

## Cost-benefit analysis

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## 1 Overview

This text describes the use of cost-benefit analysis to assess the impacts of road safety measures. The main steps of a cost-benefit analysis are outlined. The principles of cost-benefit analysis are explained and guidelines for the monetary valuation of impacts in cost-benefit analyses are provided. Figure 1 (next page) summarises the stages of cost-benefit analysis and the main requirements that must be fulfilled in order to perform such analyses. Problems that may be encountered when performing a cost-benefit analysis are discussed. The relationship between cost-benefit analysis and other normative principles for road safety policy making is discussed.

In practice it will never be possible to base road safety policy fully on cost-benefit analyses. Some of the reasons for this are briefly discussed. Important considerations that may justify departing from the policy priorities implied by cost-benefit analyses include an objective of reducing disparities in risk, thus giving high priority to measures benefiting pedestrians and cyclists, and an objective of giving priority to those measures that provide the largest reductions of the number of road traffic fatalities. These measures may not always be the most cost-effective.

Figure 1: The stages and main requirements of cost-benefit analysis

REQUIREMENT FOR DOING COST-BENEFIT ANALYSIS	STAGE OF COST-BENEFIT ANALYSIS (CBA)	POTENTIALLY RELEVANT CONSIDERATIONS OUTSIDE THE FRAMEWORK OF COST-BENEFIT ANALYSIS
<i>Inclusion of all relevant impacts (policy objectives)</i>	<i>Determine policy objectives and relevant impacts</i>	<i>Distributional objectives not normally considered in CBA</i>
<i>There should not be any indivisibilities</i>	<i>Develop measures and alternatives for their use</i>	<i>Perfect optimisation may be impossible</i>
<i>The reference scenario should reflect exogenous effects only</i>	<i>Describe a reference scenario (do-nothing option)</i>	<i>Past trends partly reflect effects of road safety measures</i>
<i>Some relevant impacts may be illegitimate to include</i>	<i>Identify relevant impacts of each measure</i>	<i>Controversies about impacts better resolved by negotiations</i>
<i>Numerical estimates of all impacts needed</i>	<i>Estimate impacts in "natural" units</i>	<i>Some impacts are qualitative in nature</i>
<i>Monetary valuation of human life must be applied</i>	<i>Convert all impacts to monetary terms</i>	<i>Values of human life are controversial and imprecise</i>
<i>The marginal utility of money is constant</i>	<i>Compare cost and benefits for all measures</i>	<i>The marginal utility of money depends on wealth</i>
<i>All sources of uncertainty must be quantified</i>	<i>Conduct a sensitivity analysis of results</i>	<i>All sources of uncertainty cannot currently be quantified</i>
<i>All potentially effective measures have been surveyed</i>	<i>Recommend cost-effective policy options</i>	<i>Recommendations assume that similar analyses have been made all over</i>

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## 1 Introduction

This text explains the main points of the application of cost-benefit analysis of road safety measures as an element of road safety policy making. The following questions are discussed:

- What is cost-benefit analysis? What are the essential steps of such an analysis?
- Why do cost-benefit analysis? Is it applicable to road safety?
- What are the basic rules for cost-benefit analysis? How should it be done and what should it include?
- What is the relationship between cost-benefit analysis and other normative ideals for road safety, in particular *Vision Zero*? Are these ideals compatible or not?
- What are the decision rules in cost-benefit analysis? How should choices be made between different road safety measures for which cost-benefit analyses have been performed?
- How should impacts of road safety measures be valued monetarily? What are the best current estimates of the value of preventing road traffic fatalities and injuries?
- What do we need to know to do cost-benefit analysis? Are certain road safety measures less amenable to cost-benefit analysis than others?
- What are the principal problems that may be encountered in a cost-benefit analysis and that may prevent its results from being strictly applied?
- Can the results of cost-benefit analyses be generalised across countries? What are the main findings of recent cost-benefit analyses at the European level?
- Can the results of cost-benefit analyses always be applied in a straightforward manner, or are there other relevant considerations for priority setting of road safety measures?

This text does not aim to teach readers how to perform a cost-benefit analysis, but will discuss the use of such analyses in more general terms. For a detailed description of how to perform cost-benefit analyses, references will be given to relevant textbooks.

## 2 What is cost-benefit analysis?

Cost-benefit analysis is a formal analysis of the impacts of a measure or programme, designed to assess whether the advantages (benefits) of the measure or programme are greater than its disadvantages (costs). Cost-benefit analysis is one of a set of formal tools of efficiency assessment (Hakkert & Wesemann, 2005). Efficiency assessment refers to analyses made for the purpose of identifying how to use scarce resources to obtain the greatest possible benefits of them.

Cost-benefit analysis is a technique which is based on welfare economics. There are many textbooks explaining in detail the problems encountered in a cost-benefit analysis and how to solve these (Boardman et al., 2011; Pearce et al., 2006; Hanley & Spash, 1993; Layard & Glaister, 1994; Mishan, 1988; Adler & Posner, 2001; Sen, 2000). Only the main features of the technique are described here. The main steps of a cost-benefit analysis are as follows:

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1. Develop measures or programmes intended to help reduce a certain social problem (e.g. road crashes or environmental pollution).
  2. Develop alternative policy options for the use of each measure or programme.
  3. Describe a reference scenario (sometimes referred to as business-as-usual or the do-nothing alternative).
  4. Identify relevant impacts of each measure or programme. There will usually be several relevant impacts.
  5. Estimate the impacts of each measure or programme in “natural” units (physical terms) for each policy option.
  6. Obtain estimates of the costs of each measure or programme for each policy option.
  7. Convert estimated impacts to monetary terms, applying available valuations of these impacts.
  8. Compare benefits and costs for each policy option for each measure or programme. Identify options in which benefits are greater than costs.
  9. Conduct a sensitivity analysis or a formal assessment of the uncertainty of estimated benefits and costs.
  10. Recommend cost-effective policy options for implementation.

Brief comments will be given with respect to each of these stages.

Cost-benefit analysis is typically applied to help find efficient solutions to social problems that are not solved by the market mechanism. Typical characteristics of problems to which cost-benefit analysis is applied include (Elvik, 2001):

1. They involve public expenditures, often investments. Projects are sometimes financed by direct user payment, but more often by general taxation.
2. There are multiple policy objectives, often partly conflicting and requiring trade-offs to be made. It is assumed that policymakers want solutions that realise all policy objectives to the maximum extent possible.
3. One or several of the policy objectives concern the provision of a non-marketed public good, like less crime, a cleaner environment or safer roads.
4. It is assumed that an efficient use of public funds is desirable, since these funds are scarce and alternative uses of them numerous.

Road safety problems have these characteristics. Efficiency is a technical term in welfare economics. Without going into details, a measure or programme is judged to be efficient if the benefits are greater than the costs. In principle, it will then be possible for those who gain from the measure to compensate those who lose from it, so that nobody becomes a net loser.

To identify relevant measures or programmes, a broad survey of potentially effective road safety measures should be conducted. A measure is regarded as potentially effective if it has been shown to improve road safety – and has not already been fully implemented – or if there is reason to believe that it will improve road safety by favourably influencing risk factors that are known to contribute to crashes or injuries.

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For each road safety measure, alternative options for its use should be considered. If the problem to be solved is bicyclist injuries, and the measure considered is bicycle helmets, alternative policy options could be:

1. Do nothing; leave to each bicyclist to decide whether or not to wear a helmet.
2. Conduct a campaign for bicycle helmets, while leaving their use voluntary.
3. Make the use of bicycle helmets mandatory for children.
4. Make the use of bicycle helmets mandatory for everybody.

These are distinct and mutually exclusive options. For very many road safety measures, however, options for their use are best conceived of as a continuous variable. Thus, one may convert 50 junctions to roundabouts, 51 junctions, 52 junctions, and so on. Most infrastructure-related road safety measures can be applied in very small gradual steps like this. These steps can be approximated as a continuous variable, since there would normally be thousands of junctions or thousands of kilometres of road that are candidates for the use of a certain road safety measure.

Policy options in cost-benefit analysis are always compared to a reference scenario and represent changes from that scenario. Often the reference scenario will be to do nothing, i.e. not introduce the road safety measure for which a cost-benefit analysis is performed. In some cases, however, one may foresee that a certain road safety measure will be introduced without any action from government. As an example, electronic stability control is now rapidly becoming standard equipment on new cars and will spread in the car fleet during the next 10-15 years due to new legislation. In such cases, the foreseen rate of introduction should be regarded as the reference scenario.

The most relevant impact of a road safety measure is, of course changes in the number of crashes or injury severity. Some road safety measures may, however, have additional impacts on mobility (travel time) and the environment. If a measure has such impacts, they should be included in a cost-benefit analysis. One of the objectives of such analyses is to help make trade-offs between different, and sometimes conflicting, policy objectives. Impacts that are relevant for all policy objectives must therefore be included.

All relevant impacts should first be estimated in “natural” units, for example number of crashes prevented, number of additional hours of travel, and so on. Then all impacts should be converted to monetary terms, applying monetary valuations of the various impacts. More will be said later about the economic valuation of road safety.

Cost-benefit analysis is designed to identify policy options for which benefits are greater than costs. According to the theory underlying cost-benefit analysis, a policy option should normally not be adopted if benefits are smaller than costs. It will, however, often be the case that costs and benefits are not known with certainty. An explicit consideration of uncertainty, as a minimum in the form of a sensitivity analysis should be part of any cost-benefit analysis.

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### 3 Why do cost-benefit analysis of road safety measures?

Cost-benefit analysis is a prescriptive technique. It has an explicit normative basis and is performed for the purpose of informing policymakers about what they ought to do. It is based on welfare economics and requires all policy impacts to be stated in monetary terms.

Some people find the very idea of assigning a monetary value to lifesaving or to quality of life, which is an essential element of cost-benefit analysis, meaningless and ethically wrong. Human life, it is argued, is not a commodity that can be traded against other goods. It should therefore not carry a price tag. However, the purpose of assigning a monetary value to human life is not to engage in trading in the usual sense of that term. It is simply to provide a guideline with respect to the amount of resources we would like to spend on the prevention of crashes or injuries, given the fact that not all of our resources can be spent for this purpose. Some form of economic reasoning – that is some form of thinking that recognises the fact that resources are limited and can be put to very many alternative uses – is simply inevitable, given the following basic facts:

- A limited amount of resources is at our disposal for the prevention of crashes or injuries, or indeed for catering to any human need.
- Human needs and value systems are complex and multi-dimensional. While safety is certainly one of the more basic human needs, it is not the only one, and no society would ever be able to spend more than a fraction of disposable resources on the prevention of crashes or injuries.
- How much to spend on the prevention of crashes or injuries will depend, and ought to depend, on how important people think this good is, seen in relation to all other goods they would like to see produced.
- It is, in principle, possible both to provide too little safety and to provide too much of it.

The objective of cost-benefit analysis is to help us find the right balance between safety and other goods.

If these basic observations are accepted as a fair description of the choices we are facing, then some kind of cost-benefit reasoning, although not necessarily formalised, is simply inevitable: We engage in this sort of thinking whether we are conscious of it or not.

The main reason for doing cost-benefit analyses of road safety measures is to help develop policies that make the most efficient use of resources, i.e. that produce the largest possible benefits for a given cost. Cost-benefit analysis seeks to identify the cheapest way of improving road safety. While one can think of arguments for choosing expensive solutions, one should never forget the fact that once resources have been committed to an expensive solution to a problem, they are no longer available for alternative, and possibly more beneficial, uses.

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## 4 The relationship between cost-benefit analysis and other normative ideals for road safety

*Vision Zero* (known generically as *Safe System*) is a widely supported long-term ideal for road safety. It states that the long-term solution to the problem of road crashes is to create a road transport system in which nobody is killed or permanently injured as a result of an crash. *Vision Zero* is based on a set of ethical principles, which are stated in the following terms by Tingvall (1997):

1. One must always do everything in one's power to prevent death or serious injury.
2. The right action must always be taken from the very beginning that is, all action taken must rest on scientific, tried-and-tested experience.
3. The best-known solution must always be applied.
4. The factor that ultimately governs the decision to change a situation must be both the risk, and potentially harmful effects of an existing situation.
5. Work must always be based on the fact that the responsibility for every death or loss of health in the road transport system rests with the person responsible for the design of that system.

Tingvall (1997) justifies the first ethical principle of *Vision Zero* by stating that “it goes without saying that human life cannot be exchanged for some gain”. The principle explicitly rules out trading off human lives against other commodities. In other words, according to this principle saving human life can never be regarded as too expensive in economic terms.

This point of view is clearly not consistent with the principles of cost-benefit analysis. Basically, a policy based on cost-benefit analysis will improve road safety if there is sufficient willingness-to-pay for it, but refrain from improving road safety if there is insufficient willingness-to-pay for it.

One should, however, not necessarily conclude that *Vision Zero* and cost-benefit analysis are fundamentally incompatible. In the first place, by setting the highest possible ambitions for improving road safety, *Vision Zero* provides an incentive for giving high priority to the most cost-effective road safety measures. To identify the most cost-effective road safety measures, some form of cost-benefit analysis needs to be made. In the second place, estimates of the costs and benefits of road safety measures are subject to frequent revisions. *Vision Zero* aims to stimulate technological innovation that may result in the development of new and more cost-effective road safety measures than those that are currently used. As an example, in-vehicle safety systems based on information technology are rapidly becoming more versatile (i.e. able to perform a wider range of actions to support the driver), more reliable and cheaper. Such technological innovation can make measures cost-effective in the future, even if they are not regarded as cost-effective today. See ERSO text on [eSafety](#). In the third place, any claim that the “optimal” level of safety has been determined by means of cost-benefit analysis should be treated with considerable scepticism. Estimates of both costs and benefits are highly uncertain. There will, therefore, not be any specific number of traffic fatalities that can be regarded as optimal. Rather, there will, at best, be a broad range

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of outcomes – not a specific number – that are within the range where the “optimal” level is likely to be found. However, as a policy guideline, a broad range is clearly less demanding and motivating, and much more difficult to communicate, than a simple ideal like *Vision Zero*.

## 5 What are the basic rules of cost-benefit analysis?

There are four main principles of cost-benefit analysis:

1. Consumer sovereignty
2. Valuation of goods according to willingness-to-pay
3. Pareto-optimality as the criterion of welfare maximisation
4. Neutrality with respect to income distribution

Consumer sovereignty is the principle that the choices made by consumers with respect to how to spend their income are accepted and are treated as data. Economists are not moralists. They will not say that someone who spends most of his income on alcohol, tobacco and unhealthy foods is a fool, whereas someone who saves part of his income for old age, while spending the rest prudently on safe foods and safe activities is a wise person. Economists simply treat individual demand for various goods and services as data.

The value of improving road safety is indicated by the willingness-to-pay for reduced risk of injury. Willingness-to-pay is the measure of benefits used in cost-benefit analysis. Assessing willingness-to-pay for non-market goods like road safety is a complex task, involving many potential sources of error. Hence, a common objection to the willingness-to-pay principle is that it is not possible to obtain credible estimates of willingness-to-pay. A more fundamental objection is that willingness-to-pay depends on ability to pay. The rich can afford to pay more for road safety than the poor. If the distribution of income is highly unequal, an indiscriminate use of the willingness-to-pay principle may lead to the provision of non-market goods, like road safety or cleaner air, only to the richest groups of the population. Since road traffic crashes represent a threat to human health, one could argue that all groups of road users ought to have equal access to measures intended to improve road safety, irrespective of their individual demand for it.

In response to these points of view, three arguments can be made in favour of basing the provision of road safety on the demand for it, as manifested in the amounts that individuals are willing to pay for safer roads. In the first place, it is never the case that the provision of road safety – at least when it is a public good – can be matched exactly to individual demand for it. The rich may state that they want to pay a lot for road safety, the poor may state that they cannot afford to pay anything, but both groups benefit when roads or cars are made safer. It is just not possible to match supply and demand at the individual level, as opposed to the case for most market goods (in the sense that, as a rule, we buy the mix of commodities that gives us the greatest satisfaction). In the second place, it is in principle possible to convert the amounts of money individuals are willing to pay for road safety to utility terms, by estimating the marginal utility of money. By converting monetary amounts to

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units of utility, one may account for the fact that giving up 1,000 Euro is a much smaller sacrifice for a rich man than giving up, say, 250 Euro would be for a poor man. At present, however, converting money to utility is not an easy task. In general, economists will recommend using the willingness-to-pay principle provided it does not lead to unacceptable changes in income distribution. What counts as “unacceptable” in this respect is, of course, ultimately a matter of politics. In the third place, basing the provision of road safety on the demand (willingness to pay) for it ensures that it is not over-provided. Road safety is over-provided if overall welfare can be improved by transferring resources from the provision of road safety to the provision of other commodities.

Pareto-optimality is the third principle of cost-benefit analysis. A measure is Pareto-optimal if it improves the welfare of at least one person without reducing the welfare of any other person. In practice, few measures taken by government will be strictly Pareto-optimal. There will almost never be only gainers and no losers. Hence, the criterion commonly applied in cost-benefit analysis is a weaker criterion, the criterion of a potential Pareto-improvement. This criterion is satisfied when those who gain from a measure can compensate those who lose from it (in utility terms), while still retaining a net benefit. A measure is commonly regarded as satisfying this criterion if its benefits are greater than the costs.

The fourth principle of cost-benefit analysis is that it remains neutral with respect to the distribution of benefits and costs among groups of the population (or groups of road users, for that matter) – provided of course that benefits in total exceed costs. Cost-benefit analysis is not intended to help find the most equitable solution to a social problem, only the most efficient solution. To the extent that realising a desired distribution requires the use of other policy instruments than those sanctioned by cost-benefit analysis, it follows that actual policy priorities cannot be based on cost-benefit analyses exclusively.

## 6 Decision rules in cost-benefit analysis

The main result of a cost-benefit analysis is a monetary estimate of the benefits and costs of a road safety measure. A measure is cost-effective if benefits are greater than costs. In general, the term costs refer to any negative impacts of a measure. By convention, however, the costs of a measure are normally defined as the costs of implementation.

The objective of cost-benefit analysis is welfare maximisation. Welfare is maximised by maximising the difference between benefits and costs:

Maximise net present value = (max) Benefits – Costs

Thus, consider the five road safety measures listed in Table 1. For each measure, three statistics showing its benefits are given:

1. Its effect on the number of fatalities
2. The net present value, i.e. the surplus of benefits over costs
3. The benefit-cost ratio

The measures have been sorted according to their effect on the number of fatalities.

Table 1: Choice between five road safety measures based on net present value

Measure	Fatalities prevented	Net present value	Benefit-cost ratio	Choice
Intelligent speed adaptation on all cars	34	7441	1.51	1
3.5 times more speed enforcement	21	855	3.28	4
4 times more random breath testing	16	716	4.62	5
Seat belt reminders in all cars (now 58 %)	10	3952	7.93	2
Front impact protection on heavy vehicles	7	1560	2.52	3

Which of these measures should be introduced first? Intelligent speed adaptation is the first choice, because it has the largest net present value (surplus of benefits to costs). It does not have the highest benefit-cost ratio; on the contrary, it has the lowest. In general, benefit-cost ratio should not be used as a decision rule in cost-benefit analysis, because it is a ratio and therefore does not account for the scale of a measure. Thus, a measure may have a very high benefit-cost ratio, yet produce minor safety benefits because it is targeted at a small group of crashes or injuries. Besides, if a measure can be used in different doses, its benefit-cost ratio will, in general, not be independent of the dose applied.

## 7 What is the best monetary valuation of road safety?

When cost-benefit analysis of transport projects started in the 1960s, the only impacts that were included in the first analyses were travel time, vehicle operating costs and crashes. The benefits of preventing crashes were normally valued according to the so called “human capital” approach, which assigned a value to preventing a fatality or an injury proportional to the value of production lost. This had the rather awkward consequence that saving the lives of people outside the labour force, like children or the retired, did not have a monetary value, since these people did not produce anything that had a market value.

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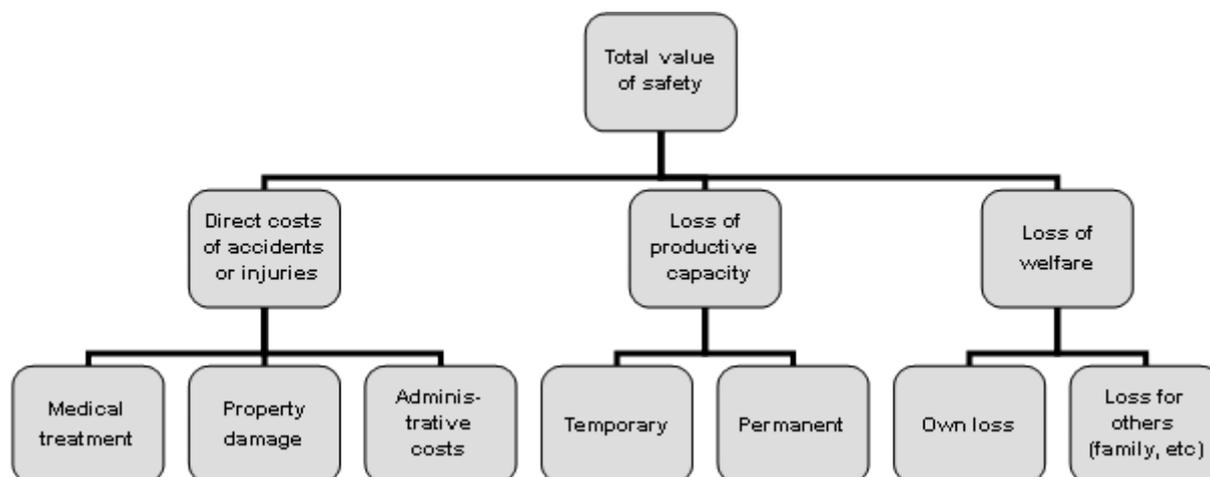
Two important papers – one by Schelling (1968), the other by Mishan (1971) – paved the way for adoption of the willingness-to-pay approach to the valuation of road safety. Today, a rather long list of impacts is included in cost-benefit analyses. Thus, in Norway the following impacts are now included in cost-benefit analyses (Samstad et al., 2010):

1. Road safety
2. Travel time (very detailed)
3. Health impacts of local air pollution
4. Global warming
5. Annoyance caused by traffic noise
6. Subjective anxiety for unprotected road users in mixed traffic
7. Subjective anxiety for landslides
8. Benefits to public health of walking or cycling
9. Opportunity cost of public expenditures funded by taxation
10. Costs of implementing a measure

With respect to road safety, the main components of valuation are shown in Figure 1.

There are three main components of valuation: direct costs of crashes, lost productive capacity and loss of welfare. The various components of valuation differ in terms of how they are manifested in economic transactions. The direct costs are real expenditures. In principle, these costs can be retrieved or at least roughly identified in the accounts of hospitals, insurance companies, the police, the courts, car repair shops and households. Estimates of lost productive capacity partly reflect monetary transactions; partly these costs are of a more abstract nature. In particular, lost productive capacity attributable to a fatality is usually estimated as the present value of future earnings. This represents the value of what the individual could have produced if alive; this can never be known with certainty and is therefore most appropriately interpreted as a loss of productive potential or capacity, not an actual loss of production.

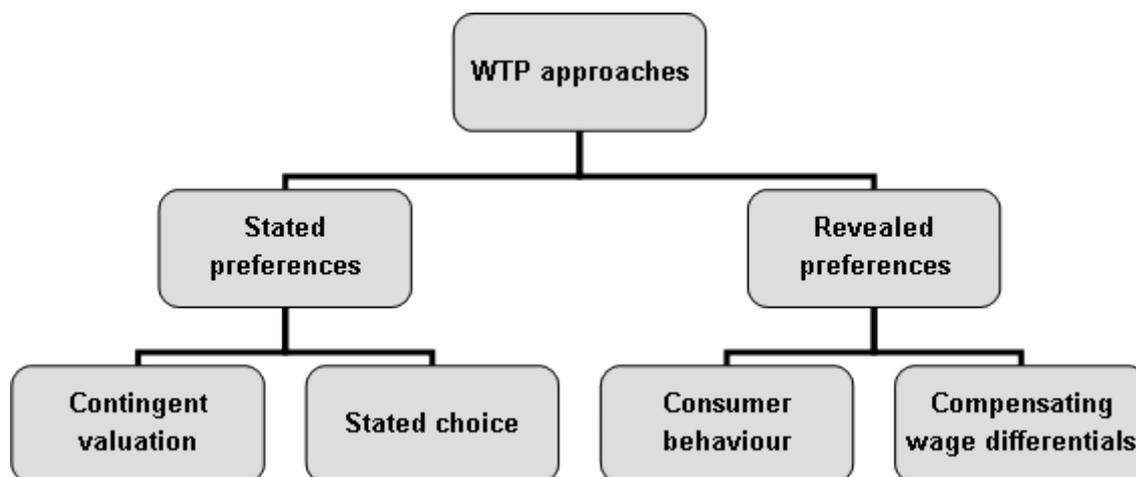
Figure 1: Main components of the monetary valuation of road safety. Based on Elvik (2010)



Willingness to pay for a reduced number of road crashes or injuries reflects the hypothetical demand for improved safety. It does not reflect any actual monetary transactions. This fact was clearly understood by the pioneers introducing the willingness to pay approach to the valuation of road safety. Thus, Schelling (1968, page 143) wrote: “Unexpected death has a hypothetical quality whether it is merely being talked about or money is being spent to prevent it.” The willingness to pay for reducing statistical risks by an amount that corresponds to the prevention of one death has nothing to do with the ex post costs generated by the death of a known individual. The latter costs are at least two orders of magnitude smaller than the valuation of preventing a death. Thus, in countries that apply the willingness to pay approach for valuing road safety, this component normally represents more than half, in some cases nearly the whole, monetary value assigned to improving road safety (Elvik 1995). The valuation of improved road safety in terms of willingness-to-pay is not subject to market transactions. This means that, although representing real benefits of improving road safety, it will not be realised in terms of added income or profits.

There are several methods for eliciting the willingness-to-pay for road safety. Figure 2 lists the most common methods.

Figure 2: Methods for eliciting willingness-to-pay for improved safety



There are two main methods for eliciting willingness-to-pay: stated preference methods and revealed preference methods. Most studies of the valuation of road safety have employed stated preference methods. These methods involve setting up a hypothetical market and asking people about the amounts of road safety they would purchase in these markets. The results of the studies are strongly affected by study design and methodology, but it would go beyond the scope of this paper to discuss methodological issues in stated preference studies in detail. It should be noted, however, that the results of stated preference studies vary considerably and have not produced any consensus estimate of the value of preventing a road traffic fatality.

Revealed preference studies examine actual choices in real markets. As far as road safety is concerned, such a choice might be the purchase of a new car. Cars differ with respect to safety features; if the relative importance of the factors that influence the choice of car, such as price, size, motor power, safety features, etc. can be determined, the implicit value placed on various safety features can be estimated. Studies of so called compensating wage differentials, i.e. extra payment for taking on risky jobs have been very common in the United States, but less common in Europe.

The best monetary valuation of road safety is based on a combination of resource cost estimates for the direct costs of road crashes and injuries, use of the human capital approach for estimating the lost productive capacity, and use of the willingness-to-pay approach for estimating loss of welfare (or, more precisely, the ex ante value of avoiding loss of welfare). This text will not recommend specific monetary values for road safety. Each country should develop its own values.

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In many European countries, studies have been made to assess willingness-to-pay (WTP) for improved road safety. The results of these studies are, however, not always strictly applied in the official monetary valuation of road safety in all countries. Thus, WTP-studies have been made in Belgium (Brabander, 2006), Denmark (Kidholm, 1995), France (Desaigues & Rabl, 1995), Great Britain (Jones-Lee & Loomes, 2003), Greece (Yannis, Papadimitriou & Evgenikos, 2005), the Netherlands (Blæij, de, 2003), Norway (Veisten, Flügel & Elvik, 2010) and Sweden (Persson et al., 2000) all showing considerably higher figures for the willingness-to-pay for road safety than the official valuations used in these countries.

Although the official valuations of road safety in most of these countries are based on the willingness-to-pay principle, the valuations represent a very conservative interpretation of the results of the studies that have been made.

An analyst basing the analysis directly on the WTP-studies quoted above, and not on the official monetary valuation of road safety in the respective countries, would, all else equal, find more road safety measures to pass the cost-benefit test than an analyst basing the analysis on official valuations. Thus, if the findings of WTP-studies are taken seriously, it would seem that the officially used monetary valuation of road safety in many European countries today is too low. This is the case even if the lowest estimates emerging from WTP-studies are used.

The main argument for interpreting WTP-studies conservatively is that there are numerous sources of error associated with such studies that may lead to inflated valuations. This point of view is correct, but a detailed discussion of it would go beyond the scope of this introduction. The details about how to perform a study of the willingness-to-pay for road safety are a hugely complex topic. An accessible, yet quite profound introduction to the topic is given in a book by Jones-Lee (1989).

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## 8 Is cost-benefit analysis applicable to road safety? What do we need to know to perform it?

Do all road safety measures lend themselves equally well to cost-benefit analysis? No - such analyses are more readily done for some measures than for others. In the Handbook of Road Safety Measures (Elvik, Høye, Vaa & Sørensen 2009), the following main groups of road safety measures are identified:

1. Road design and road equipment
2. Road maintenance
3. Traffic control
4. Vehicle design and protective devices
5. Vehicle inspection
6. Driver training and regulation of professional driving
7. Public education and information campaigns
8. Police enforcement and sanctions
9. Post-crash care
10. General purpose policy instruments

General purpose policy instruments is a heterogeneous group of measures that includes, among other things, motor vehicle taxation, regulation of commercial transport, urban and regional planning and access to medical services. Most of the general purpose policy instruments are quite complex and their effects on road safety are indirect and for some of the measures poorly known. Due to their great complexity and the comparatively poor state of knowledge regarding their effects, these measures do not lend themselves very well to cost-benefit analysis. This is not to say that it is impossible to do cost-benefit analyses of some of these measures. There have, for example, been several cost-benefit analyses of road pricing.

In general, to be amenable to cost-benefit analysis, a road safety measure should satisfy the following criteria:

1. It should be known what category of crashes or injuries the measure affects (all, those involving young drivers, those occurring in the dark, etc.), preferably so that the number of “target” crashes can be estimated numerically.
2. The effects of the measure on target crashes/injuries should be known, i.e. numerical estimates of these effects should be available. If possible, these estimates should state the severity of crashes or injuries they apply to.
3. It should be possible to describe the use of the measure in numerical terms, e.g. number of junctions converted, number of cars equipped, number of drivers trained, man hours of police enforcement, etc. This information is needed in order to estimate marginal costs and benefits of the measure.

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4. Other impacts of the measure should be known, for example impacts on speed or the environment.
  5. Costs of the measure should be known, and it should be known who pays the cost. This is because private expenditures and public expenditures are not treated identically in cost-benefit analyses. An opportunity cost of taxation is added to public expenditures, but not to private expenditures.
  6. Monetary valuations should be available for all impacts of the measure.

In short, cost-benefit analysis requires quite extensive knowledge of the impacts of a measure. This knowledge will not be available for all road safety measures.

In a recent road safety impact assessment for Norway (Elvik, 2007), a survey was made of 139 road safety measures. Only 45 of them were included in a cost-benefit analysis. A total of 94 measures were omitted. Reasons for omitting measures included:

1. Effects were not sufficiently well known: 19 measures
2. Measure was ineffective (did not improve road safety): 29 measures
3. The measure overlapped another measure: 20 measures
4. The measure has been fully implemented (in Norway): 20 measures
5. The measure was analytically intractable: 6 measures

Some of the measures that were included have so far not been used extensively, but were included because there is reason to believe they could improve road safety. This applies to ISA (Intelligent Speed Adaptation), for example, which favourably influences driving speed, a known risk factor for crashes and injuries.

To give a short example, consider the conversion of three leg junctions to roundabouts. From the Norwegian road data bank, it was determined that 120 junctions with a mean daily traffic of 12,000 are candidates for conversion to roundabouts. Thus, the effect on fatalities can be estimated as follows:

$$120 \times 12,000 \times 365 \times 0.091 \times 10^{-6} \times 0.018 \times 0.49 = 0.42$$

The first three terms (120, 12,000, 365) denote the total traffic volume in the 120 junctions during one year. This is the traffic that will be exposed to the conversion. The next term ( $0.091 \times 10^{-6}$ ) is the mean risk of injury per million vehicles entering a three leg junction. A little less than 2 % of the injuries (0.018) are fatal. The rest are serious or slight. Thus, the overall injury rate is decomposed into a rate of fatal injury, a rate of serious injury and a rate of slight injury. Finally, roundabouts reduce the number of fatalities by 49 % (0.49). Hence, in the 120 junctions, 0.42 fatalities will be prevented.

The fatalities prevented can be converted to monetary terms as follows:

$$0.42 \times 26.5 \times 14.828 = 165 \text{ million NOK}$$

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Here, 0.42 is the number of fatalities prevented, 26.5 is the value, in million NOK, of preventing a fatality, and 14.828 the accumulated present value factor for a 25-year time horizon using a discount rate of 4.5 % per year. In general the present value of a benefit (or cost) is estimated as:

$$\text{Present value} = \sum_{i=0}^n \frac{B_i}{(1+r)^i}$$

In this formula, B denotes benefit in year i and r is the discount rate. The summation is from year 0 to year n, the end of the time horizon considered. Thus, if the benefit in year 0 is 100, in year 3 it will be:

$$100/(1.045^3) = 100/1.1412 = 87.6$$

As the years pass, the present value of a constant stream of benefits gradually becomes smaller.

## 9 Problems that may be encountered in cost-benefit analysis

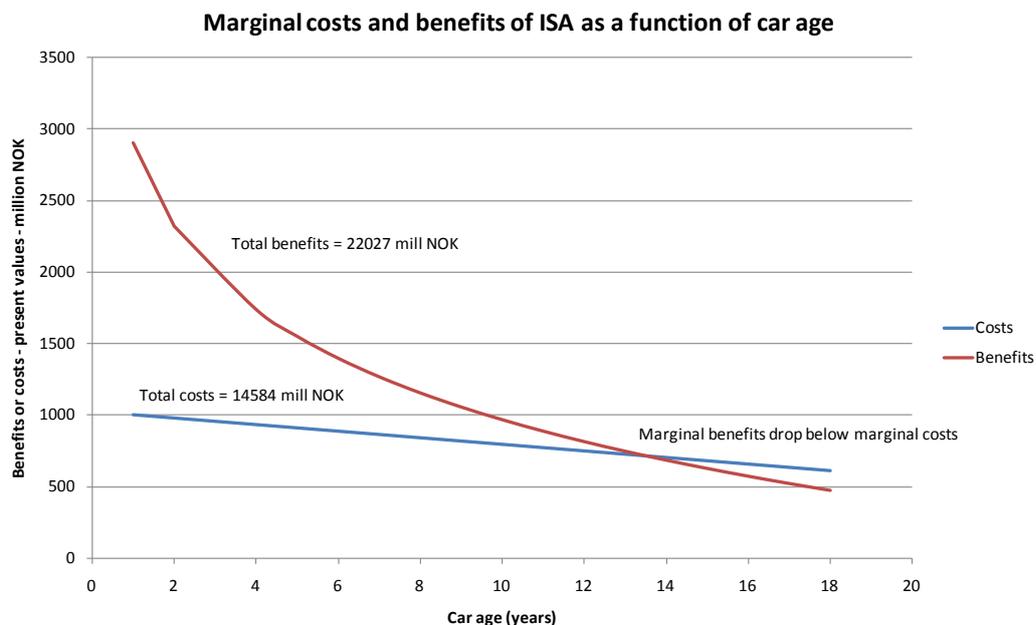
As noted in section 6, the objective of cost-benefit analysis is to identify those measures that maximise welfare. Solutions that maximise welfare will not always be possible. In this section, two problems that may be encountered will be briefly discussed: indivisibilities and path dependence.

An indivisibility occurs when a measure cannot be divided into sufficiently fine graded alternatives to permit strict optimisation. As an example, consider the case of introducing new safety features in cars. The decision is dichotomous: either to install a safety feature or not to install it. Once installed, it will in most cases be impractical to remove a safety feature. A cost benefit analysis found that the benefits of ISA (Intelligent Speed Adaptation) clearly exceed costs, see table 1. Costs and benefits were then assessed for a period of 18 years, after which the car was assumed to be scrapped.

Costs and benefits do not, however, accrue at constant rates during this period. New cars tend to be driven longer distances than old cars. Thus, all else equal, the largest benefits will accrue when the car is new. As the car gets driven less and less, benefits become smaller. This is illustrated in Figure 3. While, for the whole lifetime of the car, benefits clearly exceed costs, marginal benefits drop below marginal costs when the car is 14 years or older. It is, however, impractical to require that ISA is de-activated when the car reaches the age of 14 years. This is an example of an indivisibility. Legislation will often involve indivisibilities. Thus, a law requiring bicycle helmets must apply to all cyclists, although some cyclists will be less involved in collisions than others and will therefore benefit less from a helmet.

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Figure 3: Marginal cost and benefits of ISA as a function of car age



Another problem that can influence the possibility of maximising welfare is path dependence. This refers to the situation in which the benefits, and sometimes the costs, of a specific road safety measure depend on whether other road safety measures have been introduced.

If, for example, introducing ISA is politically impossible, one may decide to increase other means of speed enforcement. Increased speed enforcement will reduce the number of crashes and their severity and make ISA less cost-effective. In some cases, interactions between road safety measures influencing the same target crashes or injuries can make them all cost-ineffective if they are all introduced in combination, even if each measure is cost-effective if introduced by itself.

## 10 Can the results of cost-benefit analyses be generalised across countries?

The current monetary valuation of road safety differs greatly between European countries. One might, therefore, expect the results of cost-benefit analyses to vary correspondingly. To see if this is the case, results of cost-benefit analyses made in a number of European projects in recent years have been compiled and compared. Measures that have been analysed in more than one project have been selected, as only these measures can provide information on the possibility of generalising the findings of cost-benefit analyses between countries. The following measures have been selected:



- *Traffic calming and speed reducing measures:* This measure has been analysed in Great Britain (Elvik, 1999), Germany (Höhnscheid et al. 2006), Israel, Greece (Winkelbauer & Stefan, 2005), Norway (Elvik, 2007) and Sweden (Elvik & Amundsen, 2000).
- *Daytime running lights:* This measure has been analysed for Norway (Elvik & Vaa 2004), Austria, the Czech republic (Winkelbauer & Stefan, 2005) and for the EU as a whole (Koornstra et al., 1997; ETSC, 2003; Elvik, Christensen & Fjeld Olsen, 2003; COWI, 2006; Knight et al., 2006).
- *Intelligent Speed Adaptation:* This measure has been analysed for Norway (Elvik, 2007), Sweden (Elvik & Amundsen, 2000), Great Britain (Carsten & Tate, 2005) and the EU as a whole (COWI, 2006).
- *Increasing speed enforcement:* This measure has been analysed in Norway (Elvik 2007), Sweden (Elvik & Amundsen, 2000), Greece, Israel (Winkelbauer & Stefan, 2005), and the EU as a whole (ICF consulting, 2003).
- *Random breath testing:* This measure has been analysed in Norway (Elvik 2007), Sweden (Elvik & Amundsen, 2000), the Czech republic, the Netherlands, Spain (Vlakveld et al., 2005) and for the EU as a whole (ETSC 2003, ICF consulting 2003).
- *Driver eyesight testing:* This measure has been analysed for Norway, Switzerland, the Czech republic, the Netherlands and Spain (Höhnscheid et al., 2006, Vlakveld et al., 2005).

As far as traffic calming and speed-reducing measures are concerned, Elvik (1999) found benefit-cost ratios varying from 9.7 to -0.4 for Great Britain, depending on the type of road. For all types of road considered together, the benefit-cost ratio was estimated to about 3.5.

In Germany (Höhnscheid et al., 2006), the benefit-cost ratio of narrowing lanes and installing speed humps in residential areas was estimated to 17. Corresponding benefit-cost ratio were estimated to between 2 and 4 in Israel and around 1.1 to 1.2 in Greece (Winkelbauer & Stefan, 2005). For Sweden (Elvik & Amundsen, 2000) as well as for Norway (Elvik, 2007), negative benefit-cost benefit ratios have been estimated for speed reducing measures in residential areas. Thus, the findings of cost-benefit analyses of this measure are somewhat inconsistent. Reasons for the inconsistency are not known, but one can speculate that residential streets in Norway and Sweden typically carry lower traffic volumes than in the other countries and have lower crash and crash injury rates.

Daytime running lights have been found to be very cost-effective in all the analyses quoted above, except for one (Knight et al., 2006), with benefit-cost ratios typically ranging between 2 and 5. The assumptions leading to these results are questioned by Knight et al. (2006). They argue that the assumption made in most analyses of a greater effect of daytime running lights on fatal and serious crashes than on slight injury crashes is weakly supported by available evidence from evaluation studies. Replacing it by an assumption of an effect of about 6% reduction of daytime multi-party crashes at all levels of crash severity, Knight et al. (2006) find that benefits are smaller than costs. However, by slightly altering other assumptions made in the analyses, for example relying on the HEATCO recommendations

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for the monetary valuation of safety (Bickel et al., 2006), benefits once more become greater than costs, even if a uniform effect of 6% on daytime multi-party crashes is assumed. This example shows that sensitivity analyses should always be a part of cost-benefit analysis and that, in some cases, results are found to be quite sensitive to small changes in the assumptions made. On balance, it is more likely that the benefits of daytime running lights are greater than the costs than the opposite.

With respect to intelligent speed adaptation, all the analyses quoted above report that benefits are greater than costs. For this measure, therefore, there is perfect consistency in the findings of cost-benefit analyses.

Increasing other forms of speed enforcement has also been found to be very cost-effective in all analyses. It would seem that enforcement is an underutilised road safety measure in all of Europe. The same conclusion applies to random breath testing.

The cost-effectiveness of driver eyesight testing, on the other hand, has been found to vary substantially between the countries in which this measure has been analysed. More specifically, it appears to be rather ineffective in Norway and the Netherlands, but more cost-effective in Spain, the Czech republic and Switzerland. Reasons for these differences are not known.

The conclusion is that in some cases the results of cost-benefit analyses appear to be valid in many countries, while in other cases there are large differences. The lesson is that cost-benefit analyses should be performed in every country and that one should not uncritically assume that the results of a cost-benefit analysis made in one country apply to another country.

## **11 Can road safety policy be based strictly on cost-benefit analyses?**

As has been mentioned before, it is not always possible – indeed not always wise – to base road safety policy strictly on cost-benefit analyses, i.e. to implement all those, and only those, road safety measures that pass the cost-benefit test.

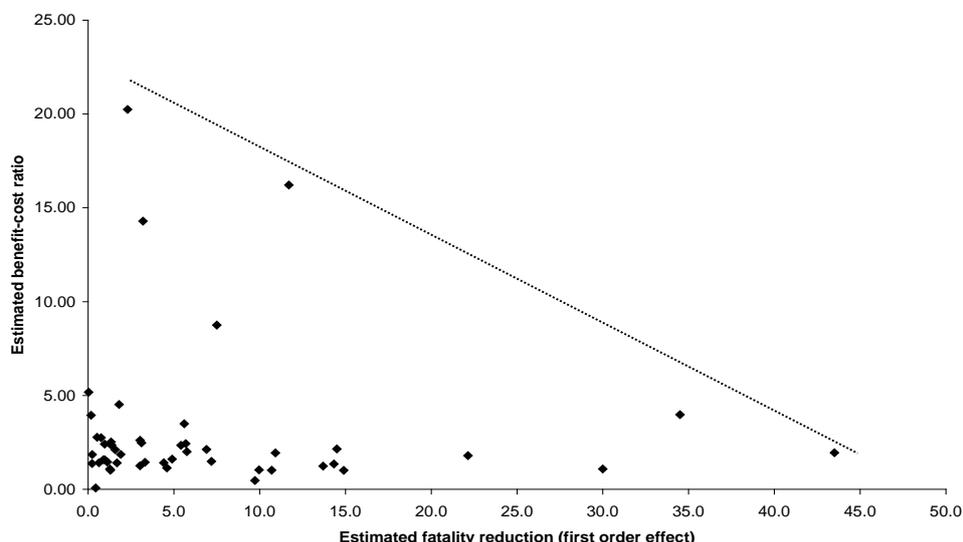
In the study of barriers to the use of efficiency assessment tools in road safety policy performed as part of the ROSEBUD thematic network (Elvik & Veisten, 2005), one of the questions that was asked to 83 road safety policymakers across Europe was the following:

Do politicians put more weight on the number of fatalities and injuries prevented than on the monetary valuation of these impacts?

A total of 70 answers were given to this question. 40 respondents answered that politicians assigned a greater weight to the number of fatalities or injuries prevented than to the benefits of preventing fatalities or injuries as stated in economic terms.

This may perhaps seem a bit puzzling. After all, the monetary valuation of all relevant impacts of a measure will, ideally, reflect its impacts on fatalities or injuries. It is not necessarily the case, however, that those road safety measures that have the most favourable benefit-cost ratios will also be those that contribute to the greatest reductions in the number of fatalities or injuries. It could be the case that measures whose benefits only marginally exceed the costs will produce the greatest improvement of road safety, maybe even a greater improvement than, say, ten very highly cost-effective measures that influence small target groups. Figure 4 probes if this is the case for the road safety measures included in the impact assessment for Norway quoted above (Elvik, 2007).

Figure 4: Relationship between estimated fatality reduction and benefit-cost ratio for road safety measures in Norway



Taking all measures into consideration, there is no correlation between the size of the estimated fatality reduction and benefit-cost ratio. Yet, as indicated by the dotted line close to the most outward data points in the figure, a tendency can be seen for the measures producing the greatest reductions in fatalities to have the lowest benefit cost ratio. The mean benefit-cost ratio for measures that may reduce the number of fatalities by more than 20 is 2.20. The corresponding mean value is 3.25 for measures that can reduce the number of fatalities by between 10 and 20, and 2.99 for measures that can reduce the number of fatalities by less than 10. There thus seems to be a tendency, although not very strong, for the most cost-effective measures to have the smallest effects on the number of road traffic fatalities. This may be felt as a dilemma for policymakers, in particular if *Vision Zero* is the basis for road safety policy, as is the case in Norway. The paramount criterion for setting priorities according to *Vision Zero* should be the size of the reduction in the number of fatalities and severe, non-fatal injuries.

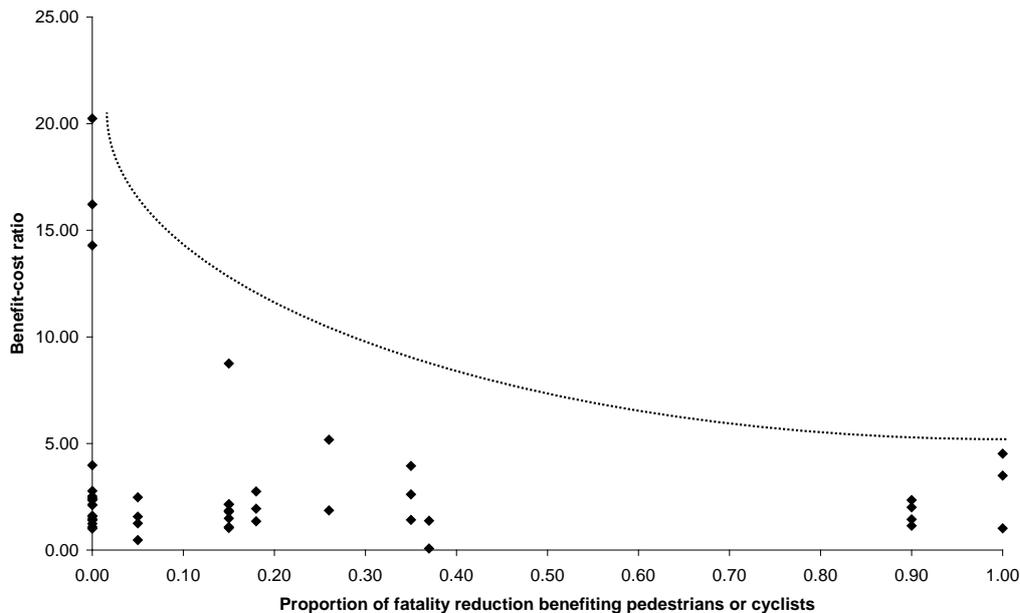
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It is not just the size of the safety effect that may compete with economic efficiency as a criterion for priority setting. Some policymakers regard pedestrians and cyclists as disadvantaged groups in the current transport system and want to favour these groups. A difficult trade-off arises if the most cost-effective measures mainly benefit motorists, rather than pedestrians or cyclists.

To investigate if this is actually the case, the estimated first order reduction in the number of fatalities for each road safety measure have been allocated between motorists and pedestrians or cyclists. The basis for allocating safety benefits between these groups of road users is analyses of Norwegian crash statistics, performed as part of the preparation of new guidelines for high-risk site management in Norway (Statens vegvesen, Håndbok 115, 2005). Figure 5 shows the relationship between the proportion of the estimated fatality reduction benefiting pedestrians or cyclists and benefit-cost ratio for the measures included in the road safety impact assessment.

As in Figure 4, a dotted line has been drawn around the outer data points in the Figure, suggesting that there is a negative relationship between the proportion of fatality reductions benefiting pedestrians or cyclists and benefit-cost ratio. The (simple) mean benefit-cost ratio for road safety measures for which more than 40% of the fatality reduction benefits pedestrians or cyclists is 2.28. The mean benefit-cost ratio for measures for which between 20 and 40 % of the fatality reduction benefits pedestrians or cyclists is 2.35. Finally, the mean benefit-cost ratio for measures for which less than 20 % of the fatality reductions benefit pedestrians or cyclists is 3.27. This suggests that the most cost-effective measures are those that provide the smallest benefits for pedestrians or cyclists. There may thus be a trade-off between efficiency and equity in road safety policy. Cost-benefit analyses focus only on efficiency, not on equity.

Figure 5: Relationship between proportion of estimated fatality reduction benefiting pedestrians or cyclists and benefit-cost ratio of road safety measures



In summary, performing cost-benefit analyses of road safety measures does not eliminate the potential presence of competing criteria for priority-setting, in particular criteria referring to the size of effects on road safety and to the distribution of safety effects between different groups of road users. To the extent policymakers regard such criteria for priority-setting as more relevant than the benefit-cost ratio, actual policy priorities may depart from the results of cost-benefit analyses.

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