Rune Elvik
TØI report 897/2007

Institute of Transport Economics
Norwegian Centre for Transport Research

Prospects for improving road safety in Norway

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Summary:
The report describes a road safety impact assessment that has been made for Norway as part of transport planning for the term 2010-2019. A target has been set for reducing the number of road accident fatalities by 50 % in 2020 compared to the annual mean number during 2003-2006 (from 250 to 125 fatalities per year). Analysis of the prospects for improving road safety by means of various measures shows that this target may be difficult to

Tittel: Utsiktene til å bedre trafikksikkerheten i Norge

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Sammendrag:
Rapporten beskriver en konsekvensanalyse av trafikksikkerhetstiltak i Norge, utarbeidet som del av grunnlaget for Nasjonal transportplan 2010-2019. Det er satt et mål om å halvere antallet drepte i trafikken, fra et gjennomsnitt på 250 per år 2003-2006 til 125 i 2020. Konsekvensanalysen viser at det kan bli vanskelig å nå dette målet ved hjelp av de trafikksikkerhetstiltak norske myndigheter kan innføre.

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Preface

This report presents a road safety impact assessment for Norway. The report is to a large extent based on work done for the Public Roads Administration in Norway as part of the preparation of the National Transport Plan for the term 2010-2019. The report is, however, also part of work package 2 of the EU-project RIPCORD-ISEREST (**R**oad **I**nfrastructure safety **P**rotection – **CO**re-**R**esearch and **D**evelopment for road safety in Europe; **I**ncreasing **S**af**E**ty and **RE**liability of secondary roads for a **S**ustainable surface **T**ransport).

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Oslo, November 2007
Institute of Transport Economics

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Summary:

Prospects for improving road safety in Norway

This report presents a road safety impact assessment for Norway, designed to assess the prospects for improving road safety. The report is to a large extent based on work done as part of the development of the National Transport Plan for the 2010-2019 planning term. The report is also part of work package 2 of the EU-project RIPCORD-ISEREST.

A broad survey of potentially effective road safety measures has been performed. A total of 139 road safety measures were surveyed; 45 of these were included in a formal impact assessment, which also included cost-benefit analyses. The other 94 road safety measures were for various reasons not included in the impact assessment. Reasons for exclusion comprise: (1) Effects of the measure are unknown or too poorly known to support a formal impact assessment; (2) The measure does not improve road safety; (3) The measure has been fully implemented in Norway; (4) The measure overlaps another measure; to prevent double counting, only one measure was included; (5) The measure is analytically intractable.

For the 45 road safety measures included in the impact assessment, use of these measures during the period until 2020 was considered. Analyses indicate that 39 of the 45 measures are cost-effective, i.e. their benefits are greater than the costs according to cost-benefit analyses. Six of the measures were not cost-effective.

A preliminary target of halving the number of road accident fatalities and the number of road users seriously injured has been set in the National Transport Plan for the term 2010-2019. This plan is as yet not finally developed and the road safety target proposed has not been officially adopted or given political support. It is nevertheless of interest to examine if such a target can be realised, as previous road safety impact assessments in Norway have indicated that it is possible to drastically reduce the number of fatalities and injuries. The preliminary targets in the National Transport Plan call for a reduction of fatalities from 250 (annual mean 2003-2006) to 125 in 2020. The number of seriously injured road users is to be reduced from 980 (mean 2003-2006) to 490.

The range of options for improving road safety has been described in terms of four main policy options, all of which apply to the period from 2007 to 2020:

1. Optimal use of road safety measures: All road safety measures are used up to the point at which marginal benefits equal marginal costs. The surplus of benefits over costs will then be maximised.
2. "National" optimal use of road safety measures: Not all road safety measures are under the control of the Norwegian government; in particular

new motor vehicle safety standards are adopted by international bodies. A version of optimal use of road safety measures confined to those that can be controlled domestically was therefore developed.

3. Continuing present policies. This option essentially means that road safety measures continue to be applied as they currently are. There will not be any increase in police enforcement, nor will new laws be introduced (e.g. a law requiring bicycle helmets to be worn).
4. Strengthening present policies. In this option, those road safety measures that it is cost-effective to use more extensively, are used more extensively than today. In particular, this implies a drastic increase in police enforcement.

Estimates show that all these policy options can be expected to improve road safety in Norway. The largest reduction in the number of killed or injured road users is obtained by implementing policy option 1, optimal use of road safety measures. Full implementation of this policy option results in a predicted number of fatalities of 138 in 2020. The predicted number of seriously injured road users is 652. These numbers clearly exceed the targets of, respectively, 125 and 490, although for the number of fatalities the discrepancy is well within the range of normal random variation. The Public Roads Administration has, based on its own analyses, concluded that it is in principle possible to reduce the number of killed or seriously injured road users by 50 % in 2020.

It is, however, not realistic to expect road safety measures to be used optimally. In the first place, some of the measures that may improve road safety if used optimally are outside the power of the Norwegian government. This applies to new motor vehicle safety standards. In the second place, for some road safety measures, optimal use implies a drastic increase. This applies to police enforcement. It is, however, unlikely that the police will increase traffic law enforcement to the optimal extent. In the third place, optimal use of road related road safety measures requires a maximally efficient selection of sites for treatment. Current selection of sites for treatment is not maximally efficient. A strictly optimal selection of sites for treatment is not easily accomplished in Norway due to resource allocation mechanisms favouring regional balancing, rather than economic efficiency.

A more realistic policy is therefore that road safety measures continue to be used along roughly the same lines as they are today. Such a policy will not bring about large improvements in road safety in Norway. A conservative estimate for the number of road accident fatalities in 2020 is about 200. A corresponding estimate for seriously injured road users is about 850. While both these numbers are lower than the current numbers, they are a long way from realising the targets set for 2020 (125 road users killed, 490 seriously injured).

It should be stressed that the estimates presented in this report are highly uncertain. It would therefore not be surprising if the actual development turns out to be different from the one estimated.

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Sammendrag:

Utsiktene til å bedre trafikksikkerheten i Norge

Denne rapporten inneholder en systematisk gjennomgang av mulighetene for å bedre trafikksikkerheten i Norge. Rapporten er i stor grad en engelsk versjon av et arbeid som er utført som ledd i Nasjonal transportplan 2010-2019. Rapporten inngår som del av work package 2 i EU-prosjektet RIPCORD-ISEREST.

Det er gjennomført en bred gjennomgang av mulige trafikksikkerhetstiltak. I alt er 139 tiltak vurdert. For 45 av disse tiltakene er det gjennomført formelle konsekvensanalyser, i form av virkningsberegninger og nyttekostnadsanalyser. For de øvrige 94 tiltak er slike analyser ikke gjennomført, enten fordi tiltakenes virkning er ukjent, fordi tiltakene ikke kan antas å bedre trafikksikkerheten, fordi tiltakene allerede er fullt ut gjennomførte i Norge eller fordi tiltakene overlapper andre tiltak eller er analytisk uhåndterlige.

For de 45 tiltakene som inngår i analysene, er bruken av tiltakene i perioden fram til 2020 vurdert. Beregningene tyder på at 39 av de 45 tiltakene gir en nytte som overstiger kostnadene. 6 av tiltakene er samfunnsøkonomisk ulønnsomme ved ethvert innsatsnivå.

I arbeidet med Nasjonal transportplan for perioden 2010-2019 er det gjennomført en studie av mulighetene for å halvere antallet drepte eller hardt skadde i trafikken fram til år 2020. Det betyr at antallet drepte skal reduseres fra 250 (årlig gjennomsnitt i perioden 2003-2006) til 125. Antallet hardt skadde skal reduseres fra 980 (gjennomsnitt 2003-2006) til 490. Gruppen hardt skadde omfatter personer som er meget alvorlig eller alvorlig skadd.

I beregningene er de valgmuligheter myndighetene står overfor i trafikksikkerhetspolitikken beskrevet ved å utvikle fire hovedalternativer for denne politikken fram til år 2020:

1. Optimal bruk av trafikksikkerhetstiltak. Dette betyr at tiltak brukes opp til det punkt der grensenytten er lik grensekostnadene. En slik bruk av tiltakene sikrer at overskuddet av nytten over kostnadene blir størst mulig.

2. Nasjonal optimal bruk av trafikksikkerhetstiltak. Det er ikke alle tiltak norske myndigheter har full kontroll over, spesielt ikke kjøretøytekniske tiltak. Nasjonal optimal bruk av tiltak betyr at de tiltak norske myndigheter rår over forutsettes brukt optimalt.

3. Videreføring av dagens politikk. Dette alternativet innebærer at en fortsetter å bruke trafikksikkerhetstiltakene som nå. Det betyr at det ikke blir noen økning av politiets eller vegvesenets kontroller og at det ikke innføres nye påbud, for eksempel påbud om bruk av sykkelhjelm.

4. Forsterkning av dagens politikk. I dette alternativet blir de tiltak det er lønnsomt å trappe opp bruken av, trappet kraftig opp. Det betyr først og fremst en kraftig økning av politiets kontrollvirksomhet i trafikken.

Beregningene viser at alle disse alternativene kan forventes å redusere antallet drepte eller skadde i trafikken. Størst reduksjon oppnås i alternativ 1, optimal bruk av trafikksikkerhetstiltak. Hvis dette alternativet gjennomføres fullt ut, er forventet antall drepte i 2020 beregnet til 138. Forventet antall hardt skadde er beregnet til 652 personer. Disse tallene ligger litt over en halvering av dagens tall, men det forventede antall drepte (138) ligger innenfor området for tilfeldig variasjon omkring et tall på 125 drepte per år. Statens vegvesen anser det i prinsippet som mulig, men svært krevende, å halvere antallet drepte eller hardt skadde innen 2020. Denne konklusjonen bygger blant annet på at det finnes flere trafikksikkerhetstiltak enn dem som inngår i analysene i denne rapporten.

Det er imidlertid lite realistisk å tenke seg at alle trafikksikkerhetstiltak kan brukes optimalt. For det første er noen av tiltakene som ved optimal bruk kan bidra mest til å bedre trafikksikkerheten utenfor norske myndigheters kontroll. Dette gjelder nye sikkerhetskrav til kjøretøy. Det kan likevel ventes at ny kjøretøyteknologi vil bidra til å bedre trafikksikkerheten. For det andre innebærer en optimal bruk at enkelte tiltak må trappes kraftig opp. Dette gjelder først og fremst politikontroll. Det må betraktes som lite sannsynlig at det er mulig å iverksette en så kraftig økning av politikontrollene som beregningene tyder på kan være optimalt. For det tredje krever en optimal bruk av tiltak på vegnettet at man kun velger å iverksette tiltak på de steder der de gir maksimal nytte. Dette krever en strengere og mer treffsikker utvelgelse av de steder der tiltak iverksettes enn den vegmyndighetene praktiserer i dag. En strengt effektiv utvelgelse av steder der tiltak bør iverksettes innebærer at disse konsentreres til de mest trafikkerte delene av vegnettet, noe som av distriktspolitiske grunner er vanskelig å få gjennomført i Norge.

Det mest realistiske er derfor at det ikke vil bli gjort vesentlige endringer i bruken av trafikksikkerhetstiltak i Norge de nærmeste årene. Dermed kan man heller ikke vente vesentlige forbedringer av trafikksikkerheten. Et nøkternt anslag er at forventet antall drepte i 2020 vil ligge omkring 200 og forventet antall hardt skadde omkring 850. Begge disse tallene er lavere enn dagens tall, men ligger langt unna de mål om halvering som foreløpig er lagt til grunn for arbeidet med Nasjonal transportplan 2010-2019.

Det understrekes at det knytter seg betydelig usikkerhet til de analyser som legges fram i denne rapporten. Det er heller ikke tatt hensyn til generelle endringer i samfunnsforhold som kan påvirke transportmengde, transportmiddelfordeling, trafikantatferd og utviklingen innenfor høyrisikogrupper. Det vil følgelig ikke være overraskende dersom den faktiske utvikling avviker betydelig fra den som er beregnet her.

1 Background and objective

This report presents a systematic approach to road safety impact assessment. The report has been written as part of the RIPCORD-ISEREST project, in which work package 2 deals with accident prediction models and road safety impact assessment. The objective of the report is to describe a systematic approach to road safety impact assessment and give an example of such an assessment for Norway.

Road safety impact assessment denotes any formal assessment of the expected impacts on road safety of any factor influencing it. The term is, however, most commonly used to refer to assessment of the expected impacts of road safety programmes (ETSC 1997). In the present report, road safety impact assessment refers to a formal assessment of the expected impacts of proposed road safety measures and integrated road safety programmes. The main questions discussed in the report are:

What are the main elements of a road safety impact assessment? What are the issues a road safety impact assessment must consider?

The context for discussing these questions will be the development of national road safety programmes. Such programmes have been developed in many European countries and usually include a formal assessment of their expected impacts on safety.

Road safety impact assessments are carried out at all levels of government. The scope of the assessments varies, depending on the level of government. At the local level of government, road safety impact assessments will usually include a more limited range of road safety measures than at the national level of government. Road safety impact assessments made by international bodies, like the European Commission, will often also be limited to road safety measures that fall within the jurisdiction of these bodies, in particular vehicle safety regulations. In drafting road safety programmes, national governments will consider as broad a range of road safety measures as possible. In this report, an impact assessment made as part of the preparation of a national road safety programme will therefore be used for illustration.

The report is, to a large extent, based on a previous report for the Swedish National Roads Administration (Elvik and Amundsen 2000). A recent road safety impact assessment for Norway is used as an example throughout the report (Elvik 2007A).

2 Context and scope of road safety impact assessment

2.1 A normative model of road safety policy making

Road safety impact assessment is part of the process of road safety policy making. An analytical, normative model of this process, taken from Elvik and Veisten (2005) is shown in Figure 1.

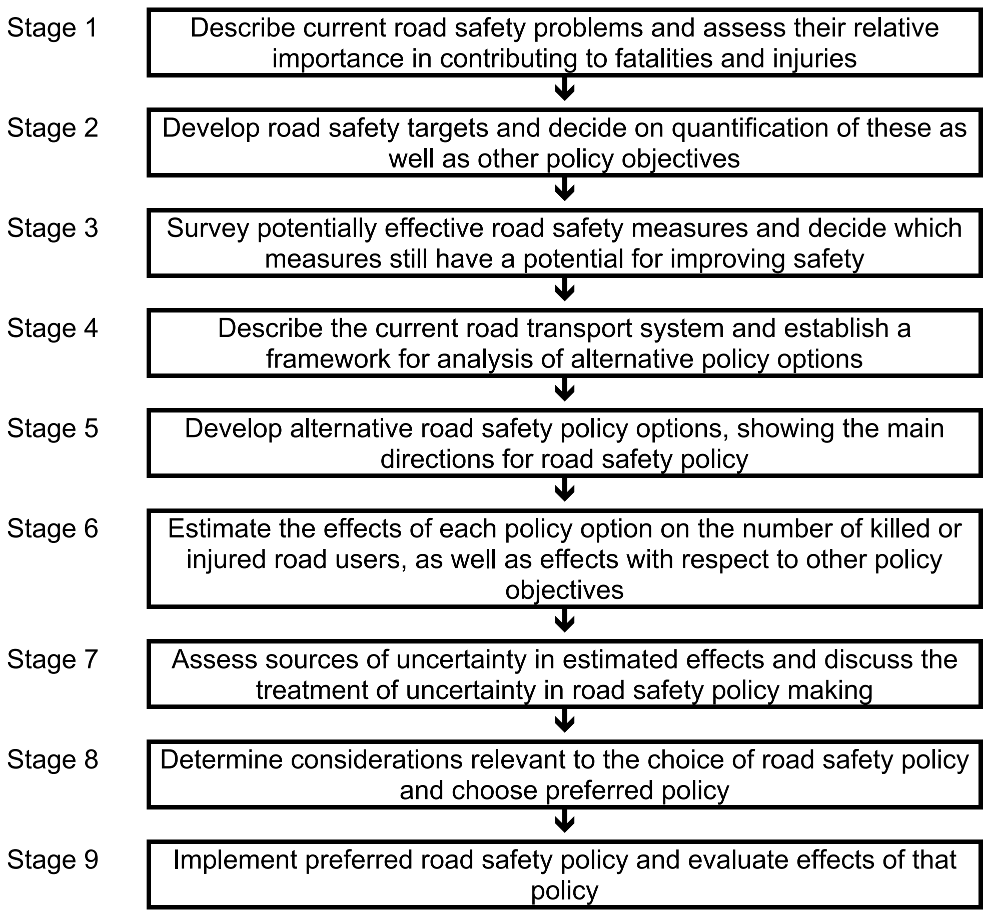

Figure 1: An analytical model of road safety policy making. Taken from Elvik and Veisten (2005)

For the purpose of this report, it will be assumed that an analysis of road safety problems has been made and the most important problems identified. Furthermore, it will be assumed that a long term road safety target has been formulated, and that one of the objectives of the road safety impact assessment is to determine which road safety measures need to be carried out in order to realise this target.

Road safety impact assessment starts at stage 3 of Figure 1. The first part of a road safety impact assessment is to survey potentially effective road safety measures with respect to the possibility of making numerical estimates of the contributions these measures can make in improving road safety during a specified period of time.

Stage 4 in Figure 1 consists of establishing the framework for a road safety impact assessment. By this is meant the assumptions that will be made concerning important parameters for analysis, such as: forecasts of traffic and accidents, discount rate, treatment of uncertainty, opportunity cost of public funds, time horizon for analysis, treatment of salvage value of investments and monetary valuation of relevant impacts. The assumptions made with respect to these and other elements are generally treated as *parameters for analysis*, that is as fixed values that are used as input in the analysis, but are themselves not part of the analysis.

Stage 5 in Figure 1 is optional. In most countries, the national road safety programme does not contain several policy options. While different policy options may have been considered during the process of developing a national road safety programme, the final programme will normally present just the recommended policy. In the example used for illustration in this report, a road safety impact assessment has been made for a set of alternative policy options.

Stage 6 in Figure 1 represents the main stage of road safety impact assessment. At this stage, numerical estimates of the expected impacts on road safety of implementing specific road safety measures are developed. Impact assessment will generally be confined to those road safety measures that are regarded as realistic to implement. Hence, an assessment of the likelihood of implementation will always underlie a road safety impact assessment, albeit often implicitly.

There are many sources of uncertainty in road safety impact assessments. It is instructive to try to consider uncertainty explicitly, confer stage 7 in Figure 1. Sources of uncertainty can be classified in many ways. One dimension refers to the source of uncertainty, which can either be the values for the parameters for analysis (external), or the values used as input in the analysis (internal). Another dimension refers to the type uncertainty, for which a distinction can be made between sources of uncertainty that can meaningfully be quantified in terms of probability distributions and sources of uncertainty that cannot be meaningfully quantified.

Once the impacts of all components of a road safety programme have been estimated, the priority to be given to each road safety measure must be determined, stage 8 in Figure 1. To support priority setting, cost-benefit analysis can be applied. It will, however, normally be the case that considerations not included in cost-benefit analyses will be regarded as relevant for policy choice. Such considerations may include distributional aspects, public acceptance of a measure or concern with respect to the validity or reliability of the results of cost-benefit analyses.

Stage 9 in Figure 1 refers to the implementation of road safety measures and the evaluation of their effects. It is important to evaluate the effects of road safety measures systematically. Improving road safety is a process of learning; it should be organised in such a way that every opportunity for learning is utilised.

In the following sections, each of the stages will be described in more detail.

2.2 Survey and selection of potentially effective road safety measures

The first part of a road safety impact assessment is to select the road safety measures to be included in it. Ideally speaking, a road safety impact assessment at the national level of government should include the broadest possible range of road safety measures. The point of taking a broad view, is to ensure that all potentially effective measures are included. A potentially effective road safety measure is any measure there is reason to believe can improve road safety. For a measure to be treated as potentially effective, it should satisfy the following requirements:

1. The measure should be known to reduce the number of accidents or the severity of injuries, or should be known to favourably influence risk factors that are associated with accident occurrence or injury severity.
2. The measure should not be fully implemented.

For road safety measures that have been used extensively, there will usually be evaluation studies that provide estimates of their effects. A large number of such studies have been summarised and are presented in the Handbook of Road Safety Measures (Elvik and Vaa 2004). The effects of a measure are treated as known if there are evaluation studies of good quality that show the effects of a measure with sufficient precision.

When new road safety measures are introduced, their effects cannot be known in advance. It is, however, sometimes possible to estimate the expected effects of a new measure by estimating its effects on risk factors that have a known relationship with accidents. In such cases, new measures can be included in road safety impact assessments.

Road safety measures that are fully implemented can no longer contribute to further improving safety. As an example, close to 100% of moped and motorcycle riders in Norway wear crash helmets. This measure is fully implemented and its benefits have already been harvested. Knowing the degree to which a measure has been implemented is one of the problems of road safety impact assessments, as there will in many cases not be a straightforward answer to this question.

Selecting road safety measures for impact assessment is discussed more in detail in Chapter 3.

2.3 Determining the framework for road safety impact assessment

This part of a road safety impact assessment consists of the following analyses:

1. Developing forecasts of accidents, intended to show expected future development for a baseline scenario. A baseline scenario denotes a path of development which is likely to occur if past trends continue and no particular interventions are made to change these trends.
2. Determining the value of parameters for analysis, more specifically the values to be used for: (a) The discount rate, (b) The opportunity cost of public money, (c) The monetary valuation of road safety, (d) The monetary valuation of other impacts of measures, including travel time, vehicle operating costs and environmental impacts.
3. Determining the service life (depreciation time) of road safety measures. The length of this time varies from measure to measure, with road infrastructure measures having the longest service life.

Defining the framework for impact assessment is discussed more in detail in Chapter 4.

2.4 Developing policy options – formal priority setting

To estimate the impacts of road safety measures in a national – or for that matter regional – road safety programme, it is necessary to determine the extent to which each measure should be used. Should, for example, 100 junctions be converted to roundabouts, or 200 junctions? The effects of converting 200 junctions will be larger than the effects of converting 100 junctions, but not necessarily twice as large. One would normally expect road safety measures to be implemented first at the locations, or within the groups, where they will provide the largest benefits. This means that the effects of road safety measures on the total number of accidents or accident victims will conform to the law of diminishing returns: effects will be largest at first, and the marginal effects of additional use of the measure will be gradually declining.

To develop efficient policy options, the most efficient schedule for implementing road safety measures should be determined for each measure. Furthermore, priorities for implementing each road safety measure should be set so that total benefits are maximised. How to accomplish this is discussed more in detail in Chapter 5.

2.5 Estimating expected effects of road safety measures

To estimate the effects of road safety measures, the following information must be obtained for reach road safety measure:

1. Definition of a suitable “unit” for implementation of the measure.
2. Definition of the target group of accidents influenced by each road safety measure

3. An estimate of the expected number of accidents for each “unit” of implementation of each road safety measure.
4. An estimate of the expected effects of each road safety measure on the target accidents or injuries.

A unit of implementation represents each case of use of a measure and should be countable. For traffic engineering measures, typical units would be junctions or kilometres of road to which a measure is applied. For vehicle-related measure, each vehicle is a natural unit of implementation. Education and information do not always have easily countable units of implementation; for these measures the total volume can be used to indicate the extent of their use. Likewise, the use of police enforcement is sometimes described in terms of multiples of the current level of enforcement (twice the current level, three times the current level, etc.).

The target group of accidents influenced by each road safety measure refers to the types of accidents it primarily seeks to prevent. For road lighting, for example, this would be accidents in the dark. For traffic signals, it would be accidents in junctions. Some road safety measures, notably speed limits and their enforcement, will influence all accidents.

The effect of a road safety measure on accidents is traditionally stated in terms of the expected percentage change in the number of accidents or number of injured road users. This is a somewhat simplistic way of representing the effects of a measure. In principle, the effects of road safety measures are likely to vary from case to case, depending on a number of characteristics of both the measures and the target groups to which they are applied. At this time, however, only a few functions have been developed in order to describe the effects of road safety measures; for most measures only estimates of mean effects are available. One then has to make the assumption that the effects are identical to mean effects for all units to which a road safety measure is applied.

Further details regarding estimation of effects of road safety measures are treated in Chapter 6.

2.6 The treatment of uncertainty

Estimates of the effect of road safety measures are uncertain. There are multiple sources of uncertainty. These are rarely discussed and analysed systematically in road safety programmes. This neglect can lead to surprises. When a programme is implemented, the actual changes in road safety are not always the same as predicted when the programme was developed. In general, such differences should not come as a surprise, and may in some cases be well within the range of outcomes to be expected on account of the uncertainty of the estimated effects of road safety programmes.

An adequate treatment of uncertainty in road safety programmes is not possible at this time. Too little is known about how different sources of uncertainty combine to enable more than simple sensitivity analyses to be made. Chapter 7 discusses the treatment of uncertainty in greater detail.

2.7 Considerations relevant to policy choice and implementation

A road safety impact assessment is intended to inform policy makers about the expected effects of road safety measures and road safety programmes (consisting of several measures). As such, a road safety impact assessment is a technical analysis that does not have to consider issues related to the implementation of the measures whose effects have been estimated. On the other hand, it is well known that not all road safety programmes are fully implemented. Estimating the impacts of road safety measures that are unlikely to be implemented is, in a sense, a wasted effort. Road safety impact assessments should therefore include a discussion of considerations relevant to policy choice and the implementation of road safety programmes.

It is very unlikely that actual policy priorities for the use of road safety measures will be based strictly on a technical analysis. Policy makers are of course perfectly entitled to add their own assessments and considerations to those included in a formal impact assessment. In particular, actual policy priorities have been found to depart from those based strictly on cost-benefit analyses (Elvik and Veisten 2005).

A further discussion of considerations relevant to policy choice and implementation is presented in Chapter 8.

2.8 Example of a road safety impact assessment and a road safety programme

An example based on Norwegian data is used throughout Chapters 3 through 8, The example is based on work done in 2007 as part of the preparation of the next long-term national transport plan for Norway, for the term 2010-2019 (Elvik 2007A). The example will be used throughout all chapters, but Chapter 9 summarises the main findings.

A parallel study of the possibilities for improving road safety has been presented by the Public Roads Administration (Løtveit 2007).

3 Selection of potentially effective road safety measures

3.1 Screening of potentially effective road safety measures

In order to develop an effective road safety programme, it is necessary to carry out a broad survey of potentially effective road safety measures. The term potentially effective is used deliberately. It denotes any safety measure that there is reason to believe will reduce the number of accidents or the severity of injuries. The term “potentially” is used in order to include new safety measures in the screening process. If a safety measure is new, in the sense that it has not been used before, its effects on safety cannot be known on the basis of evaluation studies in the traditional sense of the term. This applies to several applications of intelligent transport system technology. Measures based on such technology are potentially effective if there is reason to believe that they will favourably influence risk factors that are associated with accidents or injuries.

The process of screening of potentially effective road safety measures for inclusion into a formal assessment of their potential for improving safety, cost-effectiveness and benefit-cost ratio is carried out in two stages:

1. The first stage is to prepare a list of road safety measures that is as exhaustive as possible. An exhaustive lists includes all known measures that have improving road safety as one of their objectives.
2. The second stage is to screen these measures for inclusion in a formal assessment of their safety potentials, cost-effectiveness and benefit-cost ratio by means of a set of screening criteria. These criteria are formulated below.

A broad survey of road safety measures is presented in the Handbook of Road Safety Measure (Elvik and Vaa 2004). The measures covered by this book can be taken as the basis for preparing an exhaustive list of road safety measures. In order to make sure that all potentially effective road safety measures are included, a few measures not explicitly described in the book have been added (Erke and Elvik 2006). Table 1 presents the gross list of measures considered. The Table also indicates why certain measures have not been included in the impact assessment.

3.2 Criteria for inclusion in a formal impact assessment

The following criteria have been developed to determine which road safety measures to include in an impact assessment.

1. ***Knowledge of costs and effects***

   If neither the costs nor any of the effects of a measure are sufficiently well known to be quantified, the measure cannot be included in a formal impact assessment. In order to estimate the potential impacts of a measure on safety, its effect on accidents, injuries or risk factors must be known. In order to estimate cost-effectiveness, the costs of implementing the measure must be known as well. Finally, in order to estimate benefit-cost ratio, the effects of a measure with respect to other policy objectives, not just safety, must be known.

2. ***Effects on safety***

   If no effect, or an adverse effect, of a measure on the number of accidents or severity of injuries has been found in evaluation studies, the measure is not included in a formal road safety impact assessment. There is no point in including measures that are not known to improve safety.

3. ***Overlap of other measures***

   Some of the measures described in the Handbook of Road Safety Measures are rather closely related to each other. In some cases, measures tend to overlap each other. An example is the measure entitled "General rehabilitation and reconstruction of existing roads" (measure 1.14), which overlaps with at least two other measures: cross section improvement and improving road alignment. In order to minimise the risk of double counting of safety potentials, only one measure from a set of overlapping measures has been included.

4. ***Measure has been fully implemented***

   Some measures have, for all practical purposes, been fully implemented. A case in point is compulsory wearing of motorcycle helmets. Close to 100% of motorcycle riders in Norway wear helmets. Hence, requiring helmets to be worn is a measure that has been fully implemented.

5. ***Measure is analytically intractable***

   Some measures are difficult to define in a way that permits meaningful calculations of potential impacts on safety. Urban and regional planning is an example. There is little doubt that the pattern of urban and regional development has important implications for road safety. It is, however, very difficult to define characteristics of urban and regional planning that permit quantified estimates to be made of safety effects. It is important to realise that this does not necessarily mean that the measure is unimportant for safety. The measure is just too complex to fit into the framework of a formal impact assessment.

These criteria are obviously somewhat discretionary. As far as the first screening criterion is concerned, it may be felt as excessively conservative to confine impact assessment to measures whose effects are known. How about trying something new? The effects of new measures cannot possibly be known the same way as the effects of measures that have been used for a long time and have been extensively evaluated.

Criterion 1 is, however, not meant to exclude new measures from being included. The only condition is that there must be reason to believe that a new measure is potentially effective. Whenever a measure can be assumed to favourably influence a risk factor which is known to contribute to accidents or injuries, there is reason to believe that the measure is potentially effective.

The second criterion may also be felt to have undesirable implications in some cases. Consider, for example, the case of resurfacing roads. It has been shown that ordinary resurfacing of roads leads to a temporary increase of about 5% in the number of accidents (Elvik and Vaa 2004). This does not imply that the current policy of resurfacing roads ought to be abandoned. If a road is not resurfaced at appropriate intervals, it will deteriorate and in the end disintegrate completely. However, if the objective is to identify ways of improving road safety, resurfacing roads should not be included as it does not promote this policy objective. The measure may obviously be relevant with respect to other policy objectives, but road safety impact assessment takes impacts on safety as the starting point.

3.3 Measures selected for a formal impact assessment

Table 1 presents the measures that have been considered and states the main reason for not including all of them in the impact assessment. A total of 139 measures have been considered. 45 have been selected for inclusion in an impact assessment.

A few comments on the use of the criteria for inclusion in a formal impact assessment will be given for some of road safety measures listed in Table 1.

Measures with unknown effects. A total of nineteen (19) measures have been screened out because their effects on safety are not sufficiently well known to permit a formal assessment of safety impacts. This category include measures whose causal relationship to accidents is very indirect, which makes it unlikely that it will ever be possible to quantify their effects on the number of accidents or injuries. An example of this kind of measure is information to policy makers (measure 2). For other measures, it is in principle possible to quantify their effects on safety, but this has not been done in a way that is readily applicable to impact assessment.

It is sometimes stated that lack of knowledge is not a major barrier to effective road safety programmes. This claim is supported by the classification in Table 1. The measures whose effects were judged to be unknown represent only 14% of all measures that were considered.

Table 1: Screening of potentially effective road safety measures for assessment of their safety potentials, cost-effectiveness and benefit-cost ratio

Measure (short name)	Code number	Included	Reason for exclusion
Organisational measures	1	No	Effects unknown
Information to policy makers	2	No	Effects unknown
Targeted road safety programmes	3	No	Overlaps other measures
Safe community programmes	4	No	Overlaps other measures
Exposure control	5	No	Overlaps other measures
Land use planning	6	No	Analytically intractable
Road planning	7	No	Overlaps other measures
Road safety inspections and follow-up	8	Yes	
Motor vehicle taxation	9	No	Analytically intractable
Road pricing	10	No	Effects unknown
Changing the modal split of travel	11	No	Analytically intractable
Road traffic legislation	12	No	Overlaps other measures
Regulating commercial transport	13	No	Ineffective measure
Provision of medical services	14	No	Effects unknown
Environmental zones	15	No	Overlaps other measures
E-call (automatic accident notification)	16	Yes	
Regulating use of mobile phones	17	No	Effects unknown
Tracks for walking and cycling	101	No	Ineffective measure
Pedestrian bridge or tunnel	102	Yes	
Motorways	103	Yes	
Bypasses	104	Yes	
New urban arterial roads	105	No	Ineffective measure
Channelisation of junctions	106	No	Overlaps other measures
Roundabouts – three leg junctions	107	Yes	
Roundabouts – four leg junctions	108	Yes	
Geometric layout of junctions	109	No	Ineffective measure
Staggered junctions	110	No	Fully implemented
Interchanges	111	No	Overlaps other measures
Black spot treatment	112	No	Overlaps other measures
Cross section improvement	113	No	Overlaps other measures
Roadside safety treatment	114	Yes	
Improving road alignment	115	No	Overlaps other measures
General rehabilitation of roads	116	Yes	
Guard rails along roadside	117	Yes	
Median guard rails (on undivided roads)	118	Yes	
Median rumble strips (wide)	119	Yes	
Preventing accidents involving animals	120	No	Fully implemented
Horizontal curve treatments	121	Yes	
New road lighting	122	Yes	
Upgrading substandard road lighting	123	Yes	
Road tunnel safety measures	124	No	Overlaps other measures
Service and rest areas	125	No	Effects unknown

Table 1: Screening of potentially effective road safety measures for assessment of their safety potentials, cost-effectiveness and benefit-cost ratio, continued

Measure (short name)	Code number	Included	Reason for exclusion
Resurfacing of roads	201	No	Ineffective measure
Road surface roughness treatment	202	No	Ineffective measure
Road surface friction treatment	203	No	Ineffective measure
Brighter road surface	204	No	Ineffective measure
Landslide protection	205	No	Effects unknown
Winter maintenance of roads	206	No	Fully implemented
Winter maintenance of walking areas	207	No	Analytically intractable
Correcting erroneous highway signs	208	No	Overlaps other measures
Highway work zone safety devices	209	No	Effects unknown
Area wide urban traffic calming	301	No	Fully implemented
Environmental streets	302	Yes	
Pedestrian streets	303	No	Fully implemented
Access control on existing roads	304	No	Ineffective measure
Priority roads	305	No	Ineffective measure
Yield signs at junctions	306	No	Ineffective measure
Stop signs at junctions (four way stop)	307	No	Fully implemented
Traffic signal control of three leg junctions	308	Yes	
Traffic signal control of four leg junctions	309	Yes	
Traffic signal control of pedestrian crossings	310	Yes	
Changing speed limits on hazardous roads	311	Yes	
30 km/h speed zones in towns	312	Yes	
Road markings	313	No	Fully implemented
Upgrading pedestrian crossings	314	Yes	
Parking regulations	315	No	Overlaps other measures
One way streets	316	No	Ineffective measure
Reversible lanes	317	No	Ineffective measure
Bus lanes (HOV-lanes)	318	No	Ineffective measure
Dynamic route guidance	319	No	Effects unknown
Feedback signs for speed	320	Yes	
Railroad-highway grade crossing	321	No	Fully implemented

Table 1: Screening of potentially effective road safety measures for assessment of their safety potentials, cost-effectiveness and benefit-cost ratio, continued

Measure (short name)	Code number	Included	Reason for exclusion
Tire tread depth	401	No	Fully implemented
Use of studded tires/winter tires	402	No	Fully implemented
ABS-braking systems	403	No	Ineffective measure
High mounted stop lamps	404	No	Fully implemented
Daytime running lights on cars	405	No	Fully implemented
Daytime running lights on motorcycles	406	No	Fully implemented
Self levelling headlamp requirement	407	No	Effects unknown
Pedestrian reflective devices	408	Yes	
Electronic stability control	409	Yes	
Bicycle helmets	410	Yes	
Helmets for motorcyclists	411	No	Fully implemented
Seat belt reminder in light cars	412	Yes	
Ignition interlock for seat belts in light cars	412	Yes	
Child restraints	413	No	Fully implemented
Air bags	414	No	Fully implemented
Seat belts in heavy vehicles	415	No	Effects unknown
Seat modifications for neck injury protection	416	Yes	
Modifying car instruments and controls	417	No	Effects unknown
Intelligent cruise control	418	Yes	
Regulating vehicle mass	419	No	Ineffective measure
Systems for intelligent speed adaptation	420	Yes	
Motor power regulation of motorcycles	421	No	Ineffective measure
Improving under run guard rails on trucks	422	No	Effects unknown
Front impact protection on trucks	423	Yes	
Safety equipment on motorcycles	424	No	Analytically intractable
Safety equipment on bicycles	425	No	Overlaps other measures
Safety equipment on trailers	426	No	Effects unknown
Fire protection measures	427	No	Effects unknown
Hazardous goods transport safety	428	No	Effects unknown
Accident data recorder	429	Yes	
Safety standards for front and bumper	430	Yes	
Improving scores on EuroNCAP	431	Yes	
Ignition interlock for alcohol	432	Yes	

Table 1: Screening of potentially effective road safety measures for assessment of their safety potentials, cost-effectiveness and benefit-cost ratio, continued

Measure (short name)	Code number	Included	Reason for exclusion
Type approval of cars and spot checks	501	No	Overlaps other measures
Periodic motor vehicle inspection	502	No	Ineffective measure
Roadside inspections of heavy vehicles	503	Yes	
Garage approval and inspection	504	No	Effects unknown
Age limits for driver's license	601	No	Fully implemented
Health regulations for drivers	602	No	Fully implemented
Knowledge and skills requirements	603	No	Ineffective measure
Basic driver training	604	No	Ineffective measure
Accompanied driver training	605	Yes	
Training of problem drivers	606	No	Ineffective measure
Driver's license examination	607	No	Fully implemented
Training of motorcyclists	608	No	Ineffective measure
Training of bus and truck drivers	609	No	Ineffective measure
Graduated driver's license – curfews	610	No	Overlaps other measures
Rewarding safe driving	611	No	Overlaps other measures
Enforcement of driving and rest hours	612	Yes	
Safety regulation of emergency driving	613	No	Ineffective measure
School bus transport for children	614	No	Fully implemented
Elderly driver retraining	615	Yes	
Training of pre-school children (age <6)	701	No	Ineffective measure
Training of school children (age 6-)	702	No	Analytically intractable
Public information campaigns	703	No	Ineffective measure
Feedback signs and variable message signs	704	No	Overlaps measure 320
Speed enforcement	801	Yes	
Patrolling traffic (general enforcement)	802	No	Ineffective measure
Regulation of drinking and driving	803	No	Fully implemented
Drinking and driving enforcement	804	Yes	
Seat belt enforcement	805	Yes	
Speed cameras	806	Yes	
Section control (multiple speed cameras)	807	Yes	
Red light cameras	808	No	Ineffective measure
Fixed penalties (traffic tickets)	809	No	Ineffective measure
Ordinary traffic tickets and imprisonment	810	No	Overlaps other measures
Demerit point systems	811	No	Effects unknown
Motor vehicle insurance regulation	812	No	Effects unknown

Measures that are ineffective. A total of twenty nine (29) measures have been classified as ineffective. For some of these measures, a brief explanatory comment is in order.

Measure 104, new urban arterial roads, refers to the construction of new main roads in larger towns. According to a recent evaluation study (Elvik and Amundsen 2004) this measure does not reduce the expected number of accidents.

There is a reduction of the accident rate (number of accidents per kilometre of travel), but an offsetting increase in the amount of travel (number of vehicle kilometres of travel performed).

According to the Handbook of Road Safety Measures (Elvik and Vaa 2004), ABS brakes on cars and vans (measure 403) does slightly reduce the total number of accidents. However, the number of fatal accidents is not reduced, but actually appears to increase. The measure has therefore been classified as ineffective, as the prevention of fatal injury is more important than the prevention of less serious injuries or property-damage-only accidents. A recent study by Cummings and Grossman (2007) confirms the ineffectiveness of ABS-brakes in preventing injury accidents.

Regulation of vehicle mass (measure 419) has also been classified as ineffective. It is true that increasing vehicle mass reduces the chances of fatal or serious injury to the occupants of a car in crash. This benefit is, however, almost entirely offset by an increase in the risk of injury to other road users posed by larger vehicles.

Regulating the motor power of motorcycles (measure 421) has also been classified as an ineffective measure. The best controlled studies of this measure do, perhaps somewhat surprisingly, not show any statistically significant safety benefits of restricting the motor power of motorcycles or of prohibiting the use of large motor cycles for inexperienced drivers.

The classification of periodic motor vehicle inspection (measure 602) as an ineffective measure is based mainly on an experiment made in Norway a few years ago (Fosser 1992) and on a recent observational study (Christensen and Elvik 2007). These studies did not find any effects whatsoever on safety of periodic motor vehicle inspection.

Measure 701, training of pre-school children, is classified as ineffective. This is based mainly on a study of Children's Traffic Club made in Sweden (Gregersen and Nolén 1994). Although there are studies that indicate a favourable safety impact of such Clubs (see, for example, Schioldborg 1974), the Swedish study is the most recent and well controlled study of this measure.

Public education and information campaigns (measure 703) has also been classified as an ineffective measure. Once again, there are examples of studies that indicate that some safety campaigns have been effective in reducing the number of accidents. However, there is not enough knowledge regarding why some campaigns are effective and others are not to permit inclusion in an impact assessment.

Fixed penalties (simple traffic tickets) have been classified as ineffective, based mainly based on Swedish studies (Nilsson and Åberg 1986; Andersson 1989), and a recent Norwegian study (Elvik and Christensen 2007).

Measures that overlap other measures. A total of twenty (20) measures have been omitted because they are assumed to overlap with other measures. Brief comments are given to explain some of these cases of overlapping measures.

Measure 3, targeted road safety programmes overlaps all the specific measures analysed in this report that have been included in the impact assessment. These specific measures are what constitutes a targeted road safety programme. Measure

4, safe communities, is omitted for the same reason. Measure 5, exposure control, overlaps at least measures 9 (motor vehicle taxation) and 10 (road pricing), and possibly other measures as well. Moreover, exposure control is not as yet high on the political agenda in most countries. Measure 7, road planning, is of no interest by itself, but affects safety only to the extent that plans for specific road safety measures are carried out. This measure therefore overlaps all the specific road related measures (at least those that involve investments). Measure 11, legislation, overlaps any specific amendment to the law.

Measure 105, channelising junctions, is dominated by measure 106, roundabouts. It costs about the same, but is less effective. Measure 110, black spot treatment, overlaps a number of more specific types of treatment that are applied to road accident black spots. Measures 111 (cross section improvement) and 113 (improving road alignment) both overlap measure 114, general rehabilitation of existing roads. Measure 119, safety of road tunnels, overlaps a number of other measures. Measure 208, correcting erroneous highway signs, overlaps measure 8, road safety inspections. Finally, measure 501, type approval of new cars, is of no interest by itself, but can affect safety only to the extent that new safety requirements for cars are granted type approval. This means that this measure overlaps with a number of more specific safety requirements for cars.

Measures that have been fully implemented. Twenty (20) measures have been left out because they are, for all practical purposes, fully implemented, at least in Norway. This category includes measures like road markings, daytime running lights for cars and motorcycles, crash helmets for motorcyclists and regulation of drinking and driving. With respect to road markings, the reasoning leading to the conclusion that it is fully implemented runs as follows. All roads have road markings. Standards have been set for maintaining road markings; when the markings get worn, they are repainted. This is done on a routine basis. For the road system as a whole, this means that a certain mean standard of road markings is maintained at any time. This contributes to maintaining a certain level of road safety. To further improve safety from the baseline level, one would have to upgrade the standards for road markings, for example by renewing the markings more often, using brighter colours or enhancing the retro-reflective qualities of road markings.

As far as daytime running lights, crash helmets and drinking and driving are concerned, these are all legislative measures that have been fully implemented in the sense that the laws introducing these safety measures have been passed, and high levels of compliance – exceeding 95% – have been attained. Although compliance is not 100%, the measures are regarded as fully implemented, in the sense it is only by means of more enforcement that compliance can be improved.

Measures that are analytically intractable. Six (6) measures have been omitted from further analysis because they are analytically intractable. These are measures for which it is difficult to define the extent of their use in a way that permits meaningful calculations of costs and effects to be made. Urban and regional planning is an example of this kind of measure. It is a very complex measure, spanning the range from master plans for a region to detailed construction plans for a single property.

4 Framework for road safety impact assessment

4.1 Forecasting baseline development

The first task to be solved in establishing the basis for a road safety impact assessment is to forecast baseline development. The term baseline development denotes the changes in road safety that are expected to occur if current policy is continued during the whole period a road safety programme applies to. In short: What changes in road safety are to be expected if the effects of factors influencing it remain unchanged in the future?

This question may sound simple, but it is actually very difficult to give a good answer to it. Forecasting road safety involves two major problems:

- Past trends are to some extent endogenous, that is influenced by the same safety measures as those whose potential effects we want to assess in order to develop a road safety programme.
- It is nearly impossible to identify the factors that have produced past trends in road safety.

To illustrate these problems an analysis of long term trends in road safety in Norway is used as an example. Figure 2 shows the trend in fatalities from 1970 to 2005 along with three different trend lines that have been fitted to these data and extrapolated to 2020 to provide a baseline forecast.

The three trend lines fitted to data for the period 1970-2005 are almost indistinguishable for that period, but give widely diverging predictions for the year 2020. Moreover all trend lines fit the data almost equally well. It is therefore difficult to justify the use of them as being clearly superior to the other two in terms of goodness-of-fit.

The polynomial trend line predicts 259 fatalities in 2020. This trend line continues to slope downward until the year 2013, then remains flat for a few years and starts to climb slowly in the final two years of the period. The polynomial trend line implies that road safety improvement is slowing down. In other words: most effective road safety measures have been implemented and one should expect a less favourable trend in the future unless more effective road safety programmes are implemented.

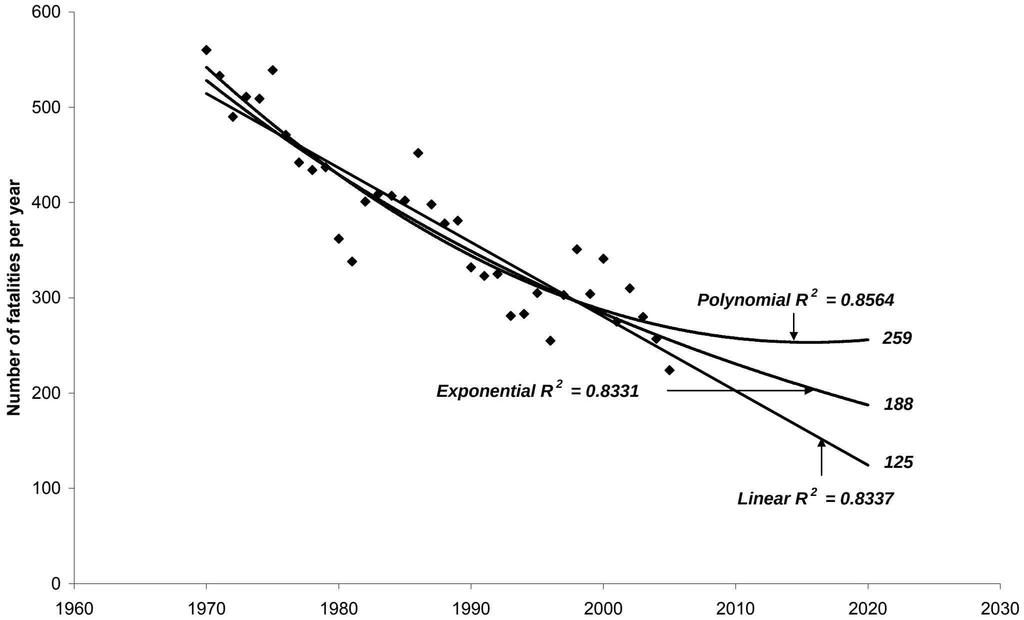

Figure 2: Long term trend in road accident fatalities in Norway from 1970 to 2005 and forecast for 2020 based on different trend lines

The linear trend line gives the most optimistic forecast. It predicts 125 fatalities in 2020. If extrapolated beyond 2020, this trend line gives nonsensical results, predicting that road accident fatalities will be eliminated by the year 2036. While it is certainly possible to greatly reduce road accident fatalities by means of known safety measures – as will become clear later in this report – it is equally clear that the measures known today will not be able to eliminate road accident fatalities. That scenario lacks credibility even if very advanced technology is developed; no technology is perfectly reliable.

The exponential trend line assumes that past progress continues at a constant rate; more specifically that the number of road accident fatalities in the long term will drop by an average of 2.1 percent per year. This trend line predicts 188 fatalities in 2020.

Is it possible to develop more precise forecasts based on an analysis of factors explaining the past trend? Elvik (2005A) attempted to explain the long term trend in the number of road accident fatalities in Norway during the years 1979-2003 by fitting a model including the following explanatory variables:

1. The total volume of travel, stated in million person kilometres travelled, including travel on foot or by bicycle.
2. The number of kilometres driven by young drivers (aged 18-24 years).
3. The number of kilometres driven by heavy vehicles.
4. Kilometres travelled on foot or bicycle.
5. Sale of new cars (thousands per year).
6. Seat belt wearing among drivers (percentage wearing seat belts, stated as a weighted mean of urban and rural wearing rates).

7. The number of fixed penalties (traffic tickets) issued per million vehicle kilometre of driving.
8. The number of vehicle kilometres driven on motorways.

The analyses were made by fitting negative binomial regression models. The models fitted were difficult to interpret, due to high co-linearity among the explanatory variables and very many omitted variables. Attempting to explain long term trends in road safety by means of multivariate analysis was therefore unsuccessful.

In all analyses, it turned out that the dependent variable had a stronger statistical association with a trend term than with any of the explanatory variables. The trend term captures the effects of omitted variables that have, over time, systematically contributed to reducing the number of fatalities.

The explanatory power of the models fitted was only marginally better than that of simple trend lines fitted directly to the data without making use of any explanatory variables at all. This means that the omitted variables, which constitute the trend term, have a dominant influence on long term trends. These unknown variables include road safety measures that have been introduced during the period covered by the study. Unfortunately, complete records of all road safety measures that have been implemented do not exist. Besides, it is reasonable to assume that many of the road safety measures were introduced at an almost constant rate per unit of time, thus not permitting their effects to be identified statistically in time-series data. Traffic engineering measures, for example, are typically implemented at a minor proportion of roads every year. Similarly, renewal of the motor vehicle fleet takes place at an almost constant rate; complete turnover takes some 15-20 years. The 95% probability range for random fluctuations in the annual number of road accident fatalities in Norway amounts to plus or minus 15% of the recorded number. This makes it highly unlikely that any statistical analysis would be able to estimate the contribution of road safety measures to the long term trend, as this contribution, on an annual basis, is likely to be considerably smaller than 15%.

Broughton et. al. (2000) provides an instructive discussion of the problem and guidelines with respect to how to solve it. To develop a relevant baseline forecast, it is necessary to at least indicate the likely contribution that road safety measures will make; provided these continue to be implemented at the same rate and with the same marginal effects as in the past. Neither of these assumptions is unproblematic; both of them need to be justified or suitably modified (e.g. by assuming that the marginal returns on road safety investments will be falling).

To forecast traffic fatalities and injuries in Norway, two major assumptions have been made and a prediction derived from them in two stages:

1. A forecast for traffic volume has been applied and a prediction made for the development of fatalities and injuries based on the relationship between traffic volume and the number of injured road users.
2. A forecast has been made regarding changes in vehicle technology. The effects of these changes on the number of road accident fatalities and injuries have been estimated.

An official traffic forecast has been developed for use in the National Transport Plan for Norway for the term 2010-2019 (Elvik 2007A). This forecast has been applied. According to the forecast, vehicle kilometres of travel is expected to grow by 17 % from 2007 to 2020. Analyses of accident data suggest that when traffic grows by 1 %, the number of fatalities grows by 0.83 %, the number seriously injured road users by 0.79 % and the number of slightly injured road users by 0.97 %, all else equal.

As basis for forecasting the number of killed or injured road users, annual mean values for the years 2003-2006 (rounded to the nearest 10) have been used. Thus, the basis for the forecasts is:

- 250 fatalities expected in 2007
- 980 seriously injured road users expected in 2007
- 10870 slightly injured road users expected in 2007

By 2020, these numbers are expected to grow to:

- 285 fatalities expected in 2020
- 1109 seriously injured road users expected in 2020
- 12650 slightly injured road users expected in 2020

These predictions apply to a situation in which no road safety measures are introduced and the growth in traffic is the only factor producing changes in road safety.

However, some new road safety measures can be expected to be introduced and have an effect even if government takes no action. More specifically, it is reasonable to assume that new vehicle safety technology will continue to spread at the same rate as it has in recent years. Even without the introduction of new vehicle safety standards, there is reason to believe that an increasing proportion of new cars will have:

1. Front- and side-impact air bags
2. Electronic stability control
3. Enhanced neck injury protection
4. Seat belt reminders
5. A four or five star rating according to the European New Car Assessment Programme (EuroNCAP).

Hence, to forecast fatalities and injuries, it is necessary to account for the effects of these developments. As far as other road safety measures are concerned, it has been assumed that national, regional and local governments are in full control of their use. This means that no assumptions will be made regarding the likely future effects of these measures, as this depends on the policy made.

Estimates have been made of the likely future spread of the vehicle safety features listed above during the years from 2007 to 2020. The estimates are conservative, meaning that any error is likely to be on the side of caution, i.e. future changes in road safety could be more favourable than indicated by the estimates, but are unlikely to be less favourable. This report will not describe in detail how the estimates were developed, as this is not its main purpose. Elvik (2007A) describes details of the estimates. Briefly summarised, the following changes in market penetration of vehicle safety systems is expected between 2007 and 2020:

1. The market penetration of air bags will increase from 67 % to 100 % of kilometres driven. It was estimated that this may prevent 15 fatalities and 29 seriously injured road users by 2020 (first order effects; see explanation of this below).
2. The market penetration of electronic stability control will increase from 19 % to 88 % of kilometres driven. It was estimated that this may prevent 35 fatalities, 81 seriously injured road users and 337 slightly injured road users by 2020 (first order effects).
3. The market penetration of enhanced neck injury protection will increase from 4 % to 50 % of kilometres driven. This may prevent 2 fatalities, 23 seriously injured road users and 231 slightly injured road users in 2020 (first order effects).
4. The market penetration of seat belt reminders will increase from 19 % to 75 % of kilometres driven by 2020. This may prevent 12 fatalities, 36 seriously injured road users and 101 slightly injured road users (first order effects).
5. The market penetration of cars that are rated 4 or 5 stars according to EuroNCAP will increase from 36 % to 72 %. This may prevent 14 fatalities and 49 seriously injured road users by 2020 (first order effects).

The term “first order effects” denotes the effects a road safety measure has when considered in isolation, and when keeping all other factors constant. The new vehicle safety features will, however, be introduced simultaneously and will to a great extent influence the same target group of accidents. Thus, if, for example, electronic stability control has reduced the number of fatalities by 35, each of the other four systems will have an impact on 35 less fatalities. If the assumption is made that the effects of a road safety measure are independent of the effects of other road safety measures (i.e. its percentage effect remains unchanged irrespective of whether other measures are used or not), and that effects combine multiplicatively, a simple model for estimating the combined effects of a set of road safety measures, called the common residuals model, can be applied. To see how this model works, partition the set of accidents or injuries influenced by a road safety measure into two complementary sets:

1. The effect, which is the share of accidents or injuries prevented by a measure.
2. The remaining share of accidents, which will be referred to as the residual.

Thus, for electronic stability control, the effect, as estimated on the basis of the predicted number of fatalities in 2020 is 34.5/285 = 0.121. The residual is (285 – 34.5)/285 = 0.879.

The common residual of all the five safety features that have been included is 0.754. This means that if all the five vehicle safety features increase their market penetration at the predicted rate, they will reduce the number of fatalities by 24.6 % in 2020. This estimate may, however, for several reasons be somewhat optimistic. All safety features are going to be introduced simultaneously on more or less the same cars. They will to some extent influence the same risk factors. For example seat belt reminders and increasing penetration of airbags will both improve crashworthiness.

The analyses reported in Chapter 7 suggest that the combined effects of a set of road safety measures are to some extent determined by the most effective measure in the set, which we may refer to as the dominant measure. A dominant measure will reduce the effects of other measures by influencing the same risk factors, or risk factors that are strongly correlated with the risk factors influenced by the other measures.

In the set of five vehicle safety features, the dominant one is electronic stability control. Its dominant effect can be modelled by raising the common residual to the power of the residual of the dominant measure. In the present case, this becomes:

$0.754^{0.879} = 0.780$

This means that the combined effects of the measures are slightly reduced to account for the correlations generated by the dominant measure. A similar correction was made to determine the combined effects of the vehicle safety features on the number of seriously or slightly injured road users.

The resulting predicted number of killed or injured road users are shown in Table 2. As can be seen, even if government does not introduce any new road safety measures, the number of road accident fatalities and the number of seriously injured road users are predicted to decline slightly by 2020. The number of slightly injured road users is expected to increase. The predictions are uncertain. Uncertainty is discussed in chapter 7.

Table 2: Predicted number of killed or injured road users in Norway in 2020 in the baseline scenario

	Predicted numbers for 2020		
Assumptions made in baseline scenario	**Fatalities**	**Seriously injured**	**Slightly injured**
Mean annual numbers 2003-2006	250	980	10870
Forecast for 2020 accounting for traffic growth	285	1109	12650
Forecast for 2020 accounting for traffic growth and increased market penetration of vehicle safety features	222	913	12010

4.2 Road safety targets in Norway

Road safety impact assessment is often provided as a basis for developing targeted road safety programmes. A crucial issue in developing a targeted road safety programme is whether or not to set a quantified target and selecting the level of such a target. Research cannot provide very firmly supported guidelines for the formulation of quantified road safety targets (Elvik 2001, 2007B, Wong et.

al. 2006). On a generous interpretation, research evaluating the effects of quantified road safety targets support targets that are:

- Ambitious, that is aim for a larger improvement in road safety than a mere prolongation of past trends would imply.
- Long-term, that is apply to a period of at least ten years, allowing a broad range of safety measures to be implemented.
- Set by national governments, ensuring commitment to the programme from all sectors and levels of government.
- Supplemented by monitoring systems and performance indicators allowing progress to be assessed regularly and adjustments in policy to be made if needed.

In Norway, the Public Roads Administration (Vegdirektoratet) has proposed an elaborate system of road safety management by objectives, designed to identify target areas for road safety interventions and ensure that effective measures are implemented. The system is part of the system of national transport planning. National transport plans, which include a long-term road safety programme, are prepared every four years in Norway. The national transport plan for the years 2010-2019 is currently in preparation. The road safety impact analysis presented in this report is part of the preparation of the National Transport Plan.

The system of management by objectives consists of two types of targets. One type of target refers to various states of the road transport system. There are 21 of these targets in total, of which 12 refer to various aspects of road user behaviour, 6 refer to safety features on motor vehicles and 3 refer to the safety standards of roads. This report will not discuss these targets further.

The other type of target set, is a target for the reduction of the number of killed or seriously injured road users. The target proposed by the Public Roads Administration is to reduce the number of killed or seriously injured road users by 50 % in 2020 compared to the mean annual numbers for the period 2003-2006. The target is to reduce the number of road accident fatalities from 250 to 125, and the number of seriously injured road users from 980 to 490.

It should be noted that at this time, the proposed target has not yet been approved politically. Traditionally, Norwegian politicians have been opposed to quantified road safety targets, arguing that such targets are unethical, and that the only ethically defensible target for road accident fatalities is zero. Vision Zero has indeed been officially adopted as the basis for transport safety policy in Norway. It applies to all modes of transport, not just the road sector. It remains to be seen if politicians are willing to support a quantified road safety target in addition to Vision Zero. This will be decided in 2008 or 2009.

4.3 General parameters for analysis

The general parameters for analysis include the discount rate and the opportunity cost of public expenditures.

As far as the discount rate is concerned, it has been estimated by means of the capital asset pricing method (Minken 2005). Since the start of year 2000, the discount rate consists of a risk free rate plus a risk premium. The risk premium only takes into account the relevant part of risk, i.e., the risk that cannot be eliminated by holding a diversified portfolio of assets. Assets in this connection include infrastructure projects, and the relevant risk is the contribution which the project makes to the risk of net national income.

The current discount rate for road projects, including road safety measures, is 4.5% per annum. This rate has been used in all cost-benefit analyses presented in this report.

The opportunity cost of public expenditures funded by means of general taxation, i.e. taxes levied on income and consumption whose revenues are not earmarked, has been fixed by the Ministry of Finance (Finansdepartementet 2005) to 20%. This means that all public expenditures are multiplied by the factor 1.2 in order to obtain the social opportunity cost.

4.4 Monetary valuation of relevant impacts

Table 3 lists the monetary valuations that have been used in the analyses. Most of these valuations have been obtained from a report by Samstad, Killi and Hagman (2005). Valuations of health impacts have been taken from the guidelines for impact assessment published by the Public Roads Administration (Statens vegvesen, Vegdirektoratet 2006).

Inclusion of health impact associated with walking or cycling has until now not been common in cost-benefit analyses of road projects. Two types of health impacts are included:

1. Reduction of insecurity, which is felt by many pedestrians or cyclists when walking or cycling in mixed traffic.
2. Improvements in public health as a result of physical exercise associated with walking or cycling.

Inclusion of these impacts has been found to have decisive influence on the results of cost-benefit analyses of road facilities designed for pedestrians or cyclists (Sælensminde 2004).

Table 3: Monetary valuation of impacts of road safety measures

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

4.5 Service life of road safety measures

The following assumptions have been made regarding the service life of various road safety measures.

Main group of road safety measures	Service life (Years)
Road investments	25
New safety features on cars	18
Signs and traffic control devices	10
Road markings	5
Driver training, ignition interlock for alcohol	2
Road maintenance and police enforcement	1

5 Developing policy options and formal priority setting

5.1 Constraints on road safety policy making

The road safety impact analyses presented in this report have been developed within the following constraints:

1. Road users can choose between all means of transport that are allowed today. Prohibiting certain means of transport, for example motor cycles, is ruled out.
2. There will be no formal restrictions on mobility. Changes in the amount of travel will depend strongly on economic changes, which cannot be influenced by means of road safety measures.
3. Current budget limits for road safety measures will not be treated as binding, meaning that if measures that produce benefits exceeding the costs require a larger budget than the current one, then the budget ought to be increased.

5.2 Efficient selection of sites for treatment

To implement road safety measures in a way that produces maximum benefits, it is necessary to select areas or units for implementation that have the highest expected number of accidents or injuries. Such selection is only possible if a state-of-the-art road safety management system has been introduced. The problem can be illustrated by reference to Figure 3.

Figure 3 shows the Empirical Bayes (EB) estimate of the expected number of injury accidents per kilometre of road for a major road in Norway. The road has a length of 55 kilometres. The sections shaded in grey are those that have the highest expected number of accidents. These sections are, however, not located next to each other, but are scattered along the road. To produce maximum benefits, road safety measures should be targeted at the sections shaded in grey.

It is important to note the fact that EB-estimates are derived as the weighted average of a normal number of accidents estimated by means of an accident prediction model, and the recorded number of accidents for reach road section. Ideally speaking, EB-estimates of safety control for regression-to-the-mean, while capturing the effects of local conditions that influence the expected number of accidents on each 1-kilometre section.

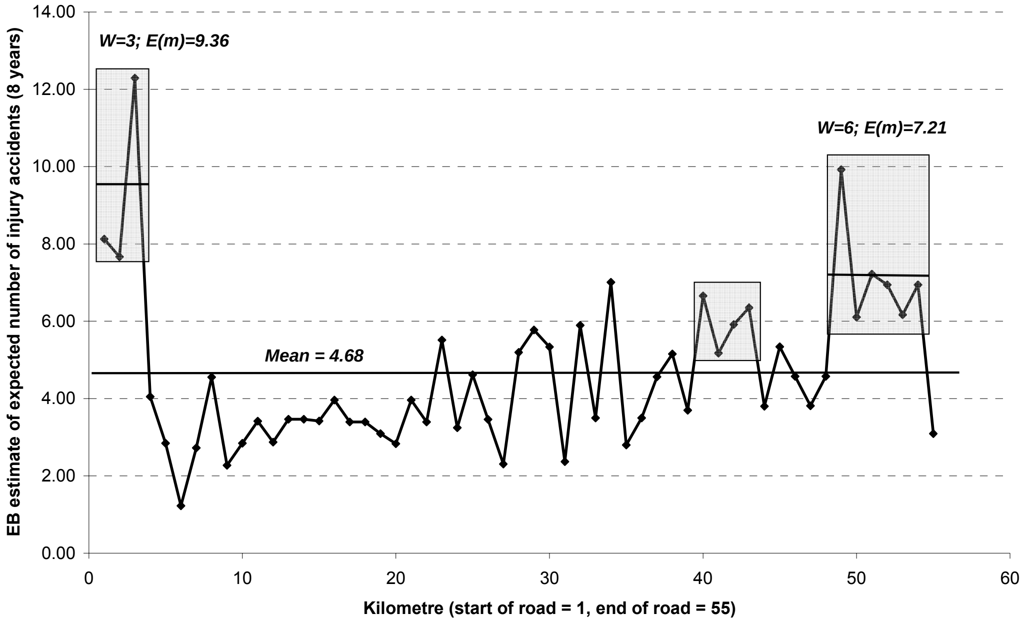

Figure 3: EB-estimates of the expected number of injury accidents per kilometre of road for a major road in Norway

Unfortunately, EB-estimates of road safety cannot be developed for all types of roadway elements in Norway. Accident prediction models have only been developed for road sections of 1 kilometre (Ragnøy, Christensen and Elvik 2002). Although simple models are available for junctions (Sakshaug and Johannessen 2005), these models do not lend themselves to estimation by means of the EB-method. No models have been developed for other roadway elements, like bridges or tunnels. It is at this time therefore not possible to use the EB-method as a means of selecting the most promising target sites for road safety measures. To model the selection of sites and objects for road safety measures, there are two other possibilities:

1. Study the actual process of selection and identify parameters that are correlated with the benefit-cost ratio of measures.
2. Develop a simple model of selection, based on one or a few variables that are known to be highly correlated with the expected number of accidents or injuries.

The process of selection for road safety treatment in Norway has been studied by Elvik (2004A). One of the objectives of the study was to assess the extent to which high-risk sites were selected for treatment. Some key findings of the study were:

1. About 47% of intersections selected for treatment had a higher-than-normal accident rate, 47% had a lower-than-normal accident rate, and 6% had an accident rate close to the normal rate. The mean ratio of the observed accident rate in treated intersections to the normal accident rate for intersections at large was about 1.60.

2. For road sections selected for safety treatment, 39% had a higher-than-normal accident rate, 39% had a lower-than-normal accident rate, and 22% had an accident rate close to the normal rate. The mean ratio of the observed accident rate for treated road sections to that for road sections in general was about 1.75.
3. Intersections and road sections selected for safety treatment in Norway have a substantially higher traffic volume than the mean traffic volume for intersections or road sections. Traffic volume appears to be an important criterion for selecting a site for treatment.
4. Selection for road safety treatment in Norway is slightly biased in favour of high-risk sites, but the bias is comparatively small and will, at least for road sections, not be associated with a very large regression-to-the-mean effect.

The data referring to roundabouts were analysed in greater detail for the purpose of identifying variables predicting the efficient selection of junctions for conversion to roundabouts (Elvik 2004B). The term efficient selection, as opposed to inefficient selection, refers to the selection of junctions that can be converted to roundabouts cost-effectively, i.e. at a cost smaller than the benefits of the conversion.

The analysis found that current selection of roundabouts for treatment is somewhat inefficient. For three-leg junctions benefits were smaller than costs in 13 junctions out of 27 converted. The conversion of these junctions to roundabouts accounted for 60% of the total costs of converting the junctions to roundabouts. These findings are illustrated in Figure 4.

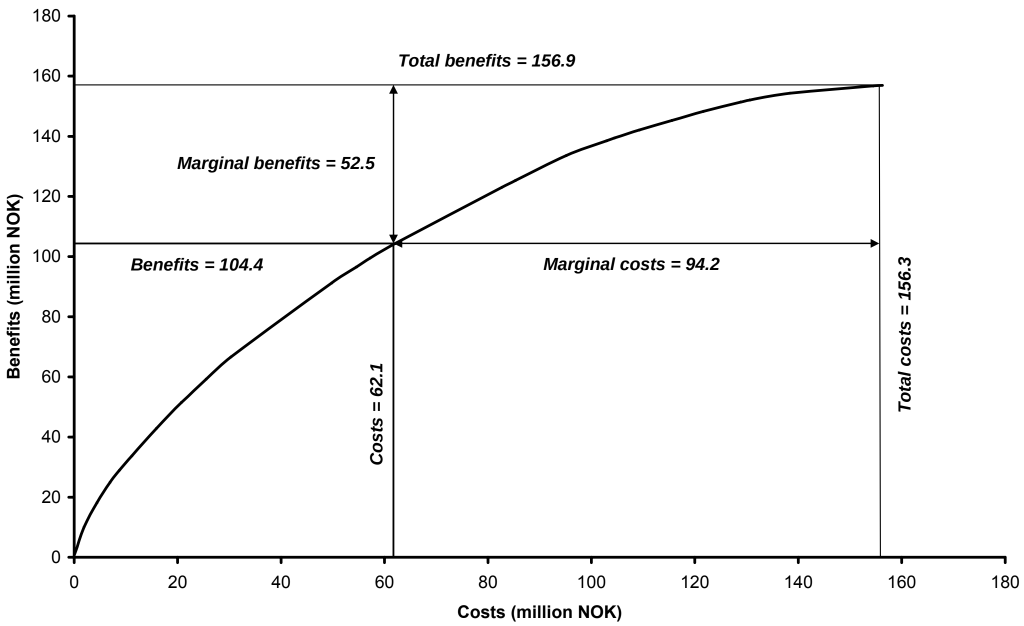

Figure 4: Costs and benefits of converting 27 three-leg junctions to roundabouts. Source: Elvik 2004B

The benefit-cost ratio of converting three-leg junctions to roundabouts was only weakly correlated with factors one might expect to influence it. Pearson's r was .044 for AADT, -.062 for the expected number of injured road users, and -.327 for the cost of conversion. One would, ceteris paribus, expect benefit-cost ratio to correlate strongly with traffic volume (AADT) and the number of injured road users.

In short, the data describing the actual selection of sites for treatment were strongly influenced by random variation and by unknown sources of site-to-site variation with respect to, for example, the cost of the measures and the level of accident risk. It is therefore not possible to model an efficient selection of sites for treatment based on data referring to the actual selection of sites for treatment. The analyses presented in this report are based on a general model of selection for treatment, designed to support marginal analysis of road safety measures.

5.3 The logic of marginal analysis of road safety measures

A marginal analysis of road safety measures is an analysis of their marginal costs and benefits. The objective of such an analysis is to determine the optimal use of road safety measures. The term optimal use refers to a maximally efficient use of road safety measures, i.e. using the measures in a way that maximises the benefit-cost ratio, and ensures that no measures are used unless the marginal benefits are equal to or exceed the marginal costs. In the following, the main stages of a marginal analysis of road safety measures will be described and illustrated for road-related road safety measures.

The first stage of analysis, at least for measures related to road design or traffic control, is to estimate the number of sites that are candidates for a certain road safety measure. To estimate the number of candidate sites, an inventory of sites is needed. Moreover, for each site, the road safety measures that have already been introduced at the site must be known. Table 4 shows an example of such data for junctions on national roads in Norway. The data have been extracted from the national road data bank.

Table 4: Junctions on national roads in Norway by safety measure

	Traffic volume (AADT)						
Junctions by measure	**0-1499**	**1500-3999**	**4000-7999**	**8000-11999**	**12000-19999**	**20000-39999**	**40000-**
All junctions on national roads	5824	5499	3082	1626	1213	339	70
Channelised junctions (islands)	142	185	293	231	272	93	1
Channelised junctions (paint)	72	183	138	69	120	17	0
Roundabouts	57	80	144	132	174	53	2
Signalised junctions	0	0	60	250	550	100	40
No measure in junction	5553	5051	2447	944	97	76	27
Candidates (for any measure)	4440	4000	2000	750	75	60	20

The first row of Table 4 shows the total number of junctions on national roads in Norway by traffic volume. The following rows shows the number of junctions in which various road safety measures have been introduced. The bottom row shows the estimated number of junctions that are candidates for any measure. A similar table has been developed for road sections.

The second stage of marginal analysis of road safety measures is to determine criteria for the selection of sites for safety measures. Traffic volume is known to be the single most important factor influencing the number of accidents. Hence, traffic volume has been used as the selection criterion.

Detailed information about each site that is a candidate for treatment is not available. The distribution of sites by number of accidents is not known in detail. It is, however, known that the distribution tends to be skew. This means that a minority of locations will have a substantially higher expected number of accidents than the mean expected number of accidents for all similar locations. A majority of locations will have a lower expected number of accidents than the mean for all locations. The road shown in Figure 3 is good example. 35 kilometres of that road, of the total of 55 kilometres, had a lower expected number of accidents than the mean for the whole road (4.68). Only 12 kilometres of road (shaded grey in Figure 3) had a substantially higher expected number of accidents than the mean value.

Although there is a tendency to select sites that have a high number of accidents for treatment, this tendency is bound to be attenuated as more and more sites are selected. It is logically impossible for all sites to have a higher expected number of accidents than the mean value in the population of sites. In the analyses, it has therefore been assumed that sites are selected for treatment according to traffic volume and that the selected sites have accident rates that are close to the mean value for the population of sites. By making this assumption, one does not need to know the distribution of the expected number of accidents in the population of sites. Moreover, the assumption is likely to be conservative, meaning that the potential for improving safety is not overestimated.

The third stage of marginal analysis is to specify the shape of the relationship between traffic volume (the selection criterion) and the number of accidents or injured road users. This relationship is often non-linear and can be modelled by a function of the form:

Number of accidents = $\boldsymbol{Q^{\beta}}$

Q is traffic volume, indicated by, for example Annual Average Daily Traffic (AADT). β is a coefficient describing the shape of the relationship between traffic volume and the number of accidents. If β is less than 1, the number of accidents increases by a smaller percentage than traffic volume. If β is 1, the number of accidents is proportional to traffic volume. If β is greater than 1, the number of accidents increases by a greater percentage than traffic volume. The value of β has been found to vary, depending on the type of accident (Fridstrøm 1999). Different values of β have therefore been used for different types of accident.

Accident severity also tends to vary, depending on the type of accident. Different distributions of accident victims by injury severity have been used for different types of accident.

The fourth stage of marginal analysis is to specify the relationship between traffic volume and the cost of road safety measures. If costs vary according to traffic volume, this has been modelled statistically. The data used to model the relationship between traffic volume and the cost of measures were taken from the survey of the actual selection of sites for treatment in Norway (Elvik 2004B).

The fifth stage of marginal analysis is to specify accident modification functions for each road safety measure. An accident modification function is a function that describes the effect of a road safety measure on target accidents or injuries as a result of factors that influence the size of the effect. For example, a meta-regression analysis (Elvik 2003A) was performed in order to estimate how the effects of converting junctions to roundabouts vary, depending on: (1) The size of the roundabout, (2) Type of traffic control before conversion, (3) Number of legs in the junction (3 or 4), (4) Country where the study was made, (5) Study design, and (6) Accident severity. Parameters were estimated for each of these variables. Effects can then be estimated for any combination of values for these variables. This enables a detailed description of the effects of converting junctions to roundabouts.

Ideally speaking, the effects of road safety measures should be described in terms of continuous functions of all variables that influence these effects. At the present state of knowledge, continuous accident modification functions are hardly available at all. In most cases, the effects of a road safety measure is stated simply as the percentage change in the number of accidents associated with the measure, e.g. : "Measure X reduces accidents of type A by 25 percent". This is a very crude way of representing the effects of road safety measures.

In the analyses presented in this report, an attempt has been made to develop estimates of effect that vary, depending on injury severity and the "dose" of the road safety measure. The concept of dose refers to the amount or standard of the measure. The concept is perhaps best applied to police enforcement. The amount of enforcement can be described in terms of the size of the police force deployed and the duration of their activities. One would then expect a large dose of enforcement to have a greater effect than a small dose of enforcement.

The sixth stage of marginal analysis of road safety measures is to model how the effects of several measures affecting the same target accidents combine. The combined effect of several road safety measures has traditionally been estimated by assuming that effects are independent and combine multiplicatively. This model, termed the common residuals model, was discussed in section 4.1, where it was applied to make the baseline forecast. The same model, modified by a power term representing the dominant road safety measure, has been applied to estimate the combined effects of road safety measures constituting a long-term programme.

To summarise, the key features of the approach taken to the marginal analysis of road safety measures in this report are:

1. The number of sites that are candidates for introduction of a road safety measure has been estimated on the basis of the national road data bank.
2. Sites are selected for treatment on the basis of traffic volume. The first site selected has the highest traffic volume, the next site selected has the next to highest traffic volume, etc, until a traffic volume is reached for which the marginal benefits equal the marginal costs of the measure.
3. The relationship between traffic volume and the expected number of accidents or injured road users is modelled by means of functions allowing for non-linearity.
4. Sites selected for treatment are assumed to have accident- or injury rates that are close to the mean values for the population of sites.
5. Account is taken of the fact that injury severity varies between different types of accident.
6. Account is taken of the fact that the costs of road safety measures may vary depending on traffic volume.

Figure 5 gives an example of the results of a marginal analysis. The example refers to conversion of three-leg junctions to roundabouts. Costs are shown on the abscissa, benefits on the ordinate. Marginal benefits equal marginal costs at an AADT of 9,500. The represents the limit for the optimal use of the measure. When used optimally, benefits (present value) are 4504 million NOK, costs are 2419 million NOK. Benefit-cost ratio is 1.86. The marginal benefit-cost ratio at this point is, of course, 1.00.

If conversion of three-leg junctions to roundabouts go beyond the optimal level, the marginal benefit-cost ratio declines rapidly. Total benefits, however, remain greater than total costs until the uppermost right point of the curve shown in Figure 5 is reached.

The curve in Figure 5 is almost perfectly described by the function ($R^2 = 0.9992$):

$$\text{Benefits} = 91.635 \cdot \text{Costs}^{0.5016}$$

By differentiating this function, one may locate exactly the point at which marginal benefits equal marginal costs. Moreover, this point can be shifted to account for the fact that the marginal benefits of a given measure are reduced when it is combined with one or more other road safety measures. The first derivative is:

$$\text{Marginal benefits} = (91.635 \cdot 0.5016) \cdot \text{Costs}^{-0.4984}$$

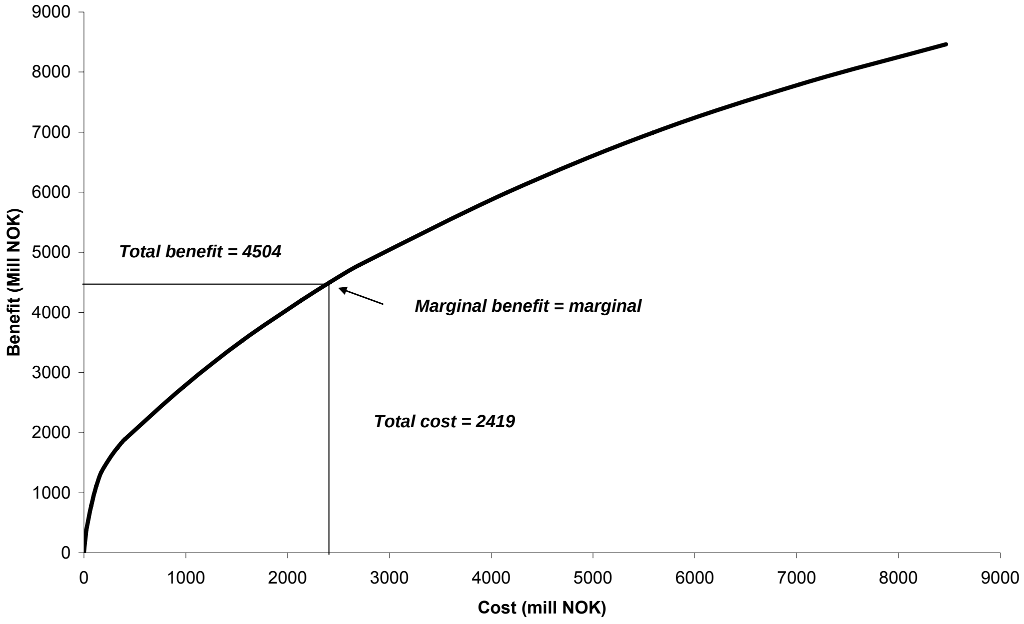

Figure 5: Costs and benefits of converting three-leg junctions to roundabouts estimated according to a model of optimal use of road safety measures

As far as vehicle-related safety measures are concerned, it has been assumed that these will be introduced for new vehicles from a certain date. They will then spread in the vehicle fleet as it turns over. Complete turnover is assumed to take 18 years. It has been assumed that marginal benefits are greatest for new vehicles and decline as vehicles age, since new vehicles are driven longer annual distances than older vehicles.

Enforcement-related measures are described in terms of dose-response relationships. These relationships also display diminishing returns to scale, analogous to the corresponding relationships for road-related and vehicle-related road safety measures. The dose-response relationships are uncertain. Uncertainty is further discussed in Chapter 7.

6 Estimating expected effects of road safety measures

6.1 First order effects of road safety measures included in analysis

Table 5 presents the estimates of the first order effects of the road safety measures that have been included in the impact assessment. Most of the estimates of effect are based on the Handbook of Road Safety Measures (Elvik and Vaa 2004).

The effects of road safety inspections refer to measures that are introduced as a result of such inspections. The estimates are conservative. They have been derived from a recent report on safety effects of road safety inspections (Elvik 2006).

Effects of eCall, or automatic accident notification, have been estimated on the basis of a recent review of relevant studies (Erke 2007). This estimate is highly uncertain, as eCall is still not widely used.

Effects of median guard rails refer to guard rails installed on two- or three-lane rural roads to prevent, or reduce the severity of, head-on accidents. The estimates have been derived from a Swedish evaluation study (Carlsson and Brüde 2005).

Effects of pedestrian reflective devices have been estimated on the basis of a Swedish study (Andersson et al 1998) and a crude estimate of effects derived from Norwegian accident statistics. Observations made in traffic in Norway in 2004 found that 16% of pedestrians wore a reflective device in the dark. Among pedestrians killed or injured, the proportion is even lower. By combining the roadside observations and accident statistics, the effects of wearing a reflective device were estimated to a reduction of the number of killed pedestrians in darkness of about 76 %, a reduction of the number of seriously injured pedestrians of 65 % and a reduction of the number of slightly injured pedestrians of about 54%. These estimates are likely to exaggerate the true effects of reflective devices; hence the more conservative estimates of Andersson et. al. were preferred.

The effects of seat belt reminders and seat belt ignition interlocks have been derived from estimates of the effects of wearing seat belts. The effects of seat belt reminders are taken to be slightly smaller than the effects of an ignition interlock, because a reminder can be ignored, whereas an interlock makes it impossible to drive the car without fastening the seat belt(s).

The studies of Jones (1987), Riley et. al. (1987) and Robinson and Riley (1991) have been used as the basis for estimating the effects of front impact protection for trucks.

Table 5: First order effects of road safety measures included in impact assessment

		Percentage change in the number of road users injured by injury severity		
Measure	**Target accidents**	**Killed**	**Seriously injured**	**Slightly injured**
Road safety inspections	All accidents	-15	-10	-5
Pedestrian bridge or tunnel	Pedestrians crossing road	-80	-80	-80
Motorways	All accidents	-57	-60	-49
Bypasses	Accidents in towns bypassed	-25	-25	-25
Roundabouts (T-junctions)	Accidents in junctions	-49	-33	-31
Roundabouts (X-junctions)	Accidents in junctions	-64	-53	-51
Roadside safety treatment	Running-off-the-road	-22	-22	-22
Rehabilitation of roads	Non-junctions accidents	-20	-20	-20
Guardrails along roadside	Running-off-the-road	-45	-45	-40
Median guard rails	Head-on accidents	-80	-45	+10
Median rumble strips (wide)	Head-on accidents	-23	-16	-8
Horizontal curve treatment	Accidents in curves	-29	-23	-16
Road lighting (new)	Accidents in darkness	-64	-45	-26
Upgrading road lighting	Accidents in darkness	-30	-20	-10
Environmental streets	Accidents in small towns	-28	-20	-10
Traffic signals (T-junctions)	Accidents in junctions	-15	-15	-15
Traffic signals (X-junctions	Accidents in junctions	-30	-30	-30
Signalised pedestrian crossing	Pedestrians crossing road	-12	-12	-12
Lowering of speed limits	All accidents	-13	-8	-4
30 km/h speed zones	All accidents	-50	-37	-21
Upgrading pedestrian crossing	Pedestrian crossing road	-50	-37	-21
Feedback signs for speed	All accidents	-25	-18	-9
E-call (accident notification)	Accidents in rural areas	-3	0	0
Pedestrian reflective devices	Pedestrian accidents at night	-50	-40	-30
Electronic stability control	Head-on and run-off-road	-25	-15	-5
Bicycle helmets	Bicycle accidents	-20	-10	-2
Seat belt reminders	Car accidents (belt not worn)	-48	-43	-24
Seat belt ignition interlock	Car accidents (belt not worn)	-50	-45	-25
Neck injury protection	Rear-end car accidents	-50	-50	-20
Intelligent cruise control	Rear-end car accidents	-50	-37	-24
Intelligent speed adaptation	All accidents	-21	-15	-8
Truck front impact protection	Head-on accidents (trucks)	-20	-15	-10
Accident data recorder	All accidents	-7	-7	-7
Front and bumper standards	Pedestrian accidents	-7	-21	+9
Euro NCAP upgrading	All accidents	-19	-19	0
Ignition interlock for alcohol	Accidents involving alcohol	-50	-50	-50
Accompanied driving	Accidents involving young	-12	-12	-12
Elderly driver retraining	Accidents involving elderly	-20	-20	-20
Inspections of heavy vehicles	Heavy vehicle accidents	-1	-1	-1
Service and rest hour checks	Heavy vehicle accidents	-2	-2	-2
Speed enforcement	All accidents	-3	-2	-1
Drink-driving enforcement	Accidents involving alcohol	-37	-37	-37
Seat belt enforcement	Car accidents	-5	-3	-1
Speed cameras	All accidents	-15	-10	-5
Section control	All accidents	-17	-11	-6

A Dutch study (Wouters and Bos 1997; 2000) evaluated the effects of accident data recorders. The results of that study have been re-analysed to obtain the estimate presented in Table 5.

Effects of new standards for front and bumper to reduce pedestrian injury have been estimated on the basis of a study by Lawrence et al (1993). The effects of Euro NCAP upgrading refer to advancing by about 1.5 stars. Effects have been estimated by Lie and Tingvall (2001). Estimates of the effects of alcohol ignition lock is based on a study by Bjerre (2005). A recent study by Ulleberg (2006) evaluated the effects of elderly driver retraining.

For several measures, estimates of effect vary according to injury severity. In most cases, these estimates have been derived on the basis of the Power model of the relationship between speed and road safety (Elvik, Christensen and Amundsen 2004).

For some measures, effects vary according to the "dose" of the measure (this applies to police enforcement). Effects stated in Table 5 refer to the optimal dose of the measure, i.e. the dose for which marginal benefits equal marginal costs.

6.2 Model for estimating expected affects on road safety

The basic model for estimating the first order effects of each measure is:

Number of injured road users prevented at a specific level of injury severity = Travel exposure x Injury risk x Scale of use x First order effects

As an illustration, consider the conversion of three-leg junctions to roundabouts. There are 120 candidates for conversion at an AADT of 12,000. The injury rate at this AADT is 0.091. Thus for fatalities, the estimation becomes:

12,000 x 365 x 120 x 0.091 x 10^{-6} x 0.018 x 0.49 = 0.42 fatalities prevented per year.

12,000 is the number of vehicles passing the junctions each day, 365 the number of days per year, 120 the number of junctions converted, 0.091 x 10^{-6} the mean injury risk per million entering vehicles, 0.018 the proportion of injuries that are fatal, and 0.49 the reduction of the expected number of fatalities (49% reduction).

Similar models have been used for all measures. For road related measures, scale of use refers to the number of sites where a certain measure is introduced, i.e. the number of junctions, number of curves or kilometres of road. For vehicle related measures, it has been assumed that the entire vehicle fleet turns over in 18 years, and that new car are driven longer distances than older cars. Scale of use for vehicle related measures refers to their market penetration rate. This has been assumed to be 10% the first year, 19% the second year, 27% the third, and so on, reaching 100% the eighteenth year.

For enforcement related measures, scale of use refers to increase from the current level. This is stated as a percentage increase. Thus, doubling the level of enforcement is equal to a 100% increase.

6.3 Estimated first order effects of road safety measures included in analysis

Table 6 shows first order effects of all measures at their optimal level of use in Norway. Measures that were found not to be cost-effective, i.e. costs were greater than benefits, are not listed. Estimates of effects apply to the year 2020 and show the effects gained in that year as a result of using the measures during the period 2007-2020. A total of 39 measures are listed in Table 6. 45 measures were included in the formal impact assessment. 6 of these were found to be cost-ineffective:

Motorways
Environmental streets
Signalised pedestrian crossings
30 km/h zones in urban areas
Seat belt ignition interlock (dominated by seat belt reminders)
Intelligent cruise control

The largest effect on safety was estimated for Intelligent Speed Adaptation (ISA). The estimate refers to a system that makes it impossible to exceed the speed limit. Such a system will eliminate speeding. Various versions of ISA have been tested in Sweden, Great Britain, and the Netherlands. Technically reliable systems based on digital maps are now available.

Potentially large contributions to improving road safety can also be gained from electronic stability control, increased drink-driving enforcement and seat belt reminders. For most of the road safety measures listed in Table 5, their estimated contribution to improving road safety is quite small. Hence, to realise a substantial improvement, it is necessary to use several measures. When combining several road safety measures, one should take care not to include more than one measure addressing the same problem; otherwise there is a risk of double counting potential safety benefits. This is why seat belt ignition interlocks were left out, since their additional contribution is minor, given the fact that seat belt reminders are becoming more common.

Increasing speed enforcement and introducing ISA are alternative measures to influence the same problem. If one of them is introduced, the other is less needed and will be less effective. Several of the road safety measures listed in Table 6 are substitutes for one another in this sense. One would clearly double count the opportunities for improving road safety by including all measures that may substitute for each other. For instance, seat belt wearing may be increased by seat belt reminders, seat belt ignition interlock or seat belt enforcement. It makes little sense, however, to include all three measures in an estimate of the total effects that can be attained by combining several road safety measures.

How best to estimate the effects of combining several road safety measures is discussed more in detail in Chapter 7.

Table 6: First order effects of road safety measures included in impact assessment – effects in 2020

		Estimated reduction in the number of road users injured by injury severity (negative = increase)		
Measure	**Target accidents**	**Killed**	**Seriously injured**	**Slightly injured**
Road safety inspections	All accidents	3.1	5.3	16.7
Pedestrian bridge or tunnel	Pedestrians crossing road	3.3	10.6	52.3
Bypasses	Accidents in towns bypassed	0.2	1.3	13.5
Roundabouts (T-junctions)	Accidents in junctions	1.9	6.1	59.9
Roundabouts (X-junctions)	Accidents in junctions	3.0	12.0	120.1
Roadside safety treatment	Running-off-the-road	0.5	2.1	12.4
Rehabilitation of roads	All accidents	1.0	3.2	19.6
Guardrails along roadside	Running-off-the-road	1.3	5.3	27.9
Median guard rails	Head-on accidents	1.7	2.5	-2.1
Median rumble strips	Head-on accidents	1.0	1.7	3.4
Horizontal curve treatment	Accidents in curves	1.4	3.4	11.2
Road lighting (new)	Accidents in darkness	10.9	26.5	97.0
Upgrading road lighting	Accidents in darkness	0.8	1.8	5.5
Traffic signals (T-junctions)	Accidents in junctions	0.0	0.1	1.6
Traffic signals (X-junctions)	Accidents in junctions	0.2	0.8	8.5
Lowering of speed limits	All accidents	3.2	4.7	18.3
Upgrading pedestrian crossing	Pedestrian crossing road	5.4	12.7	35.7
Feedback signs for speed	All accidents	1.4	2.5	7.8
E-call (accident notification)	Accidents in rural areas	4.9	0.0	0.0
Pedestrian reflective devices	Pedestrian accidents at night	5.6	11.8	39.9
Electronic stability control	Head-on and run-off-road	34.5	81.2	337.4
Bicycle helmet law	Bicycle accidents	1.3	2.4	3.2
Seat belt reminders	Car accidents (belt not worn)	11.7	35.9	101.0
Neck injury protection	Rear-end car accidents	2.3	23.0	230.9
Intelligent speed adaptation	All accidents	43.5	126.0	757.9
Truck front impact protection	Head-on accidents (trucks)	6.9	9.1	47.5
Accident data recorder	All accidents	14.5	56.8	630.0
Front and bumper standards	Pedestrian accidents	1.8	19.4	-55.9
Euro NCAP upgrading	All accidents	13.7	49.1	0.0
Ignition interlock for alcohol	Accidents involving alcohol	7.5	19.6	108.7
Accompanied driving	Accidents involving young	3.0	16.9	161.5
Elderly driver retraining	Accidents involving elderly	0.2	1.0	6.8
Inspections of heavy vehicles	Heavy vehicle accidents	0.6	1.1	7.0
Service and rest hour checks	Heavy vehicle accidents	1.1	1.9	12.4
Speed enforcement	All accidents	7.2	21.3	146.5
Drink-driving enforcement	Accidents involving alcohol	22.1	44.3	250.9
Seat belt enforcement	Car accidents	5.7	17.5	48.4
Speed cameras	All accidents	1.6	3.5	12.7
Section control	All accidents	0.9	2.2	8.9

6.4 Limitations of the current way of representing effects of road safety measures

As noted previously, the most common way of representing the effect of a road safety measure is by means of a single point estimate of its effect – an accident modification factor (AMF). This is a very crude, and potentially misleading, way of representing the effects of many road safety measures. The effects of most road safety measures are likely to vary, depending on, among other things:

- The standard to which the measure is designed (high-standard road lighting will be more effective than low-standard road lighting)
- How widely it is used (signs warning of hazardous curves are likely to become ineffective if they are put up in front of every curve, but may remain effective if used more selectively)
- Traffic volume (converting to roundabouts may be more effective at high volumes and a high proportion of vehicles entering from the minor road)
- Prevalence of target risk factors (speed enforcement may be more effective on roads that have a speeding problem than on roads that do not)
- Dominant accident pattern (traffic signals are likely to be more effective when right-angle collisions dominate than when rear-end collisions dominate)
- Road user characteristics (fragility could make protective devices, e.g. helmets, more effective for elderly road users than for young people)
- The use of other road safety measures (pedestrian reflective devices are likely to be less effective on well-lit roads than on unlit roads)

To account for such sources of systematic variation in the effect of road safety measures, their effects should be represented as continuous functions, accident modification functions (also abbreviated as AMF). At the present state of knowledge, few such functions are known. For an attempt to develop accident modification functions, see Hirst et. al (2005) and Mountain et. al. (2005)

Uncertainty with respect to sources of variation in the effects of measures is discussed in Chapter 7.

7 Sources of uncertainty and their treatment

7.1 An inventory of sources of uncertainty in road safety impact assessments

Elvik and Amundsen (2000) list the most important sources of uncertainty in road safety impact assessments. They include:

1. Uncertainty in the definition of the target group of accidents or injuries affected by each road safety measure
2. Random variation in the number of accidents or injuries affected by each road safety measure
3. Incomplete and variable reporting of accidents or injuries in official accident statistics
4. Random variation in the estimated effect of each road safety measure on the number or severity of accidents or injuries
5. Unknown sources of systematic variation in the effects of each road safety measure on the number or severity of accidents or injuries
6. Incomplete knowledge with respect to how the effects of each road safety measure are modified when it is combined with other road safety measures to form a strategy consisting of several measures affecting the same group of accidents or injuries
7. Uncertain estimates of the societal costs of accidents or injuries and the value of preventing them
8. Uncertainty with respect to the duration of the effects of each measure on accidents or injuries

The contribution of each of these sources of uncertainty can to some extent by estimated, but the joint contribution of all sources of uncertainty is virtually impossible to estimate at the current state of knowledge. Models for estimating compound errors have been developed in statistics, but these models are very complex when the different sources of uncertainty are correlated. The extent to which the sources of uncertainty listed above are correlated is not known.

This report will not discuss each of the sources of uncertainty in detail, but will go into just a few of them. More specifically, small studies that have been made to determine uncertainty with respect to systematic variation in the effects of measures (item 5), the combined effects of road safety measures (item 6), the monetary valuation of road safety (item 7) and the duration of effects (item 8) will be presented.

7.2 The possibility of estimating the contributions of various sources of uncertainty

In order to estimate the combined contribution of several sources of uncertainty to the total uncertainty in the estimated benefits and costs of a road safety programme, the elementary model for the propagation of errors has been applied (Rasmussen 1964, Strand 1987, Elvik 1993):

$$Var(R) = \left(\frac{\partial R}{\partial X}\right)^2 Var(X) + \left(\frac{\partial R}{\partial Y}\right)^2 Var(Y) + ... + \left(\frac{\partial R}{\partial W}\right)^2 Var(W)$$

It is assumed that the value of R can be written as a function of several variables:

$R = f(X, Y, ... W)$

This assumption is not restrictive, as all elementary mathematical operations (adding, subtracting, multiplying and dividing), as well as operations derived from these (exponentiating, taking square roots, etc) can be written as functions. The elementary model for the propagation of errors (compounding of uncertainties) is shown in reduced form. The reduced form assumes that the uncertainties of each of the items are uncorrelated with each other.

The estimate of the benefits of each road safety measure is the result of a multiplication. In the multiplication R = A · B, the partial derivatives are:

$$\frac{\partial R}{\partial A} = B \text{ and } \frac{\partial R}{\partial B} = A$$

This makes estimation of compound uncertainty easy, by proceeding in stages term by term. However, the shape of the distributions of the various uncertain items is not well known. Estimates of variance can nevertheless be produced for several items.

7.3 Systematic variation in the effects of road safety measures

As mentioned in Chapter 6, the effects of road safety measures are likely to vary, but these variations are currently not sufficiently known to be represented in terms of continuous functions except in a few cases. To illustrate the variations, and the uncertainty inherent in them, a couple of examples will be given.

The first example concerns roundabouts. A predictive equation was developed by means of meta-regression (Elvik 2003A) to estimate the effects of converting junctions to roundabouts as a function of: (1) The size of the roundabout (four categories), (2) Previous type of traffic control (yield or signals), (3) Number of legs (3 or 4), (4) Country in which evaluation study was made, (5) Design of evaluation study, (6) Injury severity.

Keeping country and study design constant, the effect on fatalities of converting a signal controlled three leg junction to a small roundabout can be estimated to a reduction of 21 %. The corresponding effect of converting a yield controlled four leg junction to a large roundabout can be estimated to a fatality reduction of 72 %.

This is very large difference. It shows that one must expect the effects of converting junctions to roundabouts to vary systematically, depending on number of legs, type of traffic control, size of the roundabout and injury severity. In the estimates made in this report, account was taken only of number of legs (3 or 4) and injury severity. The other factors associated with the effects of roundabouts were disregarded. This obviously means that strict optimisation cannot be achieved at an aggregate level of analysis, as it is difficult to incorporate into such an analysis all factors that influence the size of the effect of a road safety measure.

The second example concerns police enforcement. A dose-response pattern has been applied, meaning that the percentage effect on accidents or injuries of a large increase in enforcement has been assumed to be greater than the percentage effect of a small increase in enforcement. The knowledge supporting this assumption is, however, quite uncertain and based on rather few studies. Figure 6 shows estimates of percentage changes in the number of injury accidents, derived from studies that state changes in the amount of enforcement.

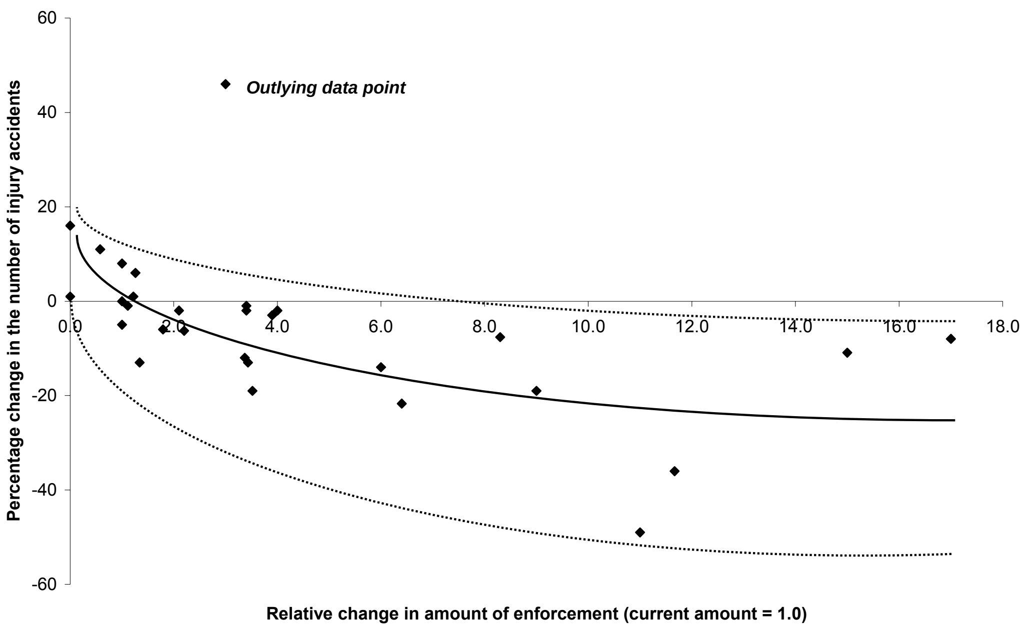

Figure 6: Variation in effects of police enforcement depending on the amount of enforcement

A solid curve has been drawn by hand in the Figure to indicate the main thrust of the findings. Dotted curves surrounding it encapsulate all data points except for a single outlying data point that has been identified in the Figure. Despite the large spread of the data points, there is a visible systematic pattern. Increasing amounts of enforcement are associated with increasing percentage accident reductions, but there are diminishing returns to scale. Except for the outlying data point, the number of accidents is always reduced if enforcement is at least doubled. When enforcement is reduced (values to the left of 1 on the abscissa), there is always an increase in the number of accidents. Thus, despite the large element of uncertainty, the results make sense and support the use of a dose-response function to describe the safety effects of changes in the amount of enforcement.

7.4 An exploratory analysis of models for estimating the combined effects of road safety measures

As explained in Chapter 2 of the report, the common residuals method is widely used to estimate the combined effects of several road safety measures. This method relies on the assumption that the percentage effect of a given road safety measure is independent of the percentage effect of other road safety measures with which it is combined in a road safety programme.

This model is, however, just one of several models that can be imagined for estimating the combined effects of several road safety measures. Table 7 shows estimates of the combined effects of two road safety measures according to different assumptions regarding how their individual effects combine.

Table 7: Models for estimating the combined effects of road safety measures

Model of combined effects	Measure A	Measure B
Accidents affected	100 accidents before any measure is introduced	
First order effect (%)	-40	-30
First order residual (proportion)	0.60	0.70
Model 1: Additive effects	70 accidents prevented, 30 remaining	
Model 2: Independent effects	58 accidents prevented, 42 remaining	
Model 3: Correlated effects	50 accidents prevented, 50 remaining	
Model 4: Dominated effects	40 accidents prevented, 60 remaining	

If the effects of the two measures are additive (model 1), the number of accidents prevented by one measure can be added to the number of accidents prevented by the other measure. Their combined effect is to prevent 70 of the 100 accidents that are affected.

If the effects are independent, as assumed in this report, the combined effect is estimated according to the method of joint residuals. This results in a combined effect of $1 - (0.60 \cdot 0.70) = 1 - 0.42 = 0.58 = 58$ accidents prevented and 42 remaining.

In many cases, however, an assumption of independent effects may be too optimistic. Once one of the measures has been introduced, the other is less effective. If a moderate negative correlation between effects is assumed, the combined effect may be that 50 accidents are prevented and 50 remain.

The most pessimistic model is that once the most effective of the two measures has been introduced (measure A), the other measure has no effect at all. In that case, only 40 accidents will be prevented and 60 will remain.

It is not known which of these models, or possibly another model not listed in table 7, is most correct. Model 2, assuming independent effects, has traditionally been used for its simplicity and because it is not positively known to be wrong. It is nevertheless instructive to explore briefly the implications for the results of adopting a different model, or a mixture of the models listed in Table 7.

Table 8 shows results of five studies that have evaluated the effects of multiple treatments applied at the same location, or similar locations. The oldest study is a study by Bali et. al. (1978) of the effects of various road markings. The study employed a cross-sectional design and compared accident rates at locations that had different combinations of road marking treatments. Care was taken to ensure that the locations were as similar as possible with respect to all other characteristics that might influence safety. Whether this procedure successfully eliminated all confounding is not a key issue in the present context. Here, the study is of interest mainly because it enables a comparison of the effects of 1, 2 or 3 road marking treatments.

The second study is an evaluation of various junction improvements by Brüde and Larsson (1985). The study employed a before-and-after controlling for regression-to-the-mean and long-term trends. Ten types of treatment were defined. Unfortunately, the number of accidents in many of the ten groups is too small to consider them separately; hence mean estimates of effect have been developed for all types of treatment put together. Up to ten different treatments were introduced in the same junction. In Table 8, comparisons are made of the estimated mean effects of 1, 2, 3, 4 and 5 or more (mean 5.71) treatments at the same site.

The third study was reported by Bach and Jørgensen in 1986. It refers to treatments in signalised junctions and enables a comparison of the effects of 1 and 2 treatments. The study was a before-and-after study controlling for long-term trends, but not for regression-to-the-mean. The fourth study, by Kulmala (1995) evaluated a number of junction treatments. The study employed the empirical Bayes method to control for regression-to-the-mean and long-term trends. Like the study of Brüde and Larsson (1985), the number of accidents for each type of treatment as too small to evaluate the difference in effect between a single treatment and two treatments. All types of treatment were therefore analysed together.

The fifth study, by Gitelman et. al. (2001) was a before-and-after employing the empirical Bayes technique to evaluate a number of junction treatments in Israel. The study controlled for regression-to-the-mean and long-term trends. It enables a comparison of the effects of 1, 2 or 3 treatments.

Table 8: Accident modification factors in studies that have evaluated the effects 1, 2 or multiple safety treatments at the same or similar locations

		Accident modification factors		Method of estimating combined effects	
Study	**Number of treatments**	**Mean estimate**	**Range of estimates**	**Common residuals**	**Dominant common residuals**
Bali et al 1978	1	0.804	0.682, 0.969		
	2	0.758		0.759	0.806
	3	0.545		0.518	0.638
	1	0.696	0.578, 0.858		
	2	0.569		0.566	0.687
	3	0.446		0.327	0.524
Brüde and Larsson 1985	1	0.856	0.513, 1.025		
	2	1.015		0.733	0.766
	3	0.556		0.627	0.671
	4	0.505		0.537	0.587
	5.71	0.500		0.412	0.468
Bach and Jørgensen 1986	1	0.770	0.540, 1.453		
	2	0.556		0.785	0.877
	1	0.881	0.835, 0.899		
	2	0.556		0.751	0.787
Kulmala 1995	1	0.942	0.357, 1.698		
	2	1.004		0.887	0.894
Gitelman et al 2001	1	0.949	0.603, 1.037		
	2	0.718		0.625	0.753
	1	0.797	0.771, 0.816		
	2	0.789		0.629	0.700
	1	0.787	0.771, 0.792		
	2	0.700		0.611	0.684
	1	0.794	0.771, 0.816		
	3	0.700		0.561	0.584
Simple combined estimates	1	0.858	0.755, 0.942		
	2	0.795		0.736	0.794
	3	0.584		0.632	0.707
	4	0.505		0.542	0.630
	5.71	0.500		0.417	0.517
Weighted combined estimates	1	0.759	0.755, 0.942		
	2	0.696		0.576	0.659
	3	0.511		0.437	0.535
	4	0.505		0.332	0.435
	5.71	0.500		0.207	0.305

Two sets of estimates have been derived from the study of Bali et. al. (1978). One of them refers to injury accidents, the other to property damage only accidents. As can be seen, two or three treatments are more effective than one. Applying the common residuals model to estimates of effect of a single treatment, the combined effect of two treatments can be estimated to 0.759 (0.782 · 0.969), which is very close to the observed effect of two treatments (0.758). Similarly, for three treatments, the combined effect is estimated to 0.518 (0.782 · 0.969 · 0.682). The observed effect of three treatments is 0.545.

In addition the common residuals model, an alternative model has been applied to estimate combined effects of several measures. This model is referred to in Table 8 as the dominant common residuals model. The basic idea underlying this model is that the most effective road safety measure in a set will to some extent dominate the others, by partly or fully influencing the same group of accidents or the same risk factors. In the study of Bali et. al., the accident modification factor for the most effective measure was 0.682. Thus, for the case of three treatments, the dominant common residuals model is: $(0.782 \cdot 0.969 \cdot 0.682)^{0.682} = 0.638$, which indicates a smaller combined effect of the three treatments than the common residuals model.

Corresponding estimates have been made for the other four studies listed in Table 8. For the study of Brüde and Larsson (1985), the common residuals model fits best for three or four treatments. The dominant common residuals model fits best for two or five or more treatments. The study of Bach and Jørgensen (1986) found two treatments to be considerably more effective than a single treatment, exceeding the combined effect as estimated both according to the common residuals model and the dominant common residuals model. In case of the study by Kulmala (1995), the dominant residuals model fits best. This study, somewhat inconsistently with most other studies, found two treatments to be less effective than a single treatment. Finally, results of the study of Gitelman et. al (2001) are closer to estimates based on the dominant common residuals model than to estimates based on the common residuals model.

An attempt has been made to synthesise the findings of all studies. All studies provide estimates of effect for a single treatment and two treatments. Three studies also provide estimates of effect for three treatments, but only the study of Brüde and Larsson (1985) provide estimates of effect for four or five or more treatments. If simple (unweighted) mean estimates of effect are used, the common residuals model predicts best the effects of three or four treatments, whereas the dominant common residuals model predicts best the effects of two or five or more treatments. If mean estimates of effect are weighted in inverse proportion to the sampling variance of the individual estimates, the dominant residuals model predicts best for all cases of multiple treatments.

While no model is clearly superior to the other, the dominant common residuals model appears to be slightly favoured. It has therefore been applied to estimate the effects of alternative road safety programmes in Chapter 9.

7.5 Uncertainty of monetary valuation of impacts of road safety measures

Monetary valuation of non-market goods, like a reduced number of fatalities and injuries in road traffic, is a key element of cost-benefit analysis. The valuations that have been applied in this impact assessment are those that are officially used in Norway. These valuations are, however, highly uncertain.

In a comprehensive meta-analysis, de Blaeij et. al. (2003) have summarised 95 estimates of the value of a statistical life in road safety. These estimates range from 143,000 US dollars (1997) to 25,949,000 US dollars. The mean value was 4.4 million US dollars (1997), the median value was 3.2 million US dollars. A meta-analysis was performed in order to identify sources of variation in the estimated value of a statistical life. Some sources were identified, but the study was not fully able to account for the observed variation. There are reasons to believe that a substantial part of it is related to methodological artefacts. Some of these may produce systematic errors, others merely introduce noise.

It is at the current state of knowledge difficult to fully quantify the uncertainty of monetary valuations of non-market goods in cost-benefit analyses of road safety measures. An attempt at quantification is made in section 7.7.

7.6 Uncertain duration of effects of road safety measures

How long do the effects of road safety measures persist? Are these effects constant, or do they change over time? No study provides satisfactory answers to these questions, since no study has attempted to evaluate the effects of road safety measures for more than about 5-10 years. Extending the duration of the study period makes it more difficult to control for confounding factors, in particular long-term trends unrelated to the effects of a specific measure. It is therefore likely that studies covering periods of, say, 15-20 years would be inconclusive.

Table 9: Percentage change in the number of injury accidents attributed to converting junctions to roundabouts in various Norwegian studies

Study	Percentage change in the number of injury accidents
Senneset 1983	−36
Johannessen 1985	−56
Nygaard 1988	−72
Giæver 1990	−47
Kristiansen 1992	−72
Seim 1994	−36
Oslo veivesen 1995	−51
Odberg 1996	−26
Giæver 1997	+25

An indirect way of obtaining information on the duration of the effects of road safety measures, is to compare the results of evaluation studies made at different times. Table 9 shows the results of a number of studies that have evaluated the effects of converting junctions to roundabouts in Norway.

The studies listed in Table did not all employ the same design. The results may therefore not be strictly comparable. Still, the trend for more recent studies to find smaller effects, or indeed adverse effects, of converting junctions to roundabouts is striking. This could suggest that the effects of converting junctions to roundabouts are becoming smaller.

7.7 The estimation of compound uncertainty: an example

As explained in Chapter 6, the benefits of each road safety measure can be modelled as the outcome of three major components:

Number of injured road users affected x Percentage effect of measure x Monetary valuation of fatalities and injuries prevented

The number of road users affected by a measure is the result of the size of the group exposed to risk and injury risk. To simplify, it will be assumed that both exposure and risk are known with certainty – which is obviously not the case, but is assumed for reasons of presentation.

Consider, as an illustration, minor improvements on roads with a daily traffic volume of 4,000. A total of 130 kilometres of road are regarded as eligible for treatment. It is estimated that 37.96 people can be expected to be injured annually on these roads. If it is assumed that injuries are the outcome of a Poisson process, the variance of the expected number of injured road users equals the expected number, i.e. 37.96.

The effect of the measure is to reduce the expected number of injuries by 20 %. According to Elvik and Vaa (2004), a 95 % confidence interval for the effect goes from an accident modification factor of 0.766 to 0.836. The variance of the estimate equals the inverse of the statistical weight it is based on:

Variance = 1/1974.872 = 0.00051

The best estimate of the number of injured road users prevented is:

$37.96 \cdot (1 - 0.80) = 7.592$.

We thus have:

Expected number of injured road users influenced (A) =	37.96
Variance of expected number of road users influenced Var (A) =	37.96
Estimate of effect of treatment (B) =	0.20
Variance of estimate of effect of treatment Var (B) =	0.00051

Applying the relationship that for a product $R = A \cdot B$:

$$\frac{\partial R}{\partial A} = B \text{ and } \frac{\partial R}{\partial B} = A$$

According to the general model for the propagation of errors we get:

$[(0.20 \cdot 0.20) \cdot 37.96] + [(37.96 \cdot 37.96) \cdot 0.00051] = 2.253$.

Thus the variance of the number of injured road users prevented is 2.253.

In principle, this variance should be estimated separately for each level of injury severity. However, since the main purpose of this exposition is to show the logic of the method, this will not be done.

The expected number of injuries prevented is multiplied by the societal cost of traffic injuries and by a constant that reflects the time horizon of the analysis and the discount rate. For the purpose of this analysis, this constant is treated as a parameter external to the analysis itself, and therefore known with certainty. Elvik et. al. (1994) discuss in detail sources of uncertainty in the valuation of non-market goods and the possibility of quantifying their contribution. As far as the cost of road accidents is concerned, it is concluded that the standard error of the mean, for the average cost of a police-reported injury accident, is equal to 16.2 % of the mean cost.

In the case of minor improvements (reconstruction and rehabilitation of roads), the mean value of an injury prevented is NOK 2,816,000. The variance can be estimated to: $2{,}816{,}000 \cdot (0.162 \cdot 0.162) = 74{,}000$.

The best estimate of the present value of safety benefits is:

$7.592 \cdot 2{,}816{,}491 \cdot 14.828 = 317.09$ million NOK. We thus have:

Expected number of injured road users prevented (A) =	7.592
Variance of expected number of road users prevented Var (A) =	2.253
Expected value of benefits of preventing one injury (B) =	2,816,000
Variance of value of benefits of preventing one injury Var (B) =	74,000

Again applying the general model for the propagation of errors we get:

$\{[(2{,}816{,}000 \cdot 2{,}816{,}000) \cdot 2.253] + [(7.592 \cdot 7.592) \cdot 74{,}000]\} \cdot 14.828 = 328.16$ million NOK

Taking the square root of this we get 18.11. Thus the benefits are estimated to 317.09 million NOK with a standard error (1 standard deviation for the best estimate) of 18.11.

8 Considerations relevant for decision making and implementation

8.1 Considerations included in, and excluded from, formal analyses of efficiency

Efficiency analysis, in particular cost-benefit analysis, is designed to answer the following question:

How can we spend scarce resources so as to get the largest possible total benefit out of them?

The scarce resources we are talking about here are private and public money that have numerous alternative uses. The benefits are improvements in road safety, but also, to the extent that policy objectives do not conflict, improvements in mobility, the environment and public health. Costs and benefits of alternative policy options are made comparable by measuring them in monetary terms. The question stated above is therefore how we ought to spend private and public funds so as to maximise total benefits for road safety and related transport policy objectives.

The answer to the question is to use all road safety measures according to the principle of marginal utility, i.e. apply them up to the point at which marginal benefits are equal to marginal costs. Such a use of road safety measures is termed optimal. When road safety measures are used optimally, the surplus of benefits over cost is maximised. This is he only admissible criterion according to economic welfare theory.

Policy based on this criterion of efficiency will disregard a number of considerations, including:

1. Who pays and who gets the benefits: It does not matter if those who pay are not the same individuals as those who get the benefits, as long as the benefits are sufficiently great that it is in principle possible for gainers to compensate losers. This criterion is usually regarded as satisfied if benefits are greater than costs.
2. Net changes in the distribution of cost and benefits: Although there is a requirement that those who gain from public policies should in principle be able to compensate those who lose, there is no requirement that compensation actually takes place. Hence, the net changes in the distribution of costs and benefits could be adverse, i.e. make unequal distributions not regarded as fair become more unequal.
3. Current allocation of spending: If the benefits of a measure are greater than the costs, it should be introduced. There is no consideration of the

current allocation of spending, for example, the current budgets allocated to public agencies. If a certain public agency has a large pool of cost-effective road safety measures within its jurisdiction, more than its current budgets allows it to introduce, the implication of efficiency analysis is that its budget is too small and should be increased. Conversely, the budgets of agencies that cannot spend all their money on cost-effective projects are too large and should be reduced. However, major reallocations of budgets between governmental agencies can be difficult and there are large rigidities in public resource allocation mechanisms.

4. Public acceptance: An efficient road safety measure need to be popular or enjoy public support. In fact, many road safety measures may represent so called social dilemmas (Dawes 1988). A social dilemma occurs when the benefits of a measures, as viewed from a private perspective, are smaller than the costs of the measure, whereas benefits are greater than costs if a societal perspective is adopted. Thus, for example, environmental gains from lowered speed limits will count as a societal benefit, but will not necessarily count as a private benefit from each motorists point of view.
5. Democratic process and legitimacy: Efficiency analysis is a technical analysis. It represents the input of technical experts into the policy making process. It has been argued (Nyborg and Spangen 2000) that cost-benefit analysis violates ideals of democratic decision making, and that its findings are often irrelevant from a political point of view (Sager and Ravlum 2005).

The fact that efficiency analysis disregards the above considerations means that the results of an efficiency analysis can never be the sole basis for decision making. In the next section, some considerations relevant to the implementation of road safety programmes developed by means of efficiency analyses are discussed.

8.2 Issues regarding implementation of road safety programmes

Figure 1 in Chapter 2 presented an analytical model of policy making, stressing the fact that this was an ideal model, not intended as a description of how policy making actually takes place. Figure 7 presents a more realistic model (Elvik and Veisten 2005). It will be briefly discussed in order to identify some issues regarding the implementation of road safety programmes that ought to be considered explicitly as part of the process of developing those programmes.

The first stage of political decision making is to develop an agenda, i.e. to identify the issues that need to be attended to and are regarded as important by the electorate and relevant political lobbies. Road safety is not an issue which is high on the political agenda in most highly motorised countries. Interest in road safety tends wax and wane in proportion to changes in the number of road accident fatalities. There may a temporary increase in interest if there is an increase in the number of road accident fatalities.

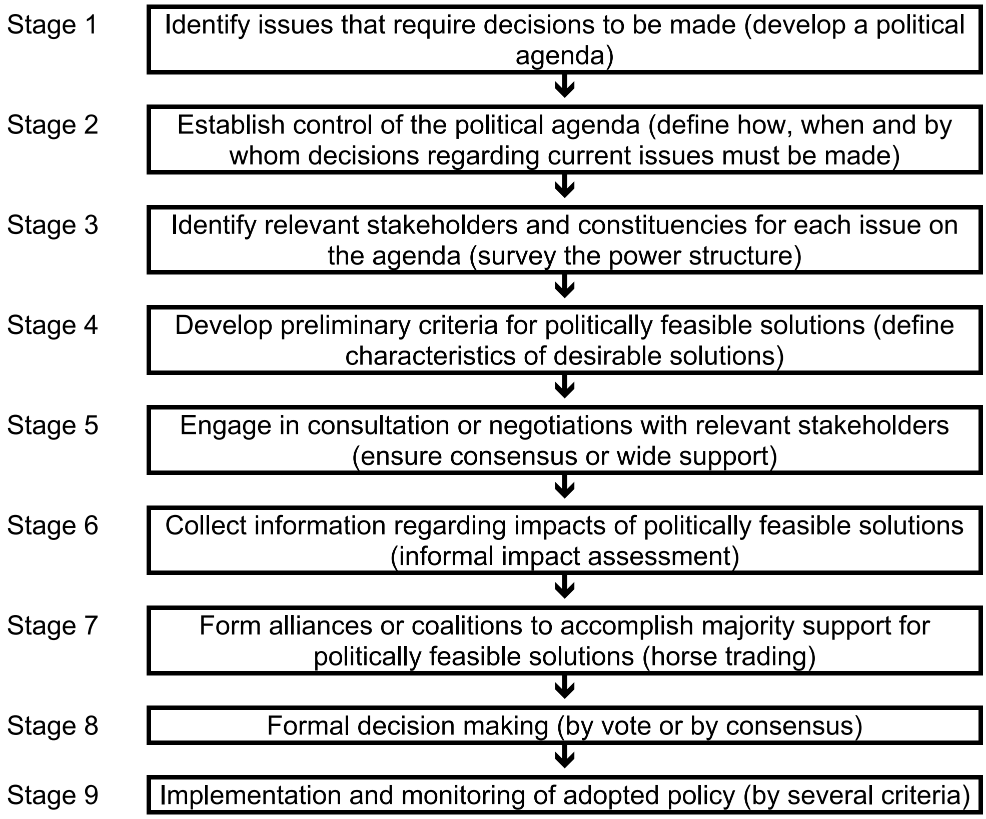

Figure 7: A model of actual road safety policy making

As can be ascertained by comparing the model in Figure 7 to the model in Figure 1, presented in section 2.1, there are big differences between the normative logic of decision-making and the logic of actual policy making. Political decision makers do not always look for the most efficient solution to a problem, although efficiency is sometimes an important criterion. While politicians seek consensus and try to embed their decisions firmly in existing institutions, efficiency analysis implicitly assumes that there is consensus on political objectives and that a suitable technical apparatus exists for implementing cost-effective policy options. These assumptions may not conform to political realities, and in actual policy making processes, it is always the political realities that determine the outcome, and not the input provided by technical experts. This suggests that the following issues are relevant for the implementation of road safety programmes that have been developed by means of efficiency analysis:

- Empowerment
- Reallocation mechanisms
- Competing incentives
- Social dilemmas
- Public acceptance

Each of these issues will be briefly discussed.

8.2.1 Empowerment

Politicians normally develop their power base by forming coalitions. To form coalitions, all, or at least most, partners engaged need to gain something. Thus, coalition building usually involves horse trading, or exchanging favours. This may severely undermine policy options based on efficiency analysis. It would go beyond the main scope of this report to discuss in detail how political horse trading may result in inefficient priority setting. For the purposes of this report, three issues related to empowerment deserve to be mentioned:

1. Road safety programmes are often made at the national level of government. However, national governments may not have the power to implement all cost-effective road safety measures. In particular, as already mentioned, the adoption of new vehicle safety standards require decisions to be taken by international bodies. The introduction of such standards is therefore, by and large, beyond the power of national governments.
2. Road safety programmes made by national government are, ideally speaking, intended to involve all levels of government. However, in many countries, Norway being no exception, there is a strong tradition for local government autonomy. Regional and local governments may refuse to do as instructed by the national government and may seek to enlarge their power to set their own policy priorities. Thus, road safety measures on the local road network may be beyond the power of national governments.
3. To enhance their likelihood of implementation, road safety programmes should contain quantified targets. However, Norwegian politicians have so far been reluctant to support such targets, arguing that it is unethical to set a specific numerical target for road accident fatalities. The absence of such a target means that an important element of commitment to improving road safety is missing. Politicians shirk responsibility for policy results by refusing to commit themselves to achieving clearly stated targets. This also means that executive agencies of government lack the political support they may need in order to implement effective measures.

As will become apparent in Chapter 9, all these issues are highly relevant for road safety policy making in Norway. Despite this, there is hardly any public discussion about them.

8.2.2 Reallocation mechanisms

Public budgeting is to a large extent the outcome of political negotiations and compromises. The resulting allocations can be very stable and resistant to change, even if they are grossly inefficient. An illustration of this is given by Elvik (1995), who shows that the allocation between the nineteen counties of Norway of state funds for national road investments has been very stable over time and can be modelled as an equilibrium solution to a vote trading game. The result is that investments are not allocated according to efficiency criteria. On the contrary, a disproportionate share of investment funds are spent in sparsely populated counties in order to promote regional development.

Steps have been taken in recent years to reform this system, in particular by defining a network “major routes”, for which investment funds are retained by the national government and no longer allocated to counties. Yet, for most national roads, the old system persists and budgets are still not allocated in proportion to the pool of unrealised, but profitable investment projects.

The rigidity of resource allocation mechanisms in the public sector means that it will be problematic to introduce major changes in funding based on efficiency analysis. The chief implication of this for efficiency analysis, is that it should always be part of such an analysis to clarify the needs for reallocating funds between sectors of government in order to provide for the optimal use of road safety measures.

The problem is not confined to the public sector. Many households face considerable rigidity in their household budgets and may not be able to reallocate sizable expenditures to, for example, new safety features on cars. Thus, even implications for private spending should always be investigated as part of a road safety programme.

8.2.3 Competing incentives

Police enforcement is an effective road safety measure, and previous analyses of road safety policy (Elvik 2003B) suggest that there is too little enforcement today. Yet, despite the benefits of increasing traffic enforcement, the police may face competing incentives. There is a strong demand for the services of the police in many areas. A report discussing the societal costs of crime (Justis- og politidepartementet 2005) identifies several categories of crime that cost more to society than road traffic law violations. The police may therefore feel a stronger pressure to deal with other types of crime than traffic law violations. There is also the possibility that this is more cost-effective than trying to reduce road traffic law violations.

The fact that a programme is cost-effective is therefore, by itself, not necessarily a sufficient incentive to implement the programme. In particular, this is so when another programme competing for the same scarce resources may be even more cost-effective. Besides, society does not have to rely on the police only in order to improve road safety. There are many other effective road safety measures. In some other areas, however, there may not be very many other policy instruments available than police enforcement.

8.2.4 Social dilemmas

A social dilemma is perhaps best illustrated by showing an example of one. The example concerns the use of studded tyres. Several cost-benefit analyses of this measure have been made in Norway. One of these analyses, made by Christensen (1993) is particularly illuminating. The main results of the analysis are summarised in Table 10.

Cars having studded tyres have a lower accident rate than cars not having studded tyres. They are driven slightly faster, and owners tend to cancel fewer trips because of slippery roads. On the other hand, studded tyres cost more than standard tyres, and are associated with a small increase in fuel consumption. Still, from the road users' point of view, studded tyres make sense. Private benefits are greater than costs, for road users (car owners), so it is not surprising that many car owners opt for studded tyres.

Table 10: Societal versus user perspective on studded tyres.

	Amounts in million NOK (1 NOK ≈ 0.12 EURO)	
Item	**Gains (favourable impacts)**	**Losses (adverse impacts)**
	Gains and losses to road users	
Accidents	132.5	
Travel time	53.1	
Additional trips made	5.0	
Costs of studded tyres		95.2
Fuel consumption		44.0
Total impacts	190.6	139.2
	Gains and losses external to road users	
Accidents	61.4	
Road wear		46.4
Air pollution		180.0
Total impacts	61.4	226.4
	Gains and losses for society as a whole	
Total impacts	252.0	365.6

The external impacts of studded tyres are, however, quite significant. Part of the benefit in terms of fewer accidents is an external benefit, since part of the costs of accidents are external from the road users' point of view. However, studded tyres wear down roads. Moreover, the grinding of the road surface by the studs tears off particles, which are suspended in air and may impair health, in particular by worsening the condition of people who suffer from respiratory diseases. Inhalation of micro-particles may also lead to premature deaths. These external impacts are clearly negative. When impacts for road users and external impacts are added, losses are larger than gains. Although it is correct to include all external effects in a cost-benefit analysis, the fact that an identifiable group of road users perceive a net benefit, which is primarily driven by expected safety gain, creates a social dilemma. Car owners will prefer studded tyres, as the advantages are greater than the disadvantages. From a societal point of view, on the other hand, studded tyres should not be allowed.

It is essential to identify road safety measures that may give rise to social dilemmas. These road safety measures may be more difficult to implement than other road safety measures. To overcome social dilemmas, it may be necessary to provide road users with incentives that make it sensible for them to support options that are cost-effective from a societal perspective.

8.2.5 Public acceptance

Even if a road safety measure provides benefits that are greater than the costs from both a private and a societal perspective, it may still not be widely accepted. A certain minimum of public acceptance is needed to introduce a road safety measure. It is therefore relevant to collect information about public acceptance of various road safety measures.

This kind of information is available for many European countries in the SARTRE survey (Dahlstedt 2006). In general, the SARTRE survey shows that a majority of drivers approve of many road safety measures. There are, however, a few exceptions. ISA-systems are, for example, greeted with a bit less enthusiasm than many other road safety measures. In Chapter 9, the relationship between the potential contribution of selected road safety measures to improving road safety and the level of public support for them will be explored.

9 An example of a road safety impact assessment

9.1 Road safety impact assessment for Norway 2010-2019

This chapter summarises the main findings of a road safety impact assessment for Norway, based on the building block put in place in the previous chapters. The following policy options have been developed:

1. "First best" optimal use of road safety measures
2. Constrained optimal use of road safety measures
3. Continuation of present policies
4. "Domestic" maximization of safety benefits

In the first policy option, each road safety measure is implemented up to the point where marginal benefits equal marginal costs. Benefits include not just safety benefits, but all relevant impacts of a measure. This policy option: (1) Includes road safety measures at all levels of government; (2) Does not treat current budgets as binding constraints on expenditure; (3) Does not embody any distributional considerations, such as promoting regional development (an important policy objective in Norway) or reducing disparities in risk between different groups of road users; (4) Does not consider public acceptance of the various measures. By disregarding all these constraints, the policy option tries to approximate a "first best" approach, designed to answer the question: in the best of all possible worlds, what would then be the road safety measures of choice?

The second policy option, constrained optimisation, is limited to those road safety measures that the Norwegian government can introduce on its own. This means that, except for systems already on the market, no new vehicle safety features are included. The reason for this is that the power to introduce to new mandatory vehicle safety standards in Europe resides with international bodies, in particular the United Nations Economic Commission for Europe and the European Commission. Standards that are introduced unilaterally by one country may be viewed as discriminatory, violating the terms of international trade and the principle of equal access to the international market. Moreover, in a global perspective, Norway is a very small market for cars. It is therefore doubtful if car manufacturers would actually comply with safety standards applying to Norway exclusively. Thus, constrained optimisation can be regarded as an optimal use of road safety measures within the jurisdiction of the Norwegian government.

The third policy option, continuation of present policies, is the most realistic of all options. In this option, all road safety measures currently used continue to be used. Their use will, however, be made more efficient, i.e. closer to the optimal.

No new measures will be introduced. This means that there will not be any new legislation, nor any new motor vehicle safety standards. Current budgets will not increase.

The fourth policy option is a strengthened version of continuing present policies. It is close to constrained optimisation, but actually departs from optimality by stepping up the use of some road safety measures to the point where total benefits equal total costs. At this point, marginal benefits will be smaller than marginal costs, but it can be argued that society as a whole is better off, since in principle the surplus of benefits in inframarginal projects (i.e. projects for which marginal benefits clearly exceed marginal costs) can be used to “cross-subsidise” the deficit in ultramarginal projects (i.e. projects for which marginal benefits are clearly smaller than marginal costs). Hence, although this policy option departs from strict optimisation, it is, in a sense, still faithful to the principles of welfare economics by complying with the criterion that gainers should be able to compensate loser and still retain a net benefit.

9.2 Main results of alternative policy options

9.2.1 Optimal use of road safety measures

Table 11 shows road safety measures that have been found to be cost-effective in Norway, i.e. measures whose benefits exceed their costs. These measures include the five vehicle safety systems that are already on the market and are expected to increase their market penetration by 2020. The recapitulate, these five systems are:

1. Front- and side airbags
2. Electronic stability control
3. Seat belt reminders
4. Enhanced neck injury protection
5. An increasing share of cars obtaining 4 or 5 stars according to EuroNCAP

Estimated effects and benefit-cost ratios in Table 11 reflect the increasing market penetration of these systems during the period from 2007 to 2020. For other road safety measures, estimates indicate the effects of optimal use of these measures during the same period. Effects refer to changes in the number of road users killed or seriously injured in 2020 compared to a situation in which none of the measures listed in Table 11 are introduced.

In Chapter 4, the increasing market penetration of the five vehicle safety systems listed above was treated as part of the baseline scenario, since it can be expected to occur even if government takes no action. However, when estimating the combined effects of all road safety measures, it is correct to include the vehicle safety systems along with other road safety measures, as they will all be introduced during the same period and will influence the same target groups of accidents or injuries.

Table 11: 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	1.44	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	2.35	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 11: Cost-effective road safety measures in Norway, continued

Road safety measure	Benefit-cost ratio	Estimated reduction of the number of road users killed or seriously injured (first order effects) 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 developing this policy option, account was taken of the fact that some measures are targeted at the same road safety problem. In such cases, only one of the measures was included. More specifically, ISA-technology (vehicle systems designed to help the driver comply with speed limits) was included, but no other type of speed enforcement was included. Account was also taken of the overlap between seat belt reminders and seat belt enforcement.

The combined effect of all measures has been estimated by means of the dominant common residuals method. ISA, which in this report refers to a system that prevents the driver from exceeding the speed limit, was the dominant measure, i.e. the measure that had the largest first order effect on the number of killed or injured road users. Thus, the combined residuals were estimated to:

- 0.484 for fatalities
- 0.588 for seriously injured road users
- 0.786 for slightly injured road users

The predicted number of fatalities in 2020 without any of the measures is 285. This can be reduced to 138 if all measures are fully used to the optimal extent. The number of seriously injured road users can be reduced from 1109 without the programme to 652 if the programme is fully implemented. The number of slightly injured road users can be reduced from 12,650 without the programme to 9,942 if the programme is fully implemented.

Table 12 summarises the effects of optimal use of road safety measures in economic terms. It is seen that benefits for road safety make up almost all benefits. Net impacts on other transport policy objectives are small. The benefit-cost ratio is 1.49. It should be noted that when the measures are combined, their benefit-cost ratio are considerably reduced compared to the first-order estimates. For example, the benefit cost ratio of road user related measures (driver training) is reduced from 1.28 to 0.94.

Table 12: Summary of effects of optimal use of road safety measures in Norway in economic terms. Present values in million NOK

Component of benefits or costs	Present value in million NOK
Benefit components (negative amount = disbenefit)	
Road accidents	82,552
Travel time	−6,199
Vehicle operating costs	1,475
Environmental impacts	968
Impacts on public health	525
Benefits of induced travel	62
Total benefits	79,385
Cost components	
Total costs	53,198
Benefit-cost ratio	1.49

A fully optimal use of all cost-effective road safety measures cannot be realised in Norway at the present time. The Norwegian government cannot pass its own vehicle safety regulations. New technologies, like ISA-systems, will therefore only become mandatory safety features if there is sufficient support for this in the European Union or the United Nations Economic Commission for Europe. Some new vehicle safety systems are going to increase their market penetration by 2020, in particular those that are part of the baseline scenario. A more realistic programme for using cost-effective road safety measures is to assume that no new vehicle safety standards are introduced, but that systems currently on the market will continue to penetrate as indicated above. Rather than introducing ISA, police enforcement will be increased.

9.2.2 Constrained optimal use of road safety measures

This policy option is confined to measure that are used today, but for which use will be optimised. Compared to “first best” optimal use of road safety measures, the following measures are not included:

- eCall
- Event recorders
- ISA systems
- Design to protect pedestrians
- Front impact attenuators on heavy vehicles
- Alcolock
- Bicycle helmet law

- Law requiring pedestrian reflective devices

The following measures, not included in “first best” optimisation, are included:

- Speed enforcement
- Speed cameras
- Section control
- Feedback signs for speed

If this policy option is implemented during the period from 2007 to 2020, the number of road accident fatalities in 2020 is expected to be reduced to 171. The number of seriously injured road users is expected to be reduced to 769 and the number of slightly injured road users is expected to be reduced to 10,974.

Aggregate benefits have been estimated to 63,013 million NOK, aggregate costs have been estimated to 36,500 million NOK. Benefit-cost ratio is 1.73. Paradoxically, this is somewhat better than in first best optimisation. The explanation for this somewhat counterintuitive finding is that in the constrained optimisation, those vehicle safety features that have the favourable benefit-cost ratios have been retained in the package of measures, whereas new vehicle safety features, whose benefit-cost ratio is, on the average, slightly less favourable, have been left out. Moreover, since a smaller number of road safety measures are combined, the marginal effects of each measures within the package are closer to first order effects than in first best optimisation. Thus, the mean benefit-cost ratio is road-related measures is 1.40 in first best optimisation, which increases to 1.53 in constrained optimisation.

Despite these more favourable results, the overall effect on road safety is smaller for the constrained optimisation option than for the first best optimisation option. Comparing the difference in costs and benefits between the two policy options, the marginal benefits of first best optimisation come to 16,372 million NOK, whereas marginal costs come to 16,698. This indicates that, despite the lower mean value for the benefit-cost ratio in the first best optimisation option, the marginal benefits of the first best optimisation option are equal to marginal costs when compared to constrained optimisation (16,372/16,698 ≈ 1).

9.2.3 Continuation of present policies

Although constrained optimisation is a more realistic policy option than first best optimisation in terms of what the Norwegian government has power to do, it may still be unrealistic. In particular, this options entails fairly drastic increases in police enforcement. This may not be feasible.

A policy option has there been developed that represents a continuation of present policies. This policy options includes the following road safety measures not included in the two optimisation options:

- Building new motorways
- Building environmental streets
- Signalising pedestrian crossings
- Cycle lanes

These measures are used today, although their benefits, as currently used, are smaller than the costs. In the continuation of present policies option, new vehicle safety features continue to increase their market penetration, identical to the baseline scenario. There will, however, be:

- No increases in police enforcement
- No improvements in systems for driver training (more accompanied driving and elderly driver retraining)
- No new legislation will be introduced (bicycle helmets, pedestrian reflective devices, alcolock)
- No changes in speed limits, even if the benefits of such changes exceed the costs.

If present policies thus defined are continued during the period 2007-2020, the predicted number of road accident fatalities in 2020 is 190. The predicted number of seriously injured road users in 2020 is 822 and the predicted number of slightly injured road users is 11,406. To continue present policies will therefore result in some improvement in road safety, but smaller than the other two policy options presented so far. The number of fatalities and seriously injured road users will be reduced compared to the present situation, but the number of slightly injured road users will not be reduced.

Benefits have been estimated to 77,642 million NOK (present value), costs to 70,731 million NOK, yielding a benefit-cost ratio of 1.10. While benefits remain greater than costs, the margin of excess benefits is smaller than in the other policy options examined so far.

9.2.4 Strengthening present policy

This policy option involves using the same road safety measures as in current policy. However, a number of road safety measures will be stepped up considerably. These include:

- Pedestrian bridges or tunnels
- Conversion of 4-leg junctions to roundabouts
- New road lighting
- Upgrading pedestrian crossings
- Speed enforcement
- Drink-driving enforcement
- Seat belt enforcement
- Introduction of eCall on all new cars from 1.1.2009

These measures will be used up to the point where total costs equal total benefits. Except for eCall, no new vehicle safety standards will be introduced. All measures will be used during the period from 2007 to 2020.

The number of road accident fatalities in 2020 is estimated to 143. The number of seriously injured road users in 2020 is estimated to 691 and the number of slightly injured road users to 10,551.

Benefits are slightly smaller than costs. Benefits (present value) are estimated to 77,038 million NOK, costs are estimated to 84,267 million NOK.

9.3 Comparison of policy options

Table 13 compares the four policy options in terms of their effects on the number of road users killed or injured.

Table 13: Predicted number of road users killed or injured in Norway in 2020 according to different options for road safety policy

	Number of road users killed or injured per year		
Policy options and assumptions made	**Killed**	**Seriously injured**	**Slightly injured**
Mean annual numbers 2003-2006	250	980	10870
Predicted for 2020 as a result of traffic growth	285	1109	12650
Predicted for 2020 as a result of traffic growth and expected market penetration of vehicle safety systems	222	913	12010
Policy option A: Optimal use of road safety measures, including effects of traffic growth and market penetration of vehicle safety systems	138	652	9942
Policy option B: Constrained optimal use of road safety measures, including effects of traffic growth and market penetration of vehicle safety systems	171	769	10974
Policy option C: Continue present use of road safety measures, including effects of traffic growth and market penetration of vehicle safety systems	190	822	11406
Policy option D: Strengthening current use of road safety measures, including effects of traffic growth and market penetration of vehicle safety systems	143	691	10551
Policy objectives for 2020	125	490	

It is seen that while one may expected a small decline in the number of fatalities and seriously injured road users as a result of the predicted increase in market penetration of vehicle safety systems, a marked reduction in the number of road users killed or injured requires the use of a large number of road safety measures.

Policy option A, optimal use of road safety measures, is associated with the lowest predicted number of road users killed or injured. This policy option has a greater effect on safety than any of the other three policy options. Still, it is not sufficient to realise the targets set for reducing the number of road users killed or seriously injured by 50 % by 2020. Besides, some of the measures included in this policy option are outside the control of the Norwegian government. It is therefore clear that this policy option cannot be implemented by the Norwegian government in the form it has been developed in this report.

Policy option B, constrained optimal use of road safety measures, is limited to those road safety measures the Norwegian government can control. By implementing this policy option, the number of road users killed or seriously injured can be reduced considerably, although by less than 50 %. The number of road users slightly injured will not be reduced compared to the annual mean number for the period 2003-2006.

Policy option B requires a reallocation of resources between road safety measures. Unless there are clear incentives to perform such a reallocation, it is unlikely to take place, as most government agencies regard their current budget allocations as the best possible compromise between the often conflicting demands and expectations they are faced with. Policy option C, continuing present policies, avoids the need for reallocating spending, but yields a comparatively modest improvement of road safety. This policy option is probably the most realistic of the four options, in that it does not rely on road safety measures outside the control of the Norwegian government, it does not require the introduction of potentially controversial new legislation, and it does not require reallocating public spending between agencies or between different programmes controlled by the same agency.

Policy option C keeps the peace, but lacks ambition. Policy option D is more ambitious and involves a drastic increase in expenditures on some road safety measures. This policy option results in a decline in the number of road users killed or injured which is almost as large as for policy option A, optimal use of road safety measures. It is, however, less cost-effective. Besides, like policy options A and B, it involves fairly extensive reallocation of expenditures between government agencies and programmes.

Table 14 summarises information regarding the estimated benefits and costs of the policy options in monetary terms, viewed from a societal perspective.

Table 14: Benefits and costs of policy options for road safety policy. Amounts in million NOK, present values. 1 NOK = 0.12 Euro

	Alternative policy options			
Benefits and costs (million NOK, present values)	**Option A: Optimal use of road safety measures**	**Option B: Constrained optimal use of road safety measures**	**Option C: Continue present use of road safety measures**	**Option D: Strengthen road safety measures currently used**
Total benefits	79,385	63,013	77,642	77,038
- of which safety (%)	104.0 %	92.0 %	83.3 %	87.2 %
- of which mobility (%)	−5.8 %	6.7 %	16.2 %	12.1 %
- of which health and environment (%)	1.8 %	1.3 %	0.5 %	0.7 %
Total costs	53,198	36,500	70,731	84,267
Benefit-cost ratio	1.49	1.73	1.10	0.91

Policy option A, optimal use of road safety measures, yields the largest total benefits, but does not have the most favourable benefit-cost ratio. Policy option C is marginally cost-effective, but considerably less so than policy option A. For policy option D, costs exceed benefits.

The bulk of the benefits in all policy options relate to road safety. The policy options that are based on current policies (C and D) provide more benefits for mobility than the other policy options.

9.4 Implications for private and public expenditures

Policy options that require large increases in private or public expenditures may be less feasible than policy options not requiring such expenditures. An estimate has therefore been made of the private and public expenditures the policy options will require.

9.4.1 Road-related measures

The current amount spent annually on road-related road safety measures is about 1,450 million NOK per year, of which about 1,190 is for investments and 260 million NOK is for operations and maintenance (Elvik 2005B). In addition, considerably larger amounts are spent on road investments in general, some of which may have improving road safety as of the objectives. The total amount spent annually on road investments is about 6,500 million OK per year. These amounts are “budget costs” that do not include the opportunity cost of public funds (which is a shadow price intended to reflect inefficiencies generated by the taxation system).

Estimated costs of road-related measures in the four policy options refer to the total expenditures in period until 2020, more specifically the 2010-2019 planning term for the National Transport Plan. In policy option A, optimal use of road safety measures, total costs amount to 13,795 million NOK for investments and 107 million NOK in annual operations and maintenance. Thus the mean annual expenditures per year during the ten years from 2010 to 2019 will be about 1,380 million NOK in investments and 107 million NOK in running costs. These costs do not exceed current expenditures and do not therefore not require a larger budget. Expenditures for road-related measures are the same in policy options A and B.

In policy option C, continuing current policies, some large investments that are normally not regarded as road safety measures have been included because these investments have already been planned for and are likely to be carried out. For this policy option, therefore, investments increase to about 4,090 million NOK per year during the term 2010-2019. Annual costs for operations and maintenance increase to 282 million NOK. These amounts, while markedly higher than in policy options A or B, are still within the current total budget for road investments and road maintenance.

Policy option D, strengthening current policies, involves and even higher spending on road related investments. The mean annual amount for the term 2010-2019 in this policy option is about 4,790 million NOK and the mean annual cost of operations and maintenance are about 335 million NOK. Again, however, these expenditures can be funded without having to increase current budget limits.

9.4.2 Vehicle-related measures

The vehicle-related measures form two main groups. One group is the five safety features already on the market and expected to continue to spread by 2020. These include airbags, electronic stability control, enhanced neck injury protection, seat belt reminders and improved scores on EuroNCAP. The other group consists of new vehicle-related safety measures. These include eCall, event data recorders, ISA-systems, modified design to protect pedestrians and impact attenuato5rs on heavy vehicles.

Table 15 summarises the cost per vehicle and the number of vehicles expected to be fitted with the various safety devices by 2020 for the two groups of measures.

Table 15: Costs of vehicle related measures – number of vehicles equipped with the measures by 2020

Measure	**Cost per vehicle (NOK)**	**Number of vehicles equipped with measure by 2020**
Group A: Measures already on the market, expected to increase market penetration by 2020		
Electronic stability control	3,000	1,980,000
Front- and side impact airbags	6,000	1,478,000
Enhanced neck injury protection	300	787,000
Seat belt reminders	500	1,488,000
EuroNCAP scores	7,900	1,001,000
Group B: New vehicle safety features, not currently offered as standard equipment		
eCall (accident notification)	600	2,086,000
Event data recorders	3,900	2,086,000
Intelligent speed adaptation (ISA)	5,000	2,086,000
Front design for pedestrian protection	200	2,086,000
Impact attenuators on heavy vehicles	15,000	89,000

The number of vehicles expected to be equipped with the various safety features by 2020 varies, depending on the current market penetration and its expected change by 2020. Complete turn over of the vehicle fleet is assumed to take 18 years; hence, new measures introduced from 2007 will have 14 years to spread by 2020 and will then reach a market penetration rate of 84 %.

The cost of the safety features already on the market is NOK 17,700. However, not all car owners choose to buy cars that have all these features. The mean cost per new car bought will therefore be lower. By comparison, the most recent survey of consumer expenditures in Norway shows that an average household spends about 50,000 NOK per year on vehicles owned by the household. It should be borne in mind that not every household will buy a car every year.

The new safety features for light vehicles cost in total 9,700 NOK per vehicle. Impact attenuators for heavy vehicles have been estimated to cost about 15,000 NOK per vehicle. These are significant costs, but all these measures have been found to be cost-effective, i.e. benefits exceed costs from a societal point of view.

9.4.3 Enforcement-related measures

As far as enforcement-related measures are concerned, effects on safety are generated by changes in the amount of enforcement, leading to changes in the perceived risk of apprehension and in turn to increased compliance with the law. For these measures, therefore, any costs will be additional costs coming on top of current costs.

For policy option A, optimal use of road safety measures, additional costs have been estimated to 166 million NOK for investments and 750 million NOK for annual running costs. For policy option B, the corresponding costs are 153 million NOK for investments and 996 million NOK for running costs. It should be remembered that “old fashioned” speed enforcement was not included in policy option A, being replaced by ISA-systems, but was included in policy option B, which is restricted to measures the Norwegian government can introduce on its own.

In policy option C, costs have been estimated to 153 million NOK for investments and 59 million NOK for running costs. In policy option D, enforcement is increased drastically, leading to costs of 336 million NOK for investments and 2,382 million for annual running costs.

9.4.4 Road user related measures

This category includes just two measures – accompanied driving and elderly driver retraining. Moreover, these measures are included in just two policy options, A and B. Costs have been estimated to 4 million per year for the public sector and 266 million per year for the private sector (training needs to be repeated for a new cohort every year).

9.4.5 Total costs

Table 16 summarises total costs. Keep in mind that these are expenditures, not social costs. For the public sector, the difference between budgetary expenses and social cost consists of the opportunity cost of public funds. However, as this is not an out-of-pocket expense, it has been left out of the summary in Table 17, in order to show as accurately as possible the actual payments that need to be made in order to implement the policy options.

Expenditures on road related measures have been assumed to accrue during the period 2010-2019 with equal amounts every year (10 years). Expenditures on vehicle related measures have been assumed to accrue with identical amounts during the years 2007-2020 (14 years). Expenditures on enforcement have also been assumed to accrue constantly during the period 2010-2019. This means that investments for enforcement have been allocated as 10 % of the total amount every year, whereas the running costs are repeated with the full amount every year. Road user related measures have been treated the same way as vehicle related measures.

Table 16: Annual expenditures on road safety measures in Norway in four different policy options. Amounts in million NOK. 1 NOK = 0.12 Euro

		Mean annual expenditures in million NOK			
		Public sector		Private sector	
Policy option	**Group of measure**	**Investment**	**Running cost**	**Investment**	**Running costs**
First best optimal	Road	1,379	107		
	Vehicle	1	1	3,233	209
	Enforcement	17	750		
	Road user		4		266
	Total	1,397	862	3,233	475
"Norwegian" optimal	Road	1,379	107		
	Vehicle			1,693	
	Enforcement	15	996		
	Road user		4		266
	Total	1,394	1,107	1,693	266
Continue present policy	Road	4,090	282		
	Vehicle			1,693	
	Enforcement	15	59		
	Road user				
	Total	4,105	341	1,693	0
Strengthen present policy	Road	4,791	336		
	Vehicle	1	1	1,782	
	Enforcement	34	2,382		
	Road user				
	Total	4,826	2,719	1,782	0

Total annual costs are lowest for the "Norwegian" optimal use of measures option (policy option B) and highest for the strengthening of present policy option (policy option D).

9.5 Assessing uncertainty

Is it possible to quantify the uncertainty of the estimated effects of the various policy options? Yes, a crude summary estimate can be derived, but it is not possible to fully estimate the uncertainty resulting from all the sources discussed in Chapter 7. A summary estimate of the uncertainty regarding effects on the number of fatalities will be derived, taking account of random variation in the number of fatalities and random variation in the estimated total effect of the road safety measures in each policy option (items 2 and 4 on the list of sources of uncertainty in Chapter 7). As far as the other sources of uncertainty discussed in Chapter 7 are concerned, a satisfactory treatment of all of them is not possible at the current state of knowledge.

As was noted in Chapter 7, random variation in the number of accidents is generally described in terms of the Poisson probability law. The variance of a

Poisson variable equals its mean. Strictly speaking, this is not correct as far as the number of road accident fatalities is concerned (Fridstrøm et. al. 1993). There is, on the average, more than one fatality per fatal accidents and fatalities are not independent events in the same sense as accidents. Thus, if one of two occupants in a car are killed, the probability of the other occupant being killed is considerably higher than in a similar accident involving two vehicles each with one occupant. The variance of the number of fatalities therefore exceeds the mean.

In all policy options, the reference value for the number of fatalities – the number expected to occur in 2020 if no new road safety measures are introduced – is 285. The variance of this number is about 335. The variance of the estimated reduction of the number of fatalities in each policy option can be estimated by applying a fixed effects weight to the estimate, the way this is done in meta-analysis. The variance of an estimate of effect is the inverse value of the statistical weight assigned to that estimate.

If, for the purposes of gaining an impression of the uncertainty, the estimated, predicted numbers of fatalities are treated as if they were observed numbers, we get for policy option A, optimal use of road safety measures:

Initial number of fatalities (“before treatment”) = 285

Final number of fatalities (“after treatment”) = 139

$$\text{Statistical weight} = \frac{1}{\frac{1}{285} + \frac{1}{138}} = 93.55$$

$$\text{Inverse of statistical weight} = \frac{1}{285} + \frac{1}{138} = 0.0108$$

We now have the following input values to estimate uncertainty with respect to the effect of this policy option on the number of fatalities:

Number of fatalities affected by policy option (A):	285
Variance of number of fatalities affected by policy option (Var(A)):	335
Estimated effect of policy option (B):	0.5128
Variance of effect of policy option (Var(B)):	0.0108
Number of fatalities prevented by policy option (A · B):	147

Estimate of variance of number of fatalities prevented:

$[(0.5128 \cdot 0.5128) \cdot 335] + [(285 \cdot 285) \cdot 0.0108] = 962.71$

The standard error of the number of fatalities prevented is the square root of the variance, which equals 31.0. Thus, for policy option A, a 95 % prediction interval for the number of fatalities prevented is:

$147 \pm 1.96 \cdot 31.0 = 147 \pm 60.8$ = lower limit = 86; upper limit = 208

There is, in other words, considerable uncertainty. Table 17 summarises estimated uncertainty for the four policy options considered.

Table 17: Estimated 95 % prediction interval for estimated effect on the number of fatalities of four options for road safety policy in Norway

Policy option	Initial number of fatalities	Best estimate of number of fatalities if option is imple-mented	Lower 95 % prediction limit	Upper 95 % prediction limit
Optimal use of road safety measures	285	138	77	199
“Norwegian” optimal use of measures	285	171	115	227
Continue present policies	285	190	136	244
Strengthen present policies	285	143	83	203

It should be noted that although the prediction intervals overlap considerably, the most effective policy option (optimal use of road safety measures) produces lower values for both the lower and upper prediction limits than any of the other options. Despite the large uncertainty, there is therefore hardly any doubt as to which policy option is the best.

10 Discussion and conclusions

10.1 Road safety impact assessment: useful or window dressing?

Will the road safety impact assessment presented in this report influence road safety policy making in Norway, or will it merely be used as window dressing? Only time can show. It is clear, however, that no road safety impact assessment can be applied as a straightforward recipe for road safety policy. The four policy options developed in this report are not equally realistic. Indeed, the technically best policy option, optimal use of road safety measures, is the least likely to be implemented. It consists in part of measures that are outside the control of the Norwegian government and requires a very strict priority setting for the measures that are controlled by the Norwegian government.

In practice, the priority given to various road safety measures is influenced by many considerations and no attempt is made to match their use precisely to an economic criterion of efficiency. The selection of sites for treatment, for example, is "inefficient" in the sense that some sites are selected at which benefits are likely to be smaller than costs, and some sites where benefits are likely to be greater than costs are not selected for treatment. This dilutes the efficiency of treatments and reduces their benefit-cost ratios.

In this discussion, the prospects of improving the efficiency of road safety policy in Norway on the basis of the road safety impact assessment presented in this report will be assessed according the following criteria:

- Competing criteria for priority setting
- The need for more efficient selection of sites for treatment
- The presence of competing incentives, in particular for the police
- The presence of social dilemmas
- Public acceptance of the road safety measures
- Power and the path dependence of efficiency of measures

10.1.1 Competing criteria for priority setting

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 and Veisten 2005), 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 questions. 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 8 probes if this is the case for the road safety measures included in this impact assessment.

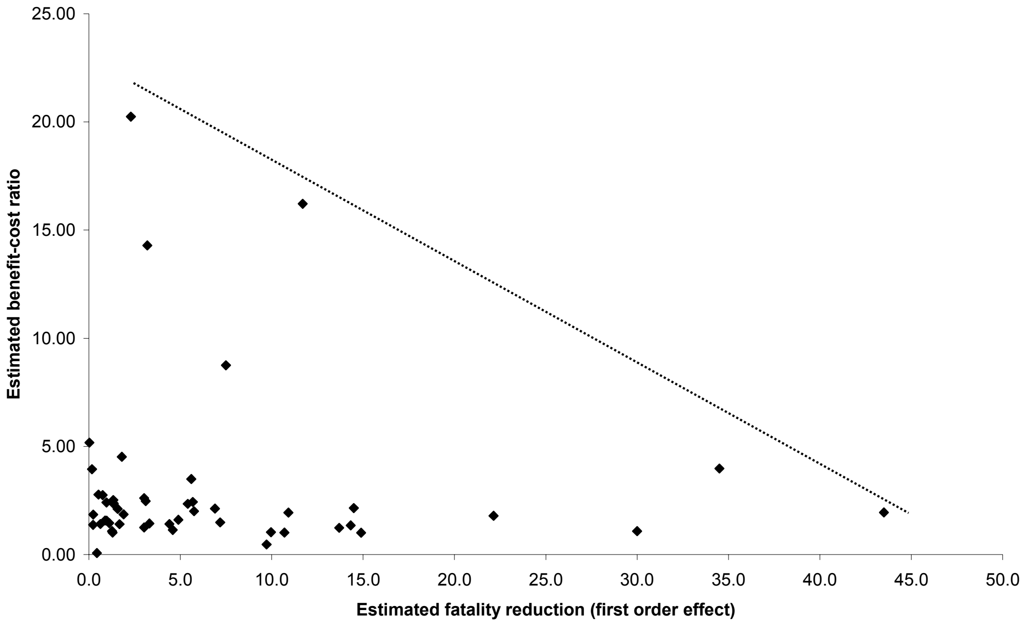

Figure 8: Relationship between estimated fatality reduction and benefit-cost ratio for road safety measures in Norway

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 (simple) 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 (Statens vegvesen, Håndbok 115, 2005). Figure 9 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.

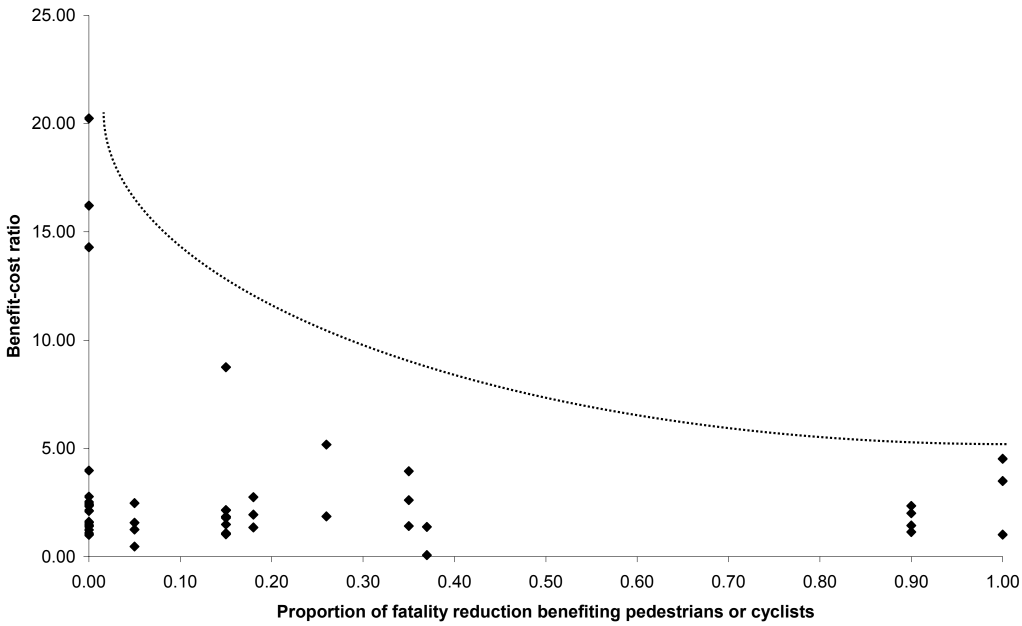

Figure 9: Relationship between proportion of estimated fatality reduction benefiting pedestrians or cyclists and benefit-cost ratio of road safety measures

As in Figure 8, 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.

10.1.2 Efficient selection of sites for treatment

In all the policy options analysed in this report, a maximally efficient selection of sites for treatment has been assumed. The term maximally efficient selection denotes a selection of the sites at which treatments will produce the most favourable benefit-cost ratios.

A previous analysis of the actual selection of sites for road safety treatment in Norway (Elvik 2004A) suggests that the current selection is not maximally efficient. More specifically, there is a tendency to select sites with a low traffic volume and in many cases no accidents recorded. The long-term expected number of accidents at these sites is obviously not zero, but if traffic volume is modest, and no accidents have been recorded, the expected number of accidents is in many cases likely to be below the threshold where the marginal benefits of treatment equal marginal costs.

It is beyond the scope of this report to examine in detail discrepancies between a maximally efficient selection of sites for treatment and actual selection. A crude comparison may nevertheless be indicative of the extent to which the process of selecting sites for treatment needs to be reformed in order to approach maximum efficiency. Table 18 provides such a comparison. The comparison includes only those measures for which the actual distribution of sites selected by traffic volume is known and can be compared to the distribution implied by an efficient selection.

As can be seen from Table 18, a certain proportion of sites as currently selected are likely to be inefficient, i.e. these are sites where the benefits of the road safety measure are likely to be smaller than the costs. This reduces the effect on fatalities and injuries of the measures that are used inefficiently.

Table 18: Comparison of maximally efficient selection of sites for safety treatment and current selection of sites for treatment in Norway

Road safety measure	Mean AADT for efficiently selected sites	Mean AADT for sites as currently selected	Estimate of per-centage of sites as currently selected that are likely to be inefficient
Bypass roads	9,430	4,525	75
Pedestrian bridge or tunnel	10,470	8,765	75
Converting T-junction to roundabout	12,825	9,090	60
Converting X-junctions to roundabouts	8,720	10,430	10
Roadside safety treatment	5,810	20,130	5
Reconstruction and rehabilitation of roads	4,915	3,270	90
Guardrails (along roadside)	4,490	10,950	50
Median guard rails on undivided roads	13,135	42,750	5
Horizontal curve treatments	1,685	1,160	35
Road lighting	5,940	8,180	5
Traffic signals in T-junctions	30,455	13,340	100
Traffic signals in X-junctions	14,955	16,430	0
Upgrading pedestrian crossings	6,210	10,485	5
Speed cameras	11,180	9,280	25
Feedback signs for speed	6,410	5,725	35

For some measures, it can be seen that the current mean AADT for sites selected for treatment is higher than the mean AADT for a sample of sites selected optimally for treatment. This does not suggest that the current selection for treatment is "super-efficient". It rather suggests that these measures are underutilised, i.e. too few sites are treated and the measures are used too restrictively. This will of course also reduce their contribution to improving road safety.

It is beyond the scope of this report to try to explain why sites are not selected in a maximally efficient manner. It is likely, however, that a process akin to negotiations takes place between municipalities and the district offices of the Public Roads Administration. This process may in some respects resemble the vote trading game that Elvik (1995) suggested may explain the allocation of road investment funds between counties of Norway. Such a resource allocation mechanism favours inefficiency and works, in a manner of speaking, as "the exploitation of the rich by the poor", something the "poor" can do by virtue of being far more numerous than the rich, thereby outnumbering them in any body making decisions by a vote or informal support from a majority. Indirect support for such a hypothesis is provided in a paper by Fridstrøm and Elvik (1997), who find that investment projects on national roads tend to be spread out to as many municipalities within a county as possible. A "poor" municipality in the present context is one in which traffic volume is too low for the investment to be cost-effective. The investment is nevertheless made, as a fair and equitable distribution of investment projects between municipalities is sought, rather than an efficient allocation.

10.1.3 Competing incentives

As indicated by the analyses presented in this report, it is cost-effective to increase police enforcement substantially. This is not a new finding. A similar analysis nearly ten years ago reached the same conclusion (Elvik 1999). Police enforcement has, however, not increased at all.

The police face competing incentives. While they may appreciate the value of traffic enforcement, other activities may bring more tangible rewards. Most traffic violations do not have a victim; they merely increase the risk of accidents. This risk is minuscule and not readily observed; nor is any increase of the risk associated with most traffic violations.

On the other hand, crimes like murder, rape, prostitution, drug trafficking and everyday burglaries all have known victims who press the police to solve the crime and prevent its repetition. Few people will complain – indeed few people will even notice – if the police fail to increase their traffic enforcement. But if the police fail to investigate murders or fail to prosecute known criminals, there will be massive complaints. The presence of beggars, drug addicts and prostitutes on streets makes many people feel unsafe, and police patrols are in great demand. There is no corresponding demand for more traffic enforcement.

10.1.4 Social dilemmas

Are any of the cost-effective road safety measures identified in this impact assessment likely to present social dilemmas? A social dilemma, it will be recalled, will arise when a measure whose benefits are greater than the costs from a societal perspective provide benefits that are smaller than the costs from a private point of view.

Consider lowering the speed limit from 90 to 80 km/h. This measure has an impressive benefit cost ratio of 14.3 from a societal perspective. How does it fare from a motorist perspