EVALUATING ROAD SAFETY MEASURES: ANALYZING DIFFERENCES BETWEEN SOCIO-ECONOMIC EVALUATION METHODS IN TERMS OF EFFECTS INCLUDED, BASIC ASSUMPTIONS, AIMS AND GOALS

Fredriek Van Malderen, Vrije Universiteit Brussel, Fredriek.Van.Malderen@vub.ac.be

Cathy Macharis, Vrije Universiteit Brussel, Cathy.Macharis@vub.ac.be

Klaas De Brucker, Hogeschool-Universiteit Brussel, Klaas.Debrucker@hubrussel.be

Koen Van Raemdonck, Vrije Universiteit Brussel, Koen.Van.Raemdonck@vub.ac.be

ABSTRACT

Appropriate measures need to be taken in order to reduce the number of victims on our roads. To select these road safety measures, it is preferable to use socio-economic evaluation methods with a multi-objective approach such as social cost benefit analysis and (multi-actor) multi-criteria analysis. Considering the limited budgets available to society and government, the most appropriate measures can be chosen using this kind of assessment tools. In this contribution, the basic assumptions, aims and goals, as well as the main advantages and disadvantages of different evaluation methods are presented. Next, the differences in terms of effects included and outputs obtained are analyzed for the cost-effectiveness analysis, the social cost-benefit analysis and the (multi-actor) multi-criteria analysis, using a case study. The fact that multiple methodologies (yielding multiple outcomes) are available might perhaps confuse the decision maker a little bit in selecting the most appropriate measure. The main recommendation of this paper is the need to develop a decision tree in order to select the most appropriate evaluation method.

Keywords: road safety, socio-economic evaluation methods, (Multi-Actor) Multi-Criteria Analysis, Social Cost-Benefit Analysis

INTRODUCTION

Reducing the number of road accident victims is one of the major challenges of our present society. In Europe, every year tens of thousands of people die in traffic and every death creates a huge physical and psychological cost for our society. Great efforts are still needed in order to decrease the number of road accidents. Despite the improvement of the road safety level in the European countries in the last decades, Europe has failed to meet the objective to reduce the number of fatalities with 50% in 2010. This seems to inspire us to make even greater efforts in reducing the number of accidents. To obtain this reduction, effective road safety measures need to be implemented, but the cost of the implementation of these measures is also extremely important. The resources available to implement the measures required are scarce. Therefore, the economic and management sciences have developed assessment techniques to formulate policy recommendations regarding the selection of efficient and effective measures to improve road safety. The most common used evaluation methods in transport and road safety are social cost-benefit analysis (SCBA) and multi-criteria analysis (MCA) (Van Malderen et al, 2010). The use of these socio-economic tools often depends on the level of expertise of the analysts and experts in the field of these methods. The reason is that both methods require specific and comprehensive knowledge. In this contribution, the basic assumptions, aims and goals, as well as the main advantages and disadvantages of various evaluation methods are presented. Next, the extent to which the effects included in SCBA and (MA)MCA are different will be studied more closely, as well as the extent to which the basic assumptions, aims and goals of these methods differ. These differences will be studied on the basis of a case study, namely the IN-SAFETY project. Here, we will look more closely at the important differences which can affect the ranking of the alternatives and thus influence the policy maker in selecting the most appropriate measure. To conclude, recommendations are made in order to monitor or manage these inconsistencies.

A MULTITUDE OF SOCIO ECONOMIC ASSESSMENT TOOLS

Several evaluation tools can be used to evaluate transport or road safety measures, such as cost effectiveness analysis (CEA), social cost benefit analysis (SCBA), multi-criteria analysis (MCA) and multi-actor multi-criteria analysis (MAMCA) developed by Macharis (2004)**.** All these methods have their own basic assumptions, aims and goals. Hence, it is not unnatural that the conclusions differ when different evaluation methods are used (De Brucker et al, forthcoming).

Cost-Effectiveness Analysis

The cost-effectiveness analysis (CEA) is an analysis whereby an alternative is evaluated in terms of its effectiveness to achieve a certain policy objective, as well as in terms of its efficiency to achieve this objective. The policy objective is thus the point of departure in a CEA (Hakkert et al, 2005; De Brucker et al, forthcoming). In fact it is a trade-off method which is frequently used to determine the effectiveness of road safety measures. The CEA namely compares the effects of implementing a particular road safety measure with the cost of that measure. The result of this comparison is an effect-cost (EC) ratio (shown in formula 1). To select the most appropriate measure, the EC ratios of the various alternatives need to be compared with each other.

$$Effectiveness - cost\ ratio = \frac{Number\ of\ fatalities\ \ prevented\ by\ a\ given\ measure}{Unit\ costs\ of\ implementation\ of\ measure} \quad (1)$$

Source: De Brucker et al, forthcoming

In a road safety context the number of lives or accidents saved as a consequence of the implementation of a measure is often used as a parameter of its effectiveness. However the number of lives saved can also be replaced by other parameters such as the number of accidents or casualties. The CEA examines, thus, which road safety measures can be implemented at the lowest cost to obtain a predefined objective (i.e. the cost-effectiveness or cost minimization perspective). Conversely, this method can also identify the best, i.e. most effective measure to improve the road safety level (i.e. the effect maximization perspective) (Hellendoorn, 2001; Vlakveld et al, 2005). It is important to convert all costs of implementation to an annual basis by using discount rates in order to make measures with different lifetimes comparable.

A major strength of the CEA is the fact that the intangible effects do not have to be monetized and that it gives the decision maker more insight in the cost of saving one statistical life or accident. However, this tool can only assess one effect. This is an important disadvantage. As a result a CEA cannot evaluate mobility, environmental and safety impacts together. If only the main goal (e.g. reducing the number of deaths) is evaluated with a CEA, a suboptimal alternative might be chosen which scores high on this safety aspect, but low on mobility and/or environment. Moreover, CEA does not allow to compare safety effects for different levels of accident severity (IN-SAFETY, 2005). Furthermore, the CEA does not take into account the various stakeholders and side effects such as rebound effects. The CEA can be defined as a mono-criterion and mono-stakeholder evaluation method (Macharis, 2007). Consequently, the CEA may result in an incomplete economic analysis, which may lead to the selection of a measure that would not be selected if more complete data were used. Finally, this tool is not able to express to which extent a specific measure is socially desirable. The reason is that there is no formal decision criterion to accept or reject a project alternative (Hakkert et al, 2005).

Social Cost-Benefit Analysis

Social cost-benefit analysis (SCBA) is a widely used technique in the context of transport and road safety evaluation and has its roots in neoclassical welfare economics. As opposed to the private investment analysis (PIA), the SCBA takes the integral social perspective into account. Principally, all project related costs and effects are taken into account in the evaluation irrespectively of the identity of the actors to whom these effects accrue (De

Brucker et al, forthcoming). Therefore, the SCBA has been applied for decades in the context of road safety evaluation (Elvik, 2001). CEA, which is described in the previous section, can be considered as a very partial form of SCBA. A CEA can indeed be carried out with only a subset of the data necessary for the SCBA. As opposed to a CEA, a SCBA examines the fundamental desirability of realizing a certain policy objective. In a SCBA, several alternatives can be examined and compared with each other and also one alternative can be examined in terms of its social relevance to create additional welfare. Since the SCBA is based on neoclassical welfare economics, the chosen alternative needs to maximize welfare. A scenario with the highest positive net present value (NPV) will be preferred. In order to obtain the NPV (presented in formula 2), the costs are to be deducted from the benefits of the measure. These costs and benefits correspond to utility losses (negative effects) and utility increases (positive effects) respectively. When applying SCBA every effect needs to be expressed in monetary values. These values are then converted into their present value in order to allow for time preference and future depreciation of money (Dasgutpa et al, 1972). In addition to the NPV, other decision criteria can be used such as the benefit-cost (BC) ratio (formula 3), the payback period, etc. (Geudens et al, 2009). By carrying out an SCBA (and using the afore-mentioned decision criteria) the measures are evaluated in a more comprehensive way as compared to CEA. In SCBA one will also look for the cheapest way to reach a policy objective, but this done by weighing the social benefits and social costs of projects aimed at realizing this policy objective.

$$NPV = Present\ value\ of\ all\ benefits - Present\ value\ of\ all\ costs \quad (2)$$

$$BC\ ratio = \frac{Present\ value\ of\ all\ benefits}{Present\ value\ of\ implementation\ costs} \quad (3)$$

Source: De Brucker et al, forthcoming

In formula (3) the term “implementation cost” refers to the budgetary cost of a measure. The benefits (i.e. the nominator of formula 3) comprise all social benefits. Negative benefits (or societal cost), such as for example increased travel time, if these were to be estimated, are subtracted from the benefits.

An important strength of the SCBA is the possibility to discount the values to their present value. As a result future effects are taken into account. This is very useful when costs and benefits are spread over a long period of time. The selection of a discount rate has an important influence on the results of the evaluation method. A high discount rate means that future effects are given less importance in the present than present effects[1]. The SCBA is a relatively simple evaluation method if the necessary data is available and if there is sufficient understanding of the effects, especially regarding the monetization of these effects. The SCBA takes the integral policy point of view into account, such as mobility effects, environmental effects, as well as road safety effects (Van Malderen et al, 2009).

[1] Effects = cost and benefits

Subsequently, the SCBA uses the Kaldor-Hicks principle to pursue Pareto-efficiency[2]. Thus, distributional or equity effects are not absent from SCBA, although these are not studied explicitly.

SCBA does, however, not follow an utilitarian approach[3] and thus disregards equity issues (Van Malderen et al, 2009). The SCBA, however, has to cope with other weaknesses. There is for instance the problem of the monetization of intangible effects, such as the value of human life. Market prices cannot be applied to determine the monetary value of these effects. For that reason some intangible effects cannot be taken into account in the SCBA. However, there are various valuation methodologies to calculate the value of intangible effects (Elvik et al, 2004b; De Brabander, 2006). The willingness-to-pay principle is a widely used technique for monetizing non-marketable effects. However, this method may give a different result compared to the willingness-to-accept method, which is another method to monetize non-marketable effects. Two approaches can be used to estimate the willingness-to-pay (or monetary value) of the intangible effects, namely the “revealed preference techniques” and the “stated preference techniques”. Stated preference methods are fraught with problems (Sen, 2000), especially when the questions asked are merely hypothetical, which means that the respondents do not clearly grasp the issues or effects surveyed because they lack experience trading them in their daily lives. Each approach can be subdivided into several other techniques (Pearce et al, 2000). However, there are significant differences between these methods. As a result, the choice of a particular valuation method can affect the results of the evaluation substantially. If a valuation method is used that assigns high values to the benefits, the chance that the investment project will be accepted is higher than when an evaluation method is used which assigns lower values to the benefits. In the first case, the cost of the investment may rise and the investment will still be considered socially acceptable (De Brabander, 2006). In addition, the investment required to implement a measure may be different in each country and the welfare levels in each country may not be the same either. This may be a problem when global evaluations are to be carried out. The welfare of a country will affect the willingness-to-pay. The amounts paid depend on the ability to pay, not only the willingness (Elvik, 2001). Subsequently there is the problem of data collection. It is difficult to gather data about the effects of certain measures. This applies to all evaluation methods. However, as regards SCBA there is an additional difficulty, as extra data are needed to obtain the monetary value of effects such as fatalities and injuries, emissions, time-savings, etc. De Brucker et al (forthcoming) have identified the data requirements to carry out a SCBA or a CEA and they also give some recommendations in order to deal with a lack of data. Finally, there is the problem and discussion regarding the discount rate in order to make measures which have different time spans comparable. Some argue in favour of one discount rate for all effects, others argue for multiple discount rates depending on the effect studied (Elvik et al, 2004b).

---

[2] The Kaldor-Hicks principle implies that persons whose welfare levels have increased (i.e. the winners) should be able to compensate the persons whose welfare levels have decreased (i.e. the losers). Pareto efficiency means that it is not possible to increase the welfare of one person without decreasing at the same time the welfare level of at least one other person. As long as a Kaldor-Hicks compensation is possible, the situation is not Pareto efficient.

[3] According to the utilitarian approach 1 euro accruing to a “poor” stakeholder results in a higher utility increase than 1 euro accruing to a “rich” stakeholder.

Multi-Criteria Analysis

The Multi-Criteria Analysis (MCA) or Multi-Criteria Decision Aid (MCDA) is an ex-ante decision-making tool, which has its roots in Operations Research (Charnes et al, 1961), developed for solving complex decision problems. The MCA is used when different alternatives have to be weighed against each other (multiple alternatives[4]) in terms of criteria expressed by indicators. In MCA the obtained values are derived from the policy makers' objectives and not from consumer willingness-to-pay, as is the case in SCBA (De Brucker et al, forthcoming). The MCA will sort and/or rank the different alternatives or choose the most optimal alternative based on the different criteria in order to reach the policy objectives. Using MCA, the decision maker can take into account all known aspects of a given problem simultaneously and in a structured and transparent way (Geudens et al, 2009). Therefore, this tool is very relevant to evaluate road safety projects where different effects and goals (safety, mobility, environment, (political) feasibility, implementation barriers, investment risk, etc.) are to be taken into account. In almost every decision-making problem, the decision maker has to deal with several (conflicting) goals which he or she may want to trade-off. In MCA different alternatives are evaluated according to multiple and sometimes conflicting criteria[5] (Belton et al, 2002). This is in contrast with CEA, where only one aspect is evaluated. In MCA, each alternative is scored on different criteria. This scoring is done on the basis of the indicator (attribute)[6] to which the alternative does contribute. Each criterion receives a weight, based on the importance of that criterion. The scores on the different criteria then need to be taken together. To aggregate these scores several methods can be used, such as AHP, ELECTRE I, II, III, IV, IS & A and PROMETHEE[7]. In a sensitivity analysis the effects of a change in the criterion weights may be simulated so as to inform the decision maker about the impact of this change on the final result (Geudens et al, 2009). The MCA will never replace the decision maker. The MCA, often called MCDA, (i.e. "multi-criteria decision *aid*") will "aid" the decision maker to make better decisions by providing information to him or her about the effects of the alternatives, as well as an interactive tool to process this information. As a result, the decision maker may be better informed and more able to motivate the choices made to the public. The subsequent steps in the MCA are discussed in many papers such as Van Malderen, et al (2009), Geudens et al (2009) and De Brucker et al (forthcoming).

The MCA also has a number of advantages and disadvantages. In an MCA the effects do not have to be based on welfare economic concepts such a consumer surplus or value added. The alternatives are compared using criteria which represent the (sub)objectives of the stakeholders (De Brucker, 2000). A major strength is thus that every effect (tangible or intangible) has to be measured either quantitatively or qualitatively, but not necessarily monetized. As a result heterogeneous (quantitative and qualitative) information can be included in the evaluation process. Another advantage is the fact that the MCA is a sound

---

[4] Alternative zero, project alternative A, project alternative B, …

[5] A criteria is a medium or standard to make a judgment

[6] For example: Criterion = road safety; Indicator (attribute) = number of accidents.

[7] AHP: Analytic Hierarchy Process; ELECTRE : ELimination Et Choix Traduisant la REalité (Elimination and choice translating reality) ; PROMETHEE: Preference Ranking Organization METHod for Enrichments Evaluations

evaluation method, where multiple effects can be included. In addition the multi-criteria processes make the lowest demands in terms of data (Baum et al, 2001). An important disadvantage, however, may be “rank reversal”. Rank reversal changes the ranking of the remaining alternatives when an undesirable alternative is added or deleted (Bana e Costa et al, 2008). This problem does only occur in some specific MCA-methods, not in all methods. A full description of all these MCA methods lies, however, out of the scope of this paper (see for example Hanne, 1999 & De Brucker, 1998, 2000). As opposed to SCBA, MCA cannot evaluate an isolated measure. Multiple alternatives are needed in order to conduct a MCA. Another criticism regarding MCA is related to the (preferential and structural) independence of the criteria. This is a basic assumption underlying most MCA methods. In some specific cases, the requirement regarding preferential independence of criteria may pose a problem. When there is preferential dependence between criteria, it may be impossible to express preferences (and derive criterion scores) independently of the score obtained by the same alternative on another criterion. Structural dependence on the other hand may result in double counting of effects. As a result, the importance of the criteria may rise (Fenton et al, 2001). Another fundamental weakness related to MCA is that this method does not address the fundamental desirability of project alternatives. The effects are weighed against each other and the policy makers’ task is to make a choice about the implementation of the alternative which realizes their objectives. The SCBA is easier to interpret. The alternative which generates the highest net present value for the society is considered as the most desirable one. This “failure”, however, is seen by some as a strength, because policy makers have to make an informed choice and cannot completely rely on one evaluation method. De Brucker (2000, 2006 and 2007) developed an eclectic evaluation framework in the form of an MCA (called “eclectic multi-criteria analysis” or “EMCA”). In the EMCA, effects included in different evaluation methods (SCBA, regional economic impact study and environmental impact assessment) are integrated and weighed using an MCA procedure. To conduct a MCA, the analyst should also have sufficient knowledge about the different aggregation methods (full, partial or iterative aggregation[8]). Another major criticism of MCA is related to the alleged subjectivity associated with weighting the objectives and criteria. This criticism, however, also applies to other evaluation methods such as SCBA. In the SCBA, economists disagree on which effect is a cost and which a benefit, as well as on the monetary value of these effects (De Peuter, 2007). In fact important decisions always entail multiple objectives, and weighing these, is subjective by nature. In fact objectivity is nothing more than “agreed upon subjectivity”. The only thing that is possible is to be as objective as possible or to follow objective procedures (Forman and Selly, 2001; Buchanan et al, 1998).

Multi-Actor Multi-Criteria Analysis

Recently the MCA method has evolved to accommodate multiple stakeholders’ and decision makers’ needs to make group decisions. Each of these stakeholders wants his or her own and sometimes conflicting criteria to be taken into account in the evaluation process (Macharis et al, 2009). Thus, the MAMCA developed by Macharis (2004), explicitly includes

[8] The iterative aggregation is especially suitable for evaluating a large number of project alternatives or alternatives that may vary continuously. The first two methods are preferred in case the project alternatives are discrete.

the relevant stakeholders. When there are conflicting interests between the stakeholders, it is extremely useful to conduct a MAMCA. By including the stakeholders in the evaluation process, the chance of acceptance and success of the measures will increase. The interaction between stakeholders might also result in new alternatives being constructed. The MAMCA is a MCA and thus enjoys the same benefits as the MCA (Macharis, 2007). As a result, it is not necessary to monetize all of the effects. Furthermore, the MAMCA can solve some weaknesses of the MCA. The criticism regarding potential structural dependence among the criteria does not apply to the MAMCA, because criteria trees are structured around stakeholders' objectives or points of view. Usually structural dependence among criteria does not pose a problem and does not result in double counting when the criteria represent different points of view or contribute to different actors' objectives. This is precisely the case in MAMCA. So the same (or similar) criteria may be included more than once in the decision tree as long as they are part of different subsystems of the MAMCA, i.e. contributing to different stakeholders' objectives. Finally, the MAMCA may result in multiple solutions, in contrast to the CEA, SCBA and MCA, because the aim of MAMCA is to select (and rank) the best alternatives for each stakeholder separately. Sometimes there may be one alternative that is ranked first in terms of all stakeholders' objectives, but usually solutions differ per stakeholder. However, this weakness can be seen rather as a strength, since the aim of MAMCA is to deliver a set of alternatives per stakeholder. It is the decision maker who is responsible for making the final decision based on the outcome of MAMCA. The subsequent steps of the MAMCA are discussed in Macharis (2004) and Geudens et al (2009).

The major strengths and weaknesses of the various socio-economic evaluation methods are synthesized in Table I.

Table I - Strengths and weaknesses of socio-economic evaluation methods:

	Strengths	**Weaknesses**
CEA	▪ Easy to calculate ▪ Inclusion of non-monetary effects ▪ Explicit evaluation of the basic objective ▪ Not time consuming ▪ Low demands in terms of data	▪ No formal decision criterion to accept/reject a project ▪ Only one effect can be evaluated at a time in CEA ▪ Time horizon: short and medium term ▪ No indication of the economic efficiency ▪ Does not include stakeholders
SCBA	▪ Ex-post and ex-ante evaluation ▪ Costs and benefits over a longer period are included ▪ Sound evaluation method: can include multiple effects ▪ Easy to interpret	▪ Monetization of intangible effects ▪ Equity issues are waived (differences in marginal utility of income are not taken into account) ▪ Decision makers do not play an active role ▪ ▪ Lack of knowledge of relevant effects ▪ Cross-border evaluation ▪ Determining (a) discount rate(s) ▪ High demands in terms of data

MCA	▪ Intangible effects do not need to be monetized ▪ Sound evaluation method ▪ The decision-maker still plays an active role in the decision-making process; the MCA is a tool for "decision aid", not for "decision making" ▪ Lowest demands in terms of data ▪ Useful when dealing with conflicting objectives	▪ Rank reversal in some specific methods ▪ Dependence between the criteria ▪ Does not address the desirability issue of project alternatives ▪ Only ex-ante evaluation is possible ▪ More than one alternative is needed
MAMCA	▪ Stakeholders are included explicitly in the decision-making process ▪ Intangible effects do not need to be monetized ▪ Sound evaluation method ▪ The decision-maker still plays an active role in the decision-making process; the MCA is a tool for "decision aid", not for "decision making" ▪ In cross-border studies no conversions of monetary values are needed ▪ Especially useful when dealing with conflicting objectives	▪ Rank reversal in some specific methods ▪ Does not address the desirability issue of project alternatives ▪ Only ex-ante evaluation is possible ▪ More than one alternative is needed ▪ Does not necessarily yield one single solution

Source: Designed by the authors

ANALYZING THE DIFFERENCES BETWEEN EVALUATION METHODS WITH REFERENCE TO THE IN SAFETY CASE STUDY

In the previous sections we made clear that there are a number of differences between the various evaluation methods. In this section, the application of different socio-economic evaluation methods to Intelligent Transportation Systems (ITS) are studied in more detail. This is done in a comparative way by analyzing the IN-SAFETY case. In this pan-European project a socio-economic analysis of the efficiency and effectiveness of ITS measures is carried out in order to enhance the self-explaining (SER)[9] and forgiving features (FOR)[10] of the road and vehicle environment. In this project six scenarios or measures are evaluated using CEA, SCBA and MAMCA (IN-SAFETY, 2005), namely:

1. "In-car VMS dynamic speed limit": Dynamic legal speed limits on motorways, information available on VMS and inside the vehicle.
2. "In-car school bus warning": Warning that a school bus or taxi is nearby and that children may be ahead on the road.
3. "In-car curve speed warning": In-vehicle warning when a curve is approached when speed is to too high under given conditions (curve geometry, weather conditions).

[9] A self-explaining road (SER) is a "road designed and constructed to evoke correct expectations from road users, by definition eliciting proper driving behavior and in this way reducing the likelihood of driver errors and enhancing driving comfort" (Wiethoff et al, 2006).

[10] A forgiving road (FOR) is "designed and built in such a way as to interfere with or block the development of driving errors and to avoid or mitigate negative consequences of driving errors, once started" (Wiethoff et al, 2006).

4. "In-vehicle lane departure warnings on motorways": Warning inside the vehicle when the vehicle is about to depart from the driving lane, vehicle sensors detect lane markings and receive additional information from road side beacons in road work zones.
5. "Blind spot vehicle overtaking assistant": Warning if a vehicle in the blind spot of the driver has the intention to overtake that driver's vehicle on roads with more than one lane per direction.
6. "Approaching vehicle overtaking assistant": Warning if a vehicle is approaching when the driver intends to overtake on a two-lane road.

In the following sections the obtained effects as well as the outputs are compared between the various evaluation tools applied to this case, i.e. CEA, SCBA and MAMCA.

Overview of effects included in each evaluation method

In the CEA the number of prevented fatalities per one million dollars is calculated. Therefore, the effectiveness of the road safety measure has to be estimated in terms of the number of accidents that are prevented per unit of implementation (e.g. per vehicle, per km, etc.) and per time reference (e.g. annual basis, 15 years, etc.)[11]. This will result in the denominator of the effectiveness-cost (EC) ratio. In order to estimate the nominator, the unit costs per time reference need to be calculated. This means that we have to calculate the investment, operation and maintenance costs (IN-SAFETY, 2005). In the SCBA the same data as in the CEA are required to calculate the road safety effects. However, as stated in the previous section, extra input is needed in the SCBA to obtain the environmental and mobility effects. In addition, information about the money values is needed in order to monetize those effects. In the IN-SAFETY case the seriously injured and slightly injured victims that could be avoided as well as the reduction in the number of fatalities that result from the implementation of that measure were identified. In addition, the implementation costs were identified in order to calculate the benefit-cost ratios for the six scenarios (IN-SAFETY, 2005). The MAMCA even takes more effects into account than does SCBA. For each group of stakeholders (users, society and manufacturers) a set of criteria contributing to their objectives were identified. Besides the safety effects, also implementation costs, mobility and environmental effects as well as some other aspects such as driver comfort, socio-political acceptance, risk and technical feasibility of the measures were included in the analysis (IN-SAFETY, 2008; De Brucker et al, forthcoming). In Table II a summary of the obtained effects per evaluation method is shown for the IN-SAFETY case.

[11] In order to make the different EC-ratios comparable, all the effects and costs need to be calculated using the same time reference, because the lifetime of road safety measures can vary a lot, and the same unit of implementation. Therefore, the EC ratio is calculated based on an implementation cost of 1 million dollars.

Table II – Effects included in evaluation methods:

CEA	SCBA	(MA)MCA
▪ Road Safety effects (in terms of prevented fatalities) ▪ Unit costs of the implementation of the measure	▪ Road safety effects (prevented fatalities, seriously injured and slightly injured victims using monetary values) ▪ Implementation costs of the measure (vehicle + infrastructure)	▪ Driver comfort ▪ Mobility effects (travel time duration + network efficiency) ▪ Safety effects (driver safety + overall safety) ▪ Implementation costs (full user cost + public expenditure) ▪ Socio-political acceptance ▪ Environmental effects ▪ Risk (liability + investment) ▪ Technical feasibility

Source: Designed by the authors based on IN-SAFETY, 2005 & IN-SAFETY, 2008; Macharis et al, forthcoming

Overview of output per evaluation method

Ramjerdi (1995) argued that intangible effects such as environmental and mobility related effects are often omitted in the evaluation of road safety measures. These missing elements can influence the output of the decision tool (Tudela et al, 2006). From the previous section it became clear that, in the IN-SAFETY case, the CEA comprises the least number of effects, whereas the MAMCA comprises the most. In the Table III the outcomes of the different evaluation tools are presented. Here, it becomes clear that the results of some particular scenarios depend strongly on the evaluation method used. It is actually quite natural that the results of these evaluation tools as applied to the various measures under study differ quite a lot. It would be an error to expect a priori identical results. The reason is that the effects studied, the basic assumptions, aims and goals of the methods are quite different for each method[12]. It is, however, interesting to look more closely at the differences in the outcomes between the evaluation methods applied, because these might influence the decision maker.

[12]

- Goal CEA: Given a fixed budget, what kind of measure is the most effective one? Or alternatively how can a political objective be achieved at the lowest cost possible by selecting a measure or combination of measures?
- Goal SCBA: What is the economic efficiency and the desirability of an alternative? Does an alternative create additional welfare for the society as a whole?
- Goal MAMCA: Comparing different alternatives, what kind of measure(s) are (is) preferred taking into account the often conflicting criteria of the various stakeholders?

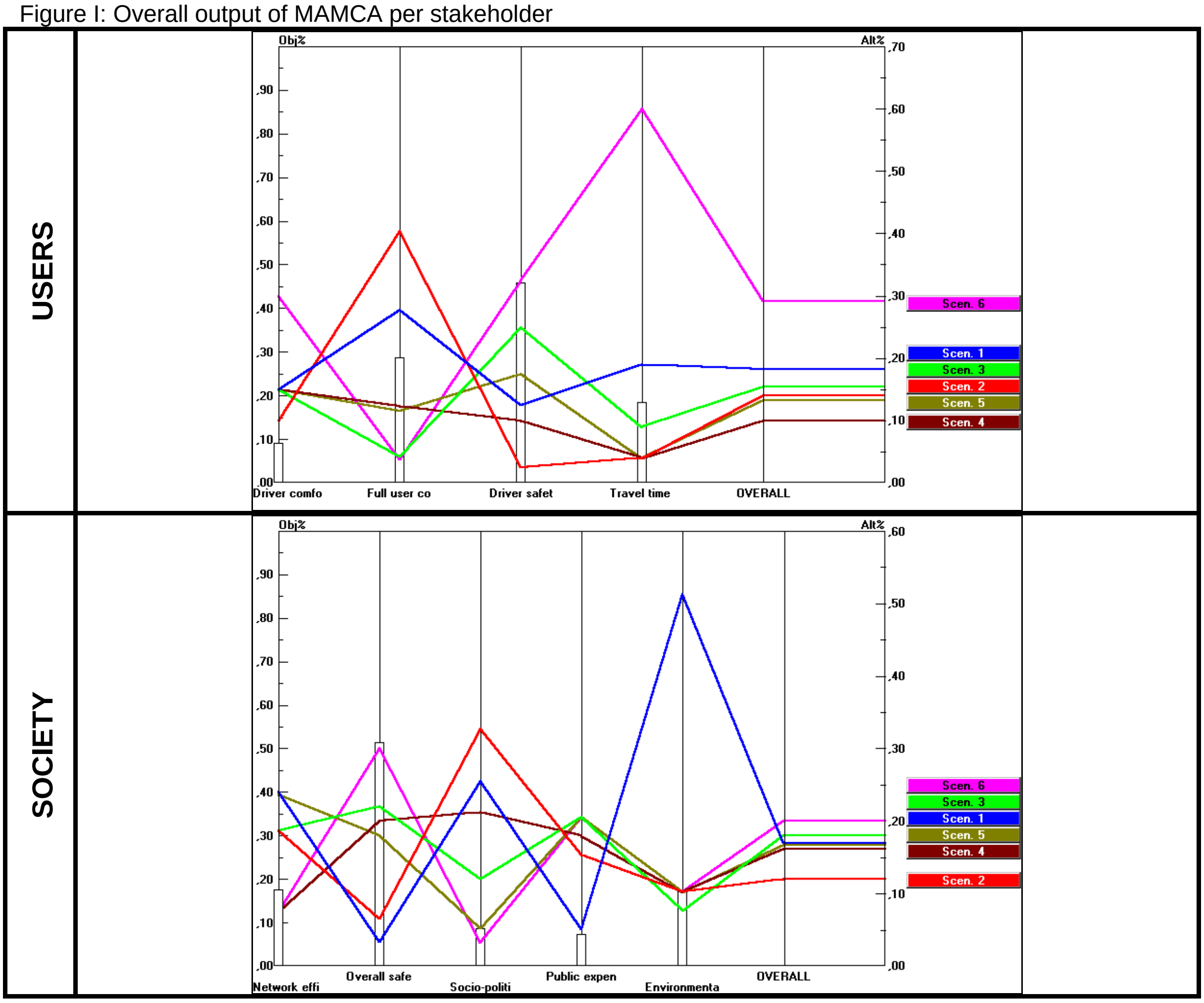
Table III - Output per evaluation method:

