- Valuation of lost quality of life (loss of welfare due to accidents)
- Costs of property damage
- Administrative costs

The relative shares of these five elements differ between fatalities and the various degrees of injuries, and also differ among countries. In the current research, it was assumed that each country has its official valuations of prevention of accident injuries and damage. Otherwise, the comparative figures from recent studies (Hakkert and Wesemann 2005) can be of help.

3.4. Implementation units and their costs

The selection of implementation units is case-specific; for instance, in the case of infrastructure measures, the appropriate unit will often be one junction or one kilometre of road, whereas in the case of area-wide or more general measures, it may be a typical area. Moreover, in the case of vehicle safety measures, one vehicle will often be a suitable unit of implementation, or, in the case of legislation introducing a certain safety measure on vehicles, it may be the percentage of vehicles equipped with this safety feature or complying with the requirement, and so on.

The implementation costs are the social costs of all means of production (labour and capital) that are employed to implement the measure. They are generally estimated on an individual basis for each investment project (ETSC 2003). As no strict rules are available on the issue, all the components of the implementation costs should be examined and explained for each case. Typical costs of engineering measures, which are common for the CBA evaluations in the country, are recommended for the application.

The implementation costs should be converted to their present values, which include both investment costs and the annual costs of operation and maintenance.

3.5. Side-effects

Road safety measures can generally produce three kinds of effects: safety, mobility and environmental (ETSC 2003). The mobility effects comprise changes in travel time and vehicle maintenance expenses; quantitative techniques for estimating the mobility effects of transportation projects are well developed and can be found in guidelines and computer programs for economic evaluations in transport, e.g. BVWP, EWS-97, RAS-W in Germany; TUBA, COBA, NESA in the UK; STEAM in the USA, etc (BASt 2003).

As many road safety measures affect the amount and/or speed of travel, they may also have impacts on emission and noise (e.g. an increase in the use of fuel, which arises from day-time running lights (DRL), will increase emissions of exhaust gases). Examples of values for estimating side-effects of safety measures are given in Hakkert and Wesemann (2005).

4. Discussion: overview of evaluation results

On the basis of the principles and techniques described in the previous sections, 18 case studies were carried out in total. In this section the results are presented and discussed.

4.1. Characteristics of the assessments performed

Table 2 summarizes the characteristics of evaluation methods applied and the results obtained. In total, the case-studies covered 10 groups of safety-related measures. Out of the 18 case-studies, three cases concerned vehicle-related measures (fitting motorcycles with ABS; compulsory DRL for the whole year), nine cases concerned infrastructure-related measures (traffic calming measures in urban areas; grade separation of at-grade rail-road crossings; installation of roadside guardrails; introducing signal control at a rural junction; constructing 2+1 road sections) and the remaining six cases concerned user-related measures (automatic speed enforcement; large-scale projects of intensive police enforcement; compulsory helmet wearing for cyclists). Moreover, 9 cases are evaluated ex ante and 9 cases are evaluated ex post.

Table 2 to be inserted here

The target accident group included all injury accidents in 7 case-studies only. In the rest of the cases the impact of the measure was expected/ estimated for a specific accident/ injury/ driver subgroup, such as 'fatal and serious injuries of motorcycle riders' in case A; roadside collisions with trees in case G; head-on collisions in cases J1-J2; and so on (see Table 2).

For the calculation of safety effects, before-after considerations with control-groups were the most common, whereas in a few cases multivariate statistical models were used. In half of the cases, estimates from the literature or from previous research were applied.

Additional (other than safety) effects, not always positive ones, were estimated in about half of the cases. In some other cases a need to account for the additional effects was mentioned but not realized due to lacking data/ models which could isolate the effects (i.e. changes in air pollution, noise level, travel time or fuel consumption) associated with the measure. For example, in the case of DRL, additional fuel consumption and emission narrow the economic benefits of accident cost reductions associated with the measure; in the case of grade-separation of rail-road crossings , the economic benefits come from eliminating train-vehicle collisions and from reducing vehicle delays, and so on (see Table 2).

4.2. Results of the assessments performed

Table 3 summarizes the results of the case-studies in terms of estimated safety effects and their confidence intervals, accident and implementation costs, and benefit-to-cost ratios. As regards safety effects, these were estimated using a comparison-group method, or estimates from the literature were applied. In the former case, confidence intervals are presented in Table 3, indicating that most of the safety effects observed were significant. In the cases of intensive police enforcement (I1-I2) safety effect values are not provided; in these cases, the safety benefits (number of accidents saved) were estimated by means of a number of statistical models (Hakkert et al. 2001, Agapakis and Mygiaki, 2003) fitted to different project areas.

*** Table 3 to be inserted here***

The results of cases E1-E3 (urban traffic calming) are particularly interesting; it can be seen that in three different countries, evaluating slightly different traffic calming schemes and using different respective data, very similar estimates of the safety effect was obtained, indicating an important degree of consistency.

As regards the benefit-to-cost ratios, those were mainly calculated on the basis of the average safety effect. The cases in which several values are available, these result from different implementation scenarios.
In particular, case E2 (traffic calming in Israel) and cases K1-K2 (compulsory helmet regulation for cyclists) consider a range of implementation costs; case F1 (grade separation of crossings) applies two models for the estimation of traffic delay and examines urban and rural sites separately; case I1 (intensive enforcement in Greece) considers models with and without a time-halo in the effect of enforcement; case I2 (intensive enforcement in Israel) considers "average" versus "conservative" estimate of the number of accidents saved and a range of implementation costs as well.

Considering the results in terms of the effectiveness of road safety measures (benefit-to-cost ratios), it can be seen that enforcement-related measures appear to be more cost-effective than other measures, partly due to lower implementation costs. The efficiency of other user-related measures and of vehicle-related measures is also relatively high due to the same reason (low implementation costs per unit of implementation). On the other hand, the efficiency of infrastructure-related measures varies widely, depending mainly on the range of construction costs.

Moreover, national-level measures appear to be generally more cost-effective than local-level measures. However, this finding mostly stems from the fact that, in the present review, the majority of local-level measures are road infrastructure improvements. Finally, no significant differences can be found in the efficiency of similar measures applied in different countries.

4.3. The evaluation techniques applied

All the case-studies followed the standardised procedure of cost-benefit analysis (CBA). None of the studies selected the cost-effectiveness analysis (CEA) due to obvious limitations of the CEA when a single measure is evaluated and, especially, when the evaluation should also account for other (than safety) effects. Besides, the discussions on the EA results with decision-makers seem easier when the results are presented in monetary terms.

None of the studies considered alternatives; by default, each study compared 'implementation of the measure' with a 'do nothing' alternative. All other steps of the CBA evaluation procedure were applied by the majority of the studies. The exceptions were basically due to lacking data.

Estimating safety effects of the measures, the emphasis was put on the application of a correct safety evaluation. In the ex ante evaluations, the best available values of safety effects (which are based on a summary of previous experience/ research) were typically applied. In the ex post evaluations, the safety effect value was typically estimated by means of the odds-ratio with a comparison group or by multivariate models.

For the economic evaluation, typical scenarios adopted were either 'conservative or best estimate', or 'with and without side effects', or based on different implementation costs in each case. In any case, consideration of a number of scenarios appears to be useful for testing sensitivity of the results and, therefore, should be recommended for the usual evaluation practice.

4.4. The efficiency assessment components: data and values

Typically, the accident costs come from official national data. In some cases such infrastructure-related measures (E1-E3, F1, H) and intensive police enforcement (I1-I2), some adaptations of the official injury costs were made to suit for the target accident groups.

The availability of implementation costs was problematic in many cases. Nevertheless, in the majority of cases the estimates of implementation costs were based on the official data provided by relevant authorities. In those cases where the evaluation was performed ex ante (e.g. ABS for motorcycles, DRL, compulsory helmets for cyclists) some practical assumptions or the valuations of similar measures applied in other countries (i.e. the 'literature' source) were accounted for in the costs.

Lack of models for evaluating side-effects associated with the safety measure (i.e. changes in air pollution, noise level, travel time or fuel consumption) and, sometimes, lack of local valuations of these effects deterred the consideration of these effects in some cases. The problem may be tackled by a systematic accumulation of recommended values and solutions (depending on safety measures considered) within the guidelines for the EA performance.

4.5. The role of barriers

During and after the EA of the selected cases, the related decision-makers were contacted. In particular, personal interviews were carried out before, during and after the case-studies in most countries. Moreover, the decision makers attended a workshop and a Conference on the EA tools and the results of case studies. In most cases, important assistance was provided by decision-makers, in terms of both provision of data and other related information and feedback on the processing and final results of cases. The ultimate goal of these contacts was the assessment of the attitude of decision-makers towards EA studies and the identification of related barriers.

None of the decision-makers involved rejected the principles of efficiency assessment. Concerning the local level of decision-making some experts doubted the practical influence of the evaluation results, however, not because of a fundamental non-acceptance of the approach but mostly due to the awareness of other factors (political, emotional) which usually influence such decisions.

Technical barriers such as typical problems with the evaluation techniques or lacking data (as mentioned above) were generally overcome. In some cases, thoroughly based statistical models were developed to ascertain the lacking values of the effects. In general, the majority of technical barriers, which might appear during the performance of an EA study, seem treatable.

A lack of obligatory procedure for performance of cost-benefit evaluations of safety effects is considered as a major institutional barrier for the application of the EA of safety measures. However, in many cases (mostly, ex post evaluations of enforcement and infrastructure measures) the CBA results emphasized the accident reduction effects and the economic savings associated with the application of the measures. As a result, the decision-makers were interested in the dissemination of the EA results and in further performance of the analyses.

As to the barriers for implementation of safety measures, different forms of these barriers were identified by the studies. The wide application of a measure is frequently limited due to economic reasons (lack of finance, high costs, etc). Sometimes, safety reasons may conflict with other considerations (e.g. environmental issues like in case G – 'measures against collisions with trees'). In other cases (e.g. helmets for bicycles, DRL, automatic speed enforcement) lack of acceptance by the general public deters the decision-makers from the promotion of the measure. However, in several cases, e.g. DRL for the Czech Republic, grade-separation of rail-road crossings in Israel, traffic calming in urban areas in Greece, the CBA results highlighted the expected/ attained benefits of the measures and, in this way, contributed to the acceptance of the measure by the decision-makers.

4.6. EA usefulness for decision-making

Frequently, consideration of EA is part of the preparation of regional or local road safety plans. At the initial stage of evaluation, safety effects are usually unknown. To influence any decision making process, EA studies have to be prepared ex ante using impact data from similar but other measures taken from other sources. This stresses the need for availability and accessibility of evaluation studies on road safety measures as well as dissemination of EA results on an international basis.

As mentioned in the previous section, at the local level, the application of a safety measure is in many cases not just an economic question but also a matter of subjective judgement. This problem can occur where the program of 'effective measures' is developed at the national level but executed at regional or local level. Benefits estimated at the national level are frequently not visible at the local level, where costs and local political interests dominate the perspective of the decision makers. During the preparation of EA studies within such an environment, the financial benefits need to be explained considering the level of future decision making.

Therefore, CEA can be more applicable at the local level as no comparison with conflicting targets is usually performed and needed. The method of CBA at lower levels of decision making appears to be quite theoretical e.g. benefits at the national or even global level are weighted low or even disregarded, since impacts are not visible at the local level.

5. Conclusions

The research intended to gain experience by testing an EA framework of road safety measures within the availability of data and values such as accident data, safety effects, valuations of the prevention of accidents, implementation costs, environmental and other impacts, in different countries, using methods developed by previous research (Hakkert and Wesemann 2005) Finally, it aimed to present the results of the case studies to decision makers, to document their feedbacks and to develop recommendations for improving usability of the EA results for decision-making, in order to identify barriers in the application of EA techniques and to develop solutions and recommendations.

According to the results, a number of recommendations addressing the 'best practice' guidelines for the evaluation framework can be suggested. First of all, further development of the EA procedures and methods is required. Particularly, for a more correct and uniform performance of CBA for safety-related measures it would be useful to elaborate a categorization of cases, indicating the types of impacts (e.g. safety, mobility, noise, air pollution) to be considered in the evaluation of each category of measures. For example, in the cases of infrastructure or enforcement measures, which have an implication on travel speeds, a consideration of changes in travel time is essential. However, valuation of benefits obtained illegally in the form of shorter travel times may need to be considered if speed limits are enforced. Another question concerns the inclusion of fines in the economic evaluation of enforcement measures. It is generally recommended that fines are not considered at macro-economic level, since they are a transfer payment. .

When a number of impacts are combined in the evaluation of a measure, a distinction should be made between the implementation costs and negative benefits of the measure. Some benefits may be negative, e.g. increased travel time. In this case, their values are subtracted from the total benefits.

Safety effects estimated should satisfy the criteria of correct safety evaluation. The distribution of a brief guide on standardized techniques for the evaluation of safety effects would be helpful for safety practitioners, in general, and particularly, for the improvement of quality of the EA studies. Consideration of a number of scenarios is useful for testing sensitivity of the results and should become common practice for the usual evaluation study.

Accordingly, a database with typical values of safety effects, based on international experience would be useful for correct and systematic performance of the ex ante studies. The Handbook on road safety measures

(Elvik and Vaa 2004), in combination with other available sources, can serve as a basis for such a database. The database might be open to a European network of experts and provide for general values of safety effects on initial steps of CBA/CEA as well as assist in comparisons of local effects observed. The values of safety effects kept in the database should be regularly updated, in accordance with the last evaluation results in the EU.

Moreover, the implementation costs of safety measures are usually lacking. Establishing national databases with typical implementation costs of safety improvements would be of help for the systematic use of these values in the EA studies.

Addressing the encouragement of use of EA procedures and evaluation results, the following recommendations were elaborated; CBA seems to be more suitable for national- and regional-level decision-making where the safety budgets are planned. CEA seems more suitable for the local level, especially when several safety solutions are compared while tackling a specific safety problem. In those countries where the safety budget is centralized, an EA of safety measures may be encouraged by stating it as a necessary condition for the application to central budget. Within this context, training of decision-markers is important to strengthen their understanding of the principles of EA. Training is also needed for those carrying out EA studies; EA-specific training for road safety experts, through a series of workshops or conferences, supported by widely accessible respective data- and knowledgebases, would be extremely useful towards the establishment of best practice in the evaluation of road safety measures.

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Figure 1. Categorization of road safety measures (BASt, 2003)

Table 1: Selected cases for evaluation

Nr.	Case Study	Road Safety Approach	Level	Countries
A	ABS motorcycle	Vehicle	National	AT
B	Section control	User + Enforcement	Local	AT, NL
C	Daytime running lights	Vehicle + User	National	AT, CZ
D*	Speed cameras	User + Enforcement	Local	FI, IL
E	Traffic calming (urban areas)	Infrastructure	Local	CZ, GR, IL
F	Railroad crossings	Infrastructure	Local	FI, IL
G	Measures against collisions with trees (guardrails)	Infrastructure	Local + National	FR
H	Road improvement mix (rural areas, national network)	Infrastructure	Local + National	IL
I	Intensive police enforcement (speed and alcohol)	User + Enforcement	National	GR, IL
J	2+1 roads	Infrastructure	Regional	FI, SW
K	Compulsory helmet regulation for cyclists	User	National	AT, DE

* Case D was finally not performed due to a lack of data

Table 2: Summary characteristics of the case-studies

Nr.	Case Study	Description of measure	Category of measure			Level of implementation			Evaluation		Country of measure	Target group		Source of implementation costs			Accident costs		Source of safety effect value			Other effects			
			Vehicle-related	Infrastructure-related	User-related	National	Regional	Local	Ex ante	Ex post		All accidents	Accident / injury / drivers' sub-group	Official data	Literature	Estimates	Official data	Estimates	Before-and-after comparison	Statistical models	Literature	Emmissions	Noise	Travel time	Fuel consumption
A	ABS-Motorcycle	Stimulate anti-lock brake systems (ABS) equipment of motorcycles by reducing taxes	√			√			√		AT		√		√	√	√	√			√				
B1	Section Control	Automatic speed enforcement in a tunnel (motorway)			√			√		√	AT	√		√			√		√			-			
B2	Section Control	Automatic speed enforcement on a motorway			√			√		√	NL	√		n/a*			√				√	-	-		
C1	Daytime running lights	DRL for the whole year	√			√			√		CZ		√		√		√				√	+		+	+
C2	Daytime running lights	DRL for the whole year	√			√			√		AT		√		√		√				√	+		+	+
E1	Traffic calming (urban areas)	Installation of speed humps (on 1 street)		√				√		√	GR	√		√		√	√	√	√						
E2	Traffic calming (urban areas)	Implementation of speed humps and woonerfs (in 1 urban area)		√				√	√		IL	√			√	√	√	√	√						
E3	Traffic calming (urban areas)	Roundabouts instead of four-arm junctions (at 8 sites)		√			√	√		√	CZ	√		√			√	√	√						
F1	Rail Road crossings	Grade-separation of at-grade rail-road crossing (2 typical sites)		√				√	√		IL		√	√		√		√		√				-	-
F2	Rail Road crossings	Grade-separation of at-grade rail-road crossing (1 site)		√				√	√		FI		√	√		√	√				√			-	
G	Measures against collisions with trees (gardrails)	Installation of roadside guardrails and trees' removal (26.5 km of road)		√				√		√	FR		√	√			√		√						
H	Road improvement mix (rural areas)	Introducing traffic signal control at a rural junction		√				√	√		IL	√			√	√	√	√	√						
I1	Intensive police enforcement (speed and alcohol)	5-year project of intensive enforcement with emphasis on speed and alcohol (rural roads)			√	√				√	GR	√		√		√		√		√					
I2	Intensive police enforcement (speed and alcohol)	1-year project of intensive general enforcement (rural roads)			√	√				√	IL		√	√		√	√	√	√	√					
J1	Variable speed signs on 2+1 roads	Constructing of 2+1 road sections with median cable barriers (575 km of road)		√			√			√	FI		√	√			√				√				
J2	Variable speed signs on 2+1 roads	Constructing of 2+1 road sections with a median cable barrier (1 road section)		√				√		√	SW		√	√			√				√				
K1	Compulsory helmet regulation for cyclists	Compulsory helmet wearing for bicycle riders			√	√			√		AT		√		√	√	√				√				
K2	Compulsory helmet regulation for cyclists	Compulsory helmet wearing for bicycle riders			√	√			√		DE		√		√	√	√				√				

*Case B2: the estimation was not finished due to missing data on costs

Table 3: Results of the case studies

Nr.	Case study (Country)	**Safety effect** - percentage change in target accidents		**Accident costs saved** (M€)		**Implementation costs** (M€)		**Estimated lifetime** (years)	**Benefit-to-cost ratio****	Comments to safety effect values
		Average	95% Conf.int.							
A	ABS for motorcycle (AT)	-8 to -10	n/a*	€ 623 to 779	(per vehicle)	€ 561	per vehicle	12	1.1 to 1.4	Based on a detailed study of motorcycle injury – Kramlich, Sporner (2000)
B1	Section control (AT)	-31	-35; -26	1.026	(annual)	0.204	(annual)	10	5.4	Estimated by the study
C1	Daytime running lights (CZ)	-20	n/a*	460.230	(total)	70.410	(total)	12	4.3	Safety effect from the literature – ETSC (2003)
C2	Daytime running lights (AT)	-20	n/a*	1,040.000	(total)	195.300	(total)	12	3.6	See above (C1)
E1	Traffic calming (GR)	-38	-64; +6	3.985	(annual)	3.320	(total)	1	1.14 to 1.2	Estimated by the study
E2	Traffic calming (IL)	-40	-56; -17	0.006	(annual)	0.004 to 0.007	(total)	5	2.0 to 4.0	Estimated by Gitelman, Hakkert et al (2001)
E3	Traffic calming (CZ)	-38	-54; -16	0.032	(per site annual)	0.300	(per site total)	20	1.3	Estimated by the study
F1	Railroad crossings (IL)	-100	n/a*	0.040 0.023	(per rural site annual) (per urban site annual)	2.600	(per site total)	15	1.9 to 2.8 (rural site) 1.0 to 1.4 (urban site)	A grade-separation of at-grade crossing totally eliminates train-vehicle collisions at the site.
F2	Railroad crossings (FI)	-100	n/a*	0.008	(annual)	5.000	(total)	20	0.25	See above (F1)
G	Measures against collisions with trees (FR)	-95	-99;-59	8.633	(total)	0.993	(total)	5	8.69	Estimated by the study
H	Road improvement mix (IL)	-30	-55; +8	0.326	(total)	0.260	(total)	15	1.25	Estimated by Gitelman, Hakkert et al (2001)
I1	Intensive police enforcement (GR)	n/a*	n/a*	274.700 to 406.200	(total)	39.525	(total)	4	6.6 to 9.7	Over 4 years, 772-1,142 accidents were prevented – based on Agapakis, Mygiaki (2003)
I2	Intensive police enforcement (IL)	n/a*	n/a*	21.100 to 29.300	(total)	5.530 to 6.070	(total)	1	3.5 to 5.0	In total, 108-150 target accidents were prevented – based on Hakkert et al (2001)
J1	2+1 roads (FI)	-100	n/a*	13.367	(annual)	417.600	(total)	20	1.25	The measure eliminates target accidents. On average, 5.5 fatal accidents are saved annually - estimated by Nokkala and Peltola (2004)
J2	2+1 roads (SE)	-100	n/a*	113.000	(total)	5.000	(total)	20	2.26	The measure eliminates target accidents.
K1	Compulsory helmet regulation for cyclists (AT)	-20	n/a*	230.919	(total)	101.081 to 202.162	(total)	10	1.1 to 2.3	Estimated by Otte (2001)
K2	Compulsory helmet regulation for cyclists (DE)	-20	n/a*	5,077.319	(total)	1,140.168 to 2,280.335	(total)	10	2.2 to 4.5	Estimated by Otte (2001)

* n/a – not applicable. See "Comments to safety effect value"

** Accounting for other effects - see Table 2