Cost-benefit analysis

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Summary

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 main principles of cost-benefit analysis are explained and guidelines for the monetary valuation of impacts in cost-benefit analyses are provided.

A recent road safety impact assessment is used to illustrate the findings of cost-benefit analyses of road safety measures, showing which measures are found to be the most cost-effective. There is still a large potential for improving road safety by using cost-effective road safety measures. Analyses in Norway and Sweden – both of which are comparatively safe countries – suggest that fatality reductions of about 50 % can be realised by applying cost-effective measures. It is reasonable to believe that benefits of a similar magnitude can be attained in many European countries.

In practice, however, 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 accident fatalities. These measures may not always be the most cost-effective.

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 of the game for cost-benefit analysis? How should it be done and what should it include?
- 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 potential barriers to cost-benefit analysis and how can they be overcome?
- What are the most promising road safety measures based on cost-benefit analyses? How far can road safety be improved by using these measures?
- 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. 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 [19]. 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 [6][20][28][30][1][33]. Only the main features of the technique are described here. The main steps of a cost-benefit analysis are as follows:

- Develop measures or programmes intended to help reduce a certain social problem (e.g. road accidents or environmental pollution).
- Develop alternative policy options for the use of each measure or programme.
- Describe a reference scenario (sometimes referred to as business-as-usual or the do-nothing alternative).
- Identify relevant impacts of each measure or programme. There will usually be several relevant impacts.
- Estimate the impacts of each measure or programme in “natural” units (physical terms) for each policy option.
- Obtain estimates of the costs of each measure or programme for each policy option.
- Convert estimated impacts to monetary terms, applying available valuations of these impacts.
- Compare benefits and costs for each policy option for each measure or programme. Identify options in which benefits are greater than costs.
- Conduct a sensitivity analysis or a formal assessment of the uncertainty of estimated benefits and costs.
- 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 [12]

- They involve public expenditures, often investments. Projects are sometimes financed by direct user payment, but more often by general taxation.
- There are multiple policy objectives, often partly conflicting and requiring tradeoffs to be made. It is assumed that policy makers want solutions that realise all policy objectives to the maximum extent possible.
- 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.
- 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 a 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 accidents or injuries.
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:

- Do nothing; leave to each bicyclist to decide whether or not to wear a helmet.
- Conduct a campaign for bicycle helmets, while leaving their use voluntary.
- Make the use of bicycle helmets mandatory for children.
- 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. 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 accidents 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 tradeoffs 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 accidents 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. A case showing this is presented in section 8.

3. Use of cost-benefit analysis

Cost-benefit analysis is a prescriptive technique. It has an explicit normative basis and is performed for the purpose of informing policy makers 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 accidents 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 accidents 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 accidents or injuries.
- How much to spend on the prevention of accidents 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 our 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.

4. Basic rules of the game

There are four main principles of cost-benefit analysis:

- Consumer sovereignty
- Valuation of goods according to willingness-to-pay
- Pareto-optimality as the criterion of welfare maximisation
- 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 accidents 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 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 overprovided. Road safety is overprovided 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 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.

5. 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 accidents. The benefits of preventing accidents 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.

Two important papers – one by Schelling [32], the other by Mishan [29] – paved the way for adoption of the willingness-to-pay approach to the valuation of road safety. More will be said about this approach later.
Today, a rather long list of impacts is included in cost-benefit analyses. Table 1 shows the current monetary valuations of impacts of transport projects used in Norway [35]. Even this long list is not regarded as exhaustive. It does, for example, not include habitat intrusion.

Table 1 Monetary valuation of impacts of road transport projects in Norway
Adapted from Statens vegvesen, Håndbok 140, 2006

Main policy objective	Unit of valuation	Valuation per unit (NOK 2005 prices)
Road safety	1 fatality	26,500,000
	1 police reported serious injury (adjusted for incomplete reporting)	7,800,000
	1 police reported slight injury (adjusted for incomplete reporting)	800,000
Travel time	1 vehicle hour of travel by means of passenger car	125
	1 vehicle hour of travel by means of van	140
	1 vehicle hour of travel by means of freight truck	470
	1 vehicle hour of travel by means of bus (including passengers)	860
Vehicle operating costs	Vehicle operating cost per kilometre – car	1.30
	Vehicle operating cost per kilometre – heavy goods vehicle	4.44
	Vehicle operating cost – bus	4.82
Environmental impacts	Traffic noise, per vehicle km, large and medium sized towns	0.38
	Traffic noise, per vehicle km, rural areas	0.00
	Local air pollution, per vehicle kilometre, large towns	0.25
	Local air pollution, per vehicle kilometre, small towns	0.11
	Local air pollution, per vehicle kilometre, rural areas	0.02
	Global air pollution (carbon dioxide), per vehicle kilometre	0.12
Health impacts	Insecurity in crossing road, per crossing	1.00
	Insecurity in walking or cycling in mixed traffic, per kilometre	2.10
	Reduction of short term sick leave, walking 1 kilometre	2.90
	Reduction of short term sick leave, cycling 1 kilometre	1.50
	Reduction of serious illness, walking 1 kilometre	5.20
	Reduction of serious illness, cycling 1 kilometre	2.60

As noted above, the first monetary valuations of the benefits to society of saving life and limb in traffic were based on the human capital approach. This approach is still used in some countries and is included as part of the valuation in countries that have adopted the willingness-to-pay approach to the valuation of road safety.
There have been several reviews of the costs to society of road traffic injury. A major review was presented in 1994 by the European Commission: "Socio-economic cost of road accidents, final report of action COST 313" [2]. This report is now more than 10 years old. A more recent survey was made as part of the ROSEBUD-project [5]. This survey first considered methods used in estimating the costs to society of traffic injury, then presented recent cost estimates for selected countries. As far as methods for estimating costs are concerned, the typology shown in Figure 1 was developed in COST-313.

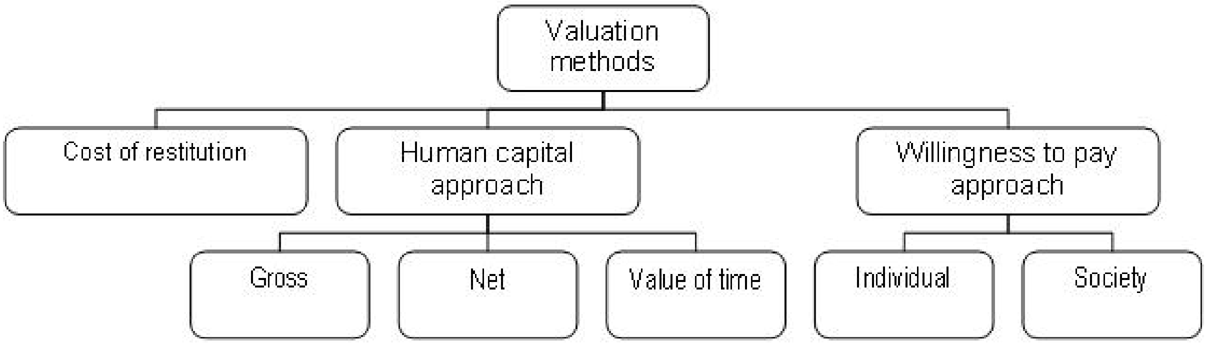

Figure 1: Methods for estimating costs of traffic injury.

The costs of restitution are the direct costs generated by road accidents (for example, medical costs, property damage or administrative costs). Generally speaking, the human capital approach is used to estimate the value of lost productive capacity due to a traffic fatality, whereas the willingness-to-pay approach is used to estimate the value of lost quality of life. Two varieties of the willingness-to-pay approach are normally used: the individual willingness-to-pay approach and the social willingness-to-pay approach. According to the former approach, information about willingness-to-pay is obtained from individuals, either by studying behaviour in situations where reduced risk must be traded off against other commodities or by means of questionnaires. According to the latter approach, society's willingness-to-pay for reduced risk is inferred from the valuation implicit in public decisions like setting speed limits. More information on the different valuation methods is given by Wesemann [39] and de Blaeij et al [5].

Based on a review made by Sælensminde [36], the review of de Blaeij et al [5] and a paper by Tecl and Konarek [37], Figure 2 shows the official monetary valuation of preventing a road accident fatality in a number of countries.

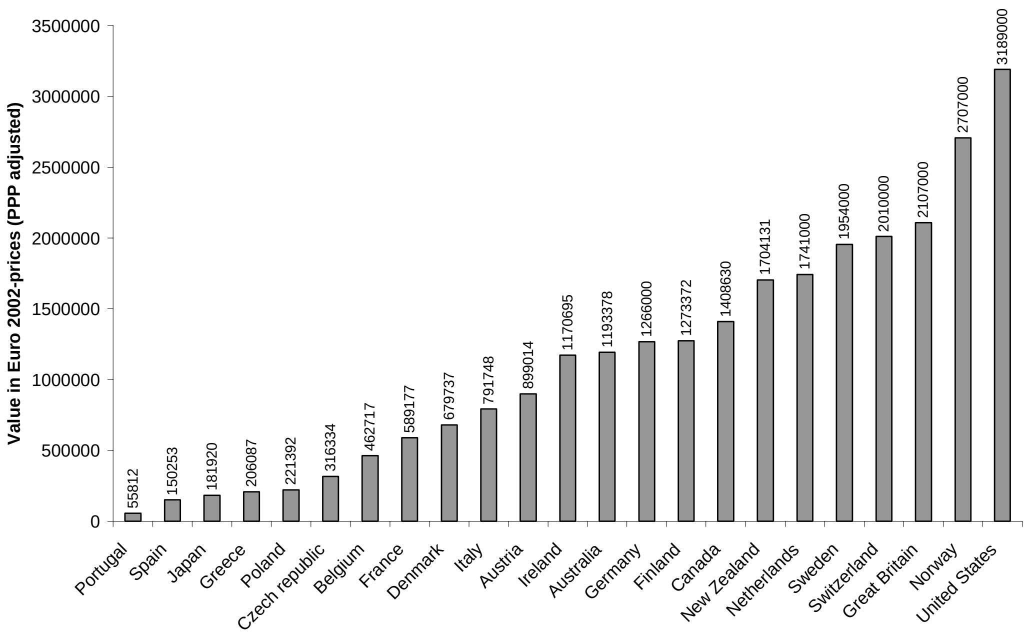

Figure 2: Official monetary valuation of a road accident fatality in selected countries. Euro in 2002-prices.

The valuations vary substantially. An interesting pattern is that some of the countries that have a good safety record, such as Norway, Great Britain, Sweden and the Netherlands, assign a high monetary value to the prevention of a traffic fatality. Some countries with a rather bad road safety record, like Portugal, Spain and Greece, assign a low monetary value to the prevention of a fatality.

The values are determined by two main factors: (1) The method used for estimating them. Values based on the willingness-to-pay approach tend to be about twice as high as values not based on the willingness-to-pay approach.(2) The level of real income in a country. Generally speaking, lower values are found in countries that have a relatively low gross domestic product per capita, higher values are found in the richer countries.

The most recent recommendations for the monetary valuation of road safety are given in a report from the HEATCO-project (Developing Harmonised European Approaches for Transport Costing and Project Assessment) [3]. The recommendations are in two parts.

The first part is a recommendation for adjusting for incomplete accident reporting in official statistics. Recommendations for these adjustments are summarised below (Table 2).

The factors listed are multiplicators, by which the officially recorded number of injured road users should be inflated. A small correction factor is applied to fatalities, due to the 30-day definition of a fatality. Whenever national correction factors are available, these should be used rather than the European average values. Work to develop further correction factors is going on within SafetyNet.

Table 2 Recommendations for European average correction factors for unreported road accidents.
Source: Bickel et al 2006, Table 5.1

	Fatality	Serious injury	Slight injury	Average injury	Damage only
Average	1.02	1.50	3.00	2.25	6.00
Car	1.02	1.25	2.00	1.63	3.50
Motorbike/moped	1.02	1.55	3.20	2.38	6.50
Bicycle	1.02	2.75	8.00	5.38	18.50
Pedestrian	1.02	1.35	2.40	1.88	4.50

The second part of the recommendations is a set of monetary values for the prevention of traffic injury.

The values are listed in Table 3.

Table 3: Recommended values of safety. Source: Bickel et al 2006, Table O.10

Country	Fatality	Severe injury	Slight injury	Fatality	Severe injury	Slight injury
	(€2002, factor prices)			(€2002 PPP, factor prices)		
Austria	1,760,000	240,300	19,000	1,685,000	230,100	18,200
Belgium	1,639,000	249,000	16,000	1,603,000	243,200	15,700
Cyprus	704,000	92,900	6,800	798,000	105,500	7,700
Czech Republic	495,000	67,100	4,800	932,000	125,200	9,100
Denmark	2,200,000	272,300	21,300	1,672,000	206,900	16,200
Estonia	352,000	46,500	3,400	630,000	84,400	6,100
Finland	1,738,000	230,600	17,300	1,548,000	205,900	15,400
France	1,617,000	225,800	17,000	1,548,000	216,300	16,200
Germany	1,661,000	229,400	18,600	1,493,000	206,500	16,700
Greece	836,000	109,500	8,400	1,069,000	139,700	10,700
Hungary	440,000	59,000	4,300	808,000	108,400	7,900
Ireland	2,134,000	270,100	20,700	1,836,000	232,600	17,800
Italy	1,430,000	183,700	14,100	1,493,000	191,900	14,700
Latvia	275,000	36,700	2,700	534,000	72,300	5,200
Lithuania	275,000	38,000	2,700	575,000	78,500	5,700
Luxembourg	2,332,000	363,700	21,900	2,055,000	320,200	19,300
Malta	1,001,000	127,800	9,500	1,445,000	183,500	13,700
Netherlands	1,782,000	236,600	19,000	1,672,000	221,500	17,900
Norway	2,893,000	406,000	29,100	2,055,000	288,300	20,700
Poland	341,000	46,500	3,300	630,000	84,500	6,100
Portugal	803,000	107,400	7,400	1,055,000	141,000	9,700
Slovakia	308,000	42,100	3,000	699,000	96,400	6,900
Slovenia	759,000	99,000	7,300	1,028,000	133,500	9,800
Spain	1,122,000	138,900	10,500	1,302,000	161,800	12,200
Sweden	1,870,000	273,300	19,700	1,576,000	231,300	16,600
Switzerland	2,574,000	353,800	27,100	1,809,000	248,000	19,100
United Kingdom	1,815,000	235,100	18,600	1,617,000	208,900	16,600

There are two sets of values. The first set, denoted factor prices, is based on national currencies. The second set of values denoted PPP; factor prices are adjusted for differences in purchasing power and are therefore intended to be more directly comparable across countries than the first set of values, since the PPP adjusted values account for differences in income and prices between countries.

The HEATCO-report states that values listed in Table 3 should only be used if no national valuation based on the willingness-to-pay approach is available. This recommendation may, however, lead to a dilemma in some cases. 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 [7], Denmark [25], France [10], Great Britain [24], Greece [41], the Netherlands [4] and Sweden [31] 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 [23].

6. Applicability cost-benefit analysis

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 [16], the following main groups of road safety measures are identified:

- General purpose policy instruments
- Road design and road furniture
- Road maintenance
- Traffic control
- Vehicle design and personal protection
- Vehicle inspection
- Public education and information campaigns
- Police enforcement

General purpose policy instruments is a heterogeneous bag 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:
It should be known what category of accidents the measure affects (all accidents, accidents involving young drivers, accidents in the dark, etc), preferably so that the number of “target” accidents can estimated numerically.
The effects of the measure on target accidents should known, i.e. numerical estimates of these effects should be available. If possible, these estimates should state the severity of accidents or injuries they apply to.

- 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.
- Other impacts of the measure should be known, for example impacts on speed or the environment.
- 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.
- 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 [13], 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:

- Effects were not sufficiently well known: 19 measures
- Measure was ineffective (did not improve road safety): 29 measures
- The measure overlapped another measure: 20 measures
- The measure has been fully implemented (in Norway): 20 measures
- 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 accidents 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 (0.091×10^{-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 x 26.5 x 14.828 = 165 million NOK

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:

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

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.

7. Barriers to the use of cost-benefit analyses

In the thematic network ROSEBUD, an attempt was made to describe potential barriers to the use of cost-benefit analysis of road safety measures [17]. The following list of potential barriers, arranged from the more basic to the more superficial was developed.

A Fundamental barriers (barriers of a philosophical nature)
A1 Rejecting the principles of welfare economics
A2 Rejecting efficiency as a relevant criterion of desirability
A3 Rejecting the monetary valuation of risk reductions

B Institutional barriers (barriers related to the organisation of policy making)
B1 Lack of consensus on relevant policy objectives
B2 Formulation of policy objectives inconsistent with cost-benefit analysis
B3 Priority given to policy objectives unsuitable for cost-benefit analysis
B4 Horse trading/vote trading
B5 Political opportunism
B6 Unfunded mandates and excessive delegation of authority
B7 Abundance of resources
B8 Rigidity of reallocation mechanisms
B9 Wrong timing of EAT information in decision-making process

C Technical/methodological barriers (barriers related to inherent elements of the efficiency assessment tools)
C1 Lack of knowledge of relevant impacts
C2 Inadequate monetary valuation of relevant impacts
C3 Indivisibilities
C4 Inadequate treatment of uncertainty

D Barriers related to the implementation of cost-effective policy options
D1 Social dilemmas
D2 Lack of power (related to B6 above)
D3 Vested interests in road safety measures
D4 Lack of incentives to implement cost-effective solutions
D5 Lack of marketing of efficient policies

Each of these potential barriers will not be discussed in detail. It was found that institutional barriers are often important. The framework of policy making is such that solutions to problems are not developed primarily with the aid of a technical analysis, like a cost-benefit analysis, but by means of a process of negotiations. As an example, resource allocation in the public sector in Norway is strongly influenced by game-like mechanisms that result in inefficient allocations, i.e. an abundance of resources in some areas and a shortage of resources in other areas. The result of this is that areas with abundant resources spend these resources on projects that are not cost effective, whereas areas with a shortage of resources are unable to implement all cost-effective projects.

It is, however, outside the scope of cost-benefit analysis as such to alter these resource allocation mechanisms. Considerations relevant to the implementation of policies based on cost-benefit analyses are discussed in section 9.

8. Promising safety measures based on cost-benefit analyses

Table 4, taken from a recent report by Elvik, shows cost-effective road safety measures in Norway, according to an analysis of road safety policy. A total of 39 measures are listed in Table 4, covering a broad range. 6 of the 45 measures that were included in the cost-benefit analysis turned out to be cost-ineffective. These measures are not listed in Table 4. The table shows first order effects. A first order effect is the effect a road safety measure has when it alone is effective and it is not combined with another measure. First order effects cannot be added, but they can be compared.

It is seen that some of the most cost-effective measures, contributing to the largest reductions in the number of fatalities, are new motor vehicle safety features. It is not within the power of the Norwegian government to introduce these measures. The safety benefits resulting from these measures will therefore only be realised if the new vehicle safety features are offered as standard equipment by car manufacturers, or if agreement is reached within the EU or the UN Economic Commission for Europe to make these vehicle safety features mandatory. Some of the vehicle safety features, notably electronic stability control, seat belt reminders and cars attaining 4 or 5 star according to EuroNCAP are already penetrating the market quickly.

The analysis indicates that there is too little police enforcement. Fairly drastic increases of police enforcement are cost-effective. It is cost-effective to treble the amount of speed enforcement and to increase random breath testing (drink-driving enforcement) by a factor of five. Again, however, one may doubt if such drastic increases will actually take place, no matter how cost-effective they are found to be.

As noted in section 5, 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 [11], Germany [21], Israel, Greece [40], Norway [13] and Sweden [14]
- *Daytime running lights*: This measure has been analysed for Norway [16], Austria, the Czech republic [40] and for the EU as a whole [27][18][15][9][26] *Intelligent Speed Adaptation*: This measure has been analysed for Norway [13] , Sweden [14] , Great Britain (Carsten and Tate 2005) and the EU as a whole [9]
- *Increasing speed enforcement*: This measure has been analysed in Norway [13], Sweden [14],Greece, Israel [40], and the EU as a whole [22]
- *Random breath testing*: This measure has been analysed in Norway (Elvik 2007), Sweden [14] (Elvik and 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.

Table 4 Cost-effective road safety measures in Norway

Road safety measure	Benefit-cost ratio	Estimated reduction of the number of road users killed or seriously injured (first order effects): Killed	Seriously injured
Road-related safety measures			
Bypass roads	1.38	0.2	1.3
Pedestrian bridge or tunnel	1.47	3.3	10.6
Converting T-junction to roundabout	1.86	1.9	6.1
Converting X-junction to roundabout	2.62	3.0	12.0
Roadside safety treatment	2.77	0.5	2.1
Reconstruction and rehabilitation of roads	1.57	1.0	3.2
Guardrails (along roadside)	2.53	1.3	5.3
Median guard rails on undivided roads	1.40	1.7	2.5
Median rumble strips (1 metre wide)	2.41	1.0	1.7
Horizontal curve treatments	2.37	1.4	3.4
Road lighting	1.94	10.9	26.4
Upgrading substandard road lighting	2.75	0.8	1.8
Follow up road safety inspections	2.48	3.1	5.3
Traffic signals in T-junctions	5.17	0.0	0.1
Traffic signals in X-junctions	3.95	0.2	0.8
Lowering speed limit on hazardous roads	14.29	3.2	4.7
Upgrading pedestrian crossings	2.36	5.4	12.7
Vehicle-related safety measures			
E-Call (assuming mandatory from 1.1.2009)	1.61	4.9	0.0
Event recorders	2.15	14.5	56.8
Electronic stability control	3.98	34.5	81.2
Front and side air bags	1.01	14.9	29.2
Enhanced neck injury protection	20.25	2.3	23.0
Seat belt reminders	16.21	11.7	35.9
4 or 5 stars in EuroNCAP	1.24	13.7	49.1
Intelligent speed adaptation (ISA-systems)	1.95	43.5	126.0
Design of car front to protect pedestrians	4.52	1.8	19.4
Front impact attenuators on heavy vehicles	2.12	6.9	9.1

Table 4: Cost-effective road safety measures in Norway, continued			
		Estimated reduction of the number of road users killed or seriously injured (first order effects	
Road safety measure	Benefit-cost ratio	Killed	Seriously injured
Enforcement-related safety measures			
Speed enforcement	1.49	7.2	21.3
Speed cameras	2.11	1.6	3.5
Section control (co-ordinated speed cameras)	1.58	0.9	2.2
Feedback signs for speed	2.35	1.4	2.5
Drink-driving enforcement	1.80	22.1	44.3
Alcolock for drivers convicted of drink-driving	8.75	7.5	19.6
Seat belt enforcement	2.44	5.7	17.5
Technical inspections of heavy vehicles	1.41	0.6	1.1
Service- and rest hour enforcement	1.45	1.1	1.9
Bicycle helmet law	1.02	1.3	2.4
Law requiring pedestrian reflective devices	3.49	5.6	11.8
Road user-related safety measures			
Accompanied driving	1.25	3.0	16.9
Elderly driver retraining	1.85	0.2	1.0

In Germany [21], 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 [40]. For Sweden [14] as well as for Norway [13], 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 accident rates.

Daytime running lights have been found to be very cost-effective in all the analyses quoted above, except for one [26], with benefit-cost ratios typically ranging between 2 and 5. The assumptions leading to these results are questioned by Knight et.al [26].They argue that the assumption made in most analyses of a greater effect of daytime running lights on fatal and serious accidents than on slight injury accidents 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 accidents at all levels of accident severity, Knight et al [26] find that benefits are smaller than costs. However, by slightly altering other assumptions made in the analyses, for example relying on the HEATCO recommendations for the monetary valuation of safety, benefits once more become greater than costs, even if a uniform effect of 6 % on daytime multi-party accidents 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 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.

9. Cost benefit analyses and policy development

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 [17], one of the questions that was asked to 83 road safety policy makers 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, may be even a greater improvement than, say, ten very highly cost-effective measures that influence small target groups.

Figure 3 probes if this is the case for the road safety measures included in the impact assessment for Norway quoted above [13]

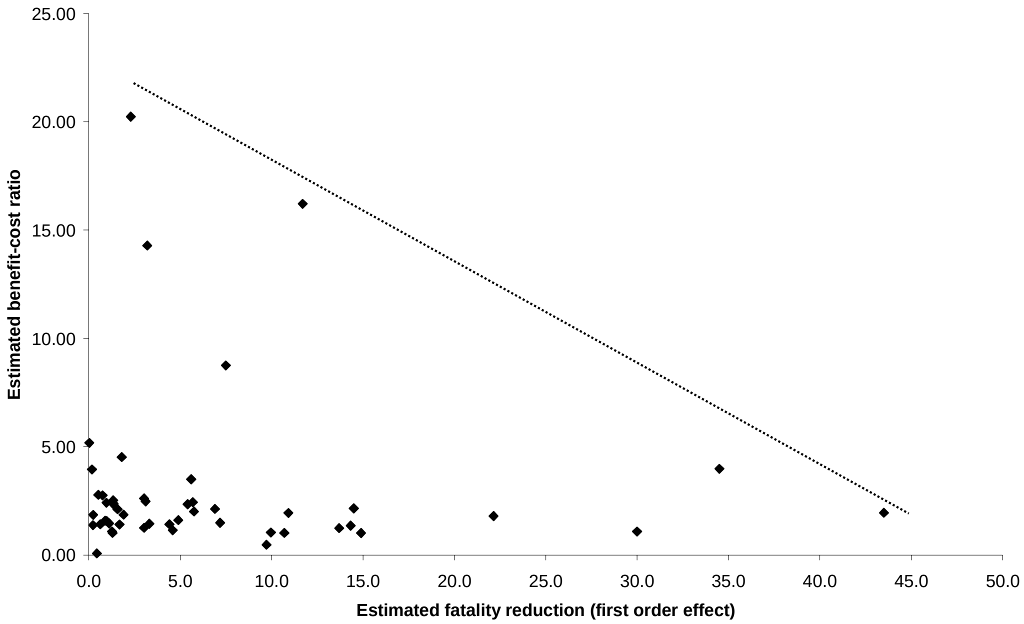

Figure 3: Relationship between estimated fatality reduction and benefit-cost ratio for road safety measures in Norway

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 accident fatalities. This may be felt as a dilemma for policy makers, 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.

It is not just the size of the safety effect that may compete with economic efficiency as a criterion for priority setting. Some policy makers 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 of 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 accident statistics, performed as part of the preparation of new guidelines for road accident black spot management in Norway [34]. Figure 4 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.

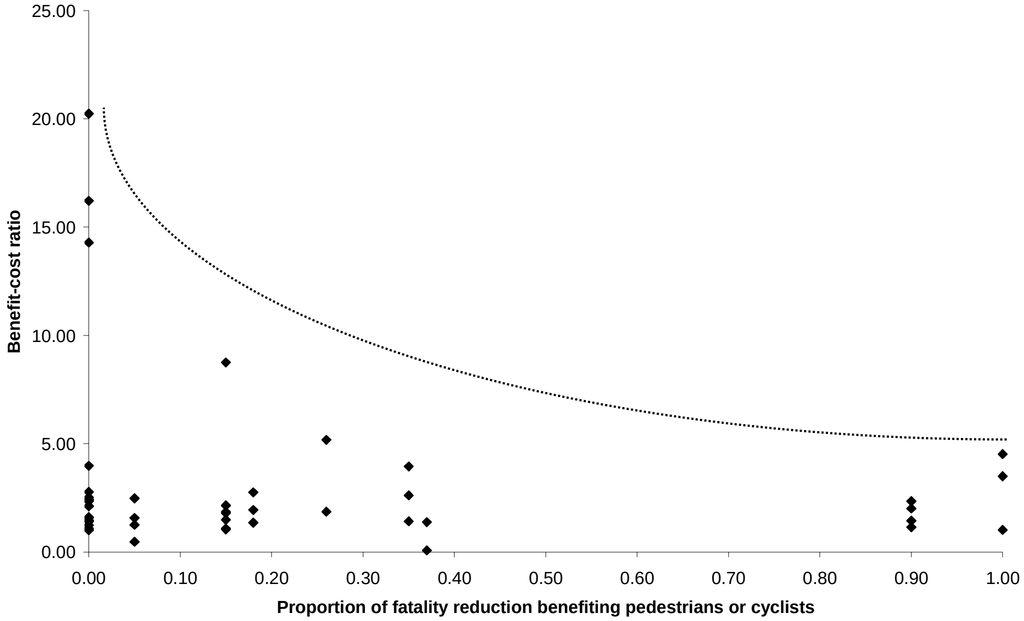

Figure 4: Relationship between proportion of estimated fatality reduction benefiting pedestrians or cyclists and benefit-cost ratio of road safety measures

As in Figure 3, 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.
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 policy makers 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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