	CEA		**SCBA**		**MAMCA**	
	Outcome (EC-ratio)	Ranking	Outcome (BC-ratio)	Ranking	Outcome (Overall)	Ranking
Scenario 1	0,19	2	0,18	3	**0,218**	**1**
Scenario 2	0,02	5	0,02	5	0,179	3
Scenario 3	**0,37**	**1**	0,62	2	*0,136*	*6*
Scenario 4	0,19	2	**0,65**	**1**	0,145	4
Scenario 5	*0,004*	*6*	*0,03*	*6*	0,143	5
Scenario 6	0,07	4	0,16	4	0,179	2

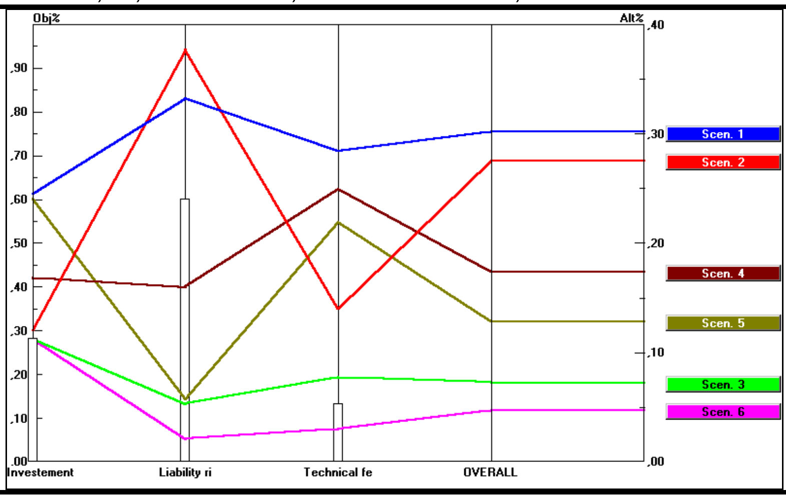
Source: Designed by the authors based on IN-SAFETY, 2005 & IN-SAFETY, 2008; De Brucker et al, forthcoming

From table III it can be concluded that scenario 3 ("In-car curve speed warning") will probably be selected if only a CEA were conducted. This scenario obtains a good score because of the high effectiveness of this alternative in terms of preventing fatalities. "In-car curve speed warning" is namely avoiding 0,37 fatalities per 1 million Euros invested. "In-vehicle lane departure warnings on motorways" (scenario 4), will presumably be chosen when only a SCBA were carried out, because this scenario is scoring mainly better on preventing fatal accidents and accidents with seriously injured and slightly injured victims. From this SCBA, it can be concluded that the cost of this alternative is greater than the benefits. Per euro invested, society will gain only 62 cent. However the benefit-cost (BC) ratios for the other scenarios are even worse. The actual BC ratio will probably be higher because the intangible effects such as travel time duration and environmental effects were not included in the SCBA. Another reason why the actual BC ratio may ultimately be higher is that the implementation cost of the safety measures may decrease over time as these tools will be implemented on a larger scale, because of economies of scale in the production process. These effects, however, might have a positive influence on the social benefits of these measures. The decision maker will probably choose scenario 3 when both tools (CEA and SCBA) are performed together, because the EC-ratio is relatively high for this scenario. The MAMCA, however, sheds a different light on scenario 3. This alternative is ranked last in the MAMCA. This is mainly due to the poor scores on the criteria of the users (driver comfort, driver safety, travel time savings and full user costs) and the society (network efficiency, overall safety, socio-political acceptance, public expenditure and environmental effects) and the bad score on the manufacturers' criteria (liability risk, technical feasibility and investment cost) compared to the other alternatives. In contrast, scenario 1 ("In-car VMS dynamic speed limit") obtains a good score in general on the criteria of the various stakeholders, especially the manufacturers' criteria. That is the reason why scenario 1 is ranked first in the MAMCA. Figure I shows all this information in a graphical way. The criteria are mentioned on the horizontal axis. The height of the vertical bars represents the criterion weights. The intersection of the various curves (i.e. the quasi horizontal lines) with the vertical lines starting at the criterion name represents the relative priority of the scenario for that specific criterion. The final rankings in terms of each stakeholder point of view are shown on the right vertical axis. If a scenario is to be chosen based on the three evaluation tools, the decision maker will probably choose between scenario 1 and 4. Here, the decision maker will have to make a trade-off between an alternative with a higher BC-ratio and an alternative which better fits with the criteria of the stakeholders. Consequently, the latter alternative will receive more support from the stakeholders and, hence, this scenario is more likely to be implemented successfully.

Figure I: Overall output of MAMCA per stakeholder



MANUFACTURERS



Source: Macharis et al, forthcoming

HOW TO COPE WITH INCONSISTENCIES IN THE RESULTS OF DIFFERENT EVALUATION METHODS

From the previous section it became clear that different socio-economic evaluation methods do not necessarily result in the same outcome. The CEA leads to another outcome than the SCBA or the (MA)MCA. The IN-SAFETY project is definitely not the only case where these inconsistencies appear (Elvik et al, 2004a; Tudela et al, 2006). At first sight, this may seem rather strange, because the alternatives evaluated are the same. The explanation is, however, quite logic. On the one hand, if the effects evaluated are different, one may expect the output to be different as well. On the other hand, each evaluation method has its own specific basic assumptions, aims and goals. Hence, the results obtained by applying these methods should be interpreted with reference to these aims and goals. The CEA for example will give the decision maker more insight in the possibility of a certain measure to achieve a predefined political objective in a cost-effective way. In the SCBA it is possible to assess how desirable a particular measure is for the society as a whole. The (MA)MCA looks for the alternative which contributes the most to the (conflicting) criteria of the stakeholder(s). As a result, we cannot argue that the (MA)MCA is a better method compared to the CEA or SCBA or vice versa. All these methods will give the decision maker relevant information whereby more insight will be created as regards the selection of a certain measure. Ideally, all three methods will be performed. By applying all of these three methods the decision maker will obtain relevant information from these three different perspectives. This is, however, not always feasible because of the resources (in terms of money and time) involved in these evaluation processes. Consequently, in a number cases it might be necessary to apply only one (or two) of these evaluation tools. Depending on the situational context the most adequate evaluation method needs to be selected. In order to support the decision maker in selecting the most adequate evaluation method, there is a need to develop a decision tree for this purpose. Elements that will play an important role in this decision tree are related for instance to the point of view of the evaluation, the point in time (ex-ante or ex-post), the feasibility to monetize the effects and the aspiration to involve the different stakeholders. The criteria that will be included in that decision tree will be based on the advantages and disadvantages, as well as on the basic assumptions, aims and goals of the evaluation methods.

CONCLUSIONS

In this paper a brief overview of various socio-economic evaluation methods, namely cost-effectiveness analysis (CEA), social cost-benefit analysis (SCBA) and (multi-actor) multi-criteria analysis ([MA]MCA) has been presented. By using evaluation methods, road safety measures can be evaluated in a systematic way, taking into account the effectiveness and efficiency of these measures. This is necessary in order to allocate the scarce resources of the government optimally. The CEA seems to be the least complete evaluation method compared to the SCBA and the (MA)MCA. However, the CEA may give the decision maker a useful insight in the possibility of the measure to achieve a policy objective in a cost-effective way. The SCBA evaluates the economic efficiency (including the desirability) of a particular alternative by monetizing all the effects of the measure. The MCA is a decision tool for complex problems, because it takes different and often conflicting criteria into account. This tool makes it, therefore, possible to perform an evaluation in terms of more objectives than only the main objective of a policy measure. For each evaluation method the basic assumptions, aims and goals, as well as the strengths and weaknesses have been reviewed in this paper. In addition, also the extent to which the effects studied (and the output obtained) differ between the various evaluation methods such as CEA, SCBA and (MA)MCA has been examined in this paper. The fact that multiple methodologies exist and may be applied simultaneously might perhaps confuse the decision maker a little bit when it comes to selecting the most appropriate alternative. This should, however, not be the case. Each method has its own basic assumptions, aims and goals and the outcome of each method should be interpreted in terms of these assumptions aims and goals. Ideally, the three evaluation methods could be performed together in order to have the different points of view. However, as each evaluation method requires a large amount of resources (in terms of time and money) most often only one method is performed. Consequently, it is important to select the most appropriate evaluation method taking into account the purpose of the evaluation. If a less appropriate evaluation method is used, this may affect the results. Since policy makers might rely on these inaccurate results, inefficient or ineffective decisions might be made. In order to avoid this, there is a need to develop a decision tool to select the most suitable evaluation method given the specific decision-making context. We can conclude this paper with the relevant quote from Meadows (2001): “When your only tool is a hammer, everything looks like a nail”.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support from the Policy Research Centre Mobility & Public Works – Track Road Safety.

REFERENCES

Bana e Costa, C.A. & Vansnick J.C. 2008. A critical analysis of the eigenvalue method used to derive priorities in AHP. European Journal of Operational Research 187:1422-1428.

Baum, H. & Höhnsheid, K.J. 2001. Economic evaluation of road traffic safety measures. European Conference of Ministers of Transport. Paris: 26-27th October 2000.

Belton V. & Stewart T.J. 2002. Multiple Criteria Decision Making. An integrated Approach. Kluwer Academic Publishers: Boston/ Dordrecht/ London.

Buchanan, J.T., Henig E.J. & Henig M.I. 1998. “Objectivity and subjectivity in the decision making process” *Annals of Operations Research,* 80: 333-345.

Charnes A. & Cooper W.W. 1961. Management models and industrial applications of linear programming. Wiley & Sons: New York.

Dasgupta, A.K. & Pearce D.W. 1972. Cost-benefit analysis: theory and practice. Macmillan, London.

De Brabander, B. 2006. Valuing the reduced risk of road accidents. Empirical estimates for Flanders based on stated preference methods” *PhD thesis,* University of Hasselt.

De Brucker, K. 1998. *Sociaal-economische evaluatie van overheidsinvesteringen in transportinfrastructuur. Kritische analyse van het bestaande instrumentarium. Ontwikkeling van een eclectisch evaluatie-instrument*, Leuven (Belgium):Garant.

De Brucker, K. 2000. Ontwikkeling van een eclectisch evaluatie-instrument voor de social-economische evaluatie van complexe investeringsprojecten, met een toepassing op het project Seine-Scheldeverbinding. *PhD thesis, University of Antwerp.*

De Brucker, K. & Verbeke, A. 2006. The Eclectic Multi-Criteria Analysis (EMCA): a Tool for Effective Stakeholder Management in Project Evaluation. In: Notteboom T. (Ed), Ports are more than piers. Liber Amicorum Willy Winkelmans. De Lloyd: Antwerp, pp. 211-232.

De Brucker, K. & Verbeke A. 2007. “The institutional theory approach to transport policy and evaluation. The collective benefits of a stakeholder’s approach: towards an eclectic multi-criteria analysis”, In: Haezendonck, E. (ed) *Transport Project Evaluation. Extending the Social Cost-Benefit Approach*, Edward Elgar: Cheltenham, pp. 55-94.

De Brucker, K., Macharis, C. & Veisten, K. forthcoming. Chapter 3: Structuring the way: a new approach on multi-criteria and cost-benefit analysis to be applied to road safety measures. In: Wiethoff, M & Gaitanidou, L. (eds.) INfrastructure and SAFETY in a collaborative world, Springer: New York.

De Brucker, K. & Macharis C. forthcoming. Chapter 16. Best things first: The application of multi-criteria analysis to derive implementation priorities for innovative road safety measures. In: Wiethoff, M & Gaitanidou, L. (eds.) INfrastructure and SAFETY in a collaborative world, Springer: New York.

De Peuter, B., De Smedt, J. & Bouckaert, G. 2007. Handleiding beleidsevaluatie. Deel 1: Evaluatiedesign en –management. Steunpunt Bestuurlijke Organisatie Vlaanderen – spoor Beleid en monitoring, Leuven.

Elvik, R. 2001. “Cost-benefit analysis of road safety measures: applicability and controversies” *Accident Analysis and Prevention.* 33: 9-17.

Elvik R. & Vaa T. 2004a. The handbook of road safety measures. Norway, Oslo: Elsevier pp. 1078

Elvik, R. & Veisten, K. 2004b. Barriers to the use of efficiency assessment tools in road safety policy. Roads safety and environmental benefit-cost and cost-effectiveness analysis for use in decision-making. ROSEBUD thematic network, report D4, European Commission, DGET, 5th framework programme.

Fenton, N. & Neil, M. 2001. Making decisions: using Bayesian nets and MCDA. Knowledge Based Systems, 14, 307-325

Forman E.H. & Selly M.A. 2001. Decision by objectives. How to convince others that you are right. World Scientific: New Jersey and London.

Geudens, T., Macharis C., Plastria F. and Crompvoets J. 2009. Assessing Spatial Data Infrastructure Strategies Using the Multi-Actor Multi-Criteria Analysis, International Journal of Spatial Data Infrastructures Research (in review)

Hakkert S. & Wesemann P. 2005. The use of efficiency assessment tools: solutions to barriers. SWOV Report R-2005-02. Institute for Road Safety Research (SWOV), Leidschendam.

Hanne, T. 1999. Meta Decision Problems in Multiple Criteria Decision Making. In: Gal, T., Stewart, T.J. & Hanne, T. (eds.) Multicriteria decision making: advances in MCDM models, algorithms, theory and applications.

IN-SAFETY (Erke, A., Veisten, K. & Elvik, R.). 2005. Cost-Benefit analysis and cost-effectiveness analysis. Implementation priorities and policy recommendations, Final deliverable (Del. 5.2) of the IN-SAFETY research project. Brussels, Commission of the European Union – Department Transport and Energy (DG TREN) (contract no. 506716) (restricted)

IN-SAFETY (Macharis, C., Verbeke, A., De Brucker, K., Gelová, E., Weinberger, J. & Vašek, J.) 2008. Implementation scenarios and further research priorities regarding forgiving and self-explaining roads, IN-SAFETY D5.3. Final deliverable (Del. 5.3) of the IN-SAFETY research project. Brussels, Commission of the European Union – Department Transport and Energy (DG TREN) (contract no. 506716). http://www.insafety-eu.org/results.html. Accessed 24 May 2010.Macharis, C. 2004. The importance of stakeholder analysis in freight transport: The MAMCA methodology. 25/26: 114-120

Macharis C., Verbeke A. & De Brucker K. 2004. The strategic evaluation of new technologies through multicriteria analysis: the advisors case. In Bekiaris E. & Nakanishi Y.J. (eds.) Economic impacts of intelligent transportation systems: innovations and case studies. Research in Transportation Economics, 8, Elsevier Ltd.: Amsterdam.

Macharis, C. 2007. Multi-Criteria Analysis as a Tool to Include Stakehoders in Project Evaluation: The MAMCA method. In Haezendonck, E (eds.) Transport Project Evaluation. Extending the Social Cost-Benefit Approach. Edward Elgar, Cheltenham.

Macharis, C., Geudens, T. & Ampe, J. 2009. The problem with quantitative target setting and cost-benefit analysis for traffic safety measures. Submitted to Journal of Transport Review.

Meadows, D.L. 2001. Tools for understanding the limits to growth: comparing a simulation and a game. Simulation & gaming 32(4): 522-536.

Pearce, D.W. & Howarth, A. 2000. Technical report on Methodology: Cost Benefit Analysis and Policy Responses". RIVM Rapport 481505020, Rijksinstituut voor Volksgezondheid en Milieu, 72 p.

Ramjerdi, F. 1995. Road pricing & toll financing with examples from Oslo and Stockholm. Doctoral Thesis. Institute of Transport Economics and Royal Institute of Technology, Oslo and Stockholm.

Sen, A.K. 2000. The discipline of cost-benefit analysis. *Journal of Legal Studies*, 29: 931-952.

Tudela, A., Akiki, N. & Cisternas, R. 2006. Comparing the output of cost benefit and multi-criteria analysis. An application to urban transport investments. Transportation Research Part A. 40: 414-423.

Van Malderen, F. & Macharis, C. 2009. Handleiding voor het evalueren van verkeersveiligheidsmaatregelen. Een eerste aanzet. Policy Research Centre Report RA-MOW-2009-03 Diepenbeek.

Van Malderen, F. & Macharis, C. 2010. Socio-economic evaluation methods: See the forest for the trees by using a decision tree. Economica, Paris.

Vlakveld W, Wesemann P, Devillers E, Elvik R & Veisten K . 2005. Detailed cost-benefit analysis of potential impairment countermeasures. SWOV Report R-2005-10. Institute for Road Safety Research (SWOV), Leidschendam.

Wiethoff, M. Marchau, V.A.W.J., de Waard, D., Walta, L. Brookhuis, K.A., Macharis, C. Lotz, C., Wenzel, G. Ferrari, E. Lu, M. & Damiani, S. 2006. Implementation scenarions and concepts towards forgiving roads. IN-SAFETY project. Deliverable D1.1, C.N. 506716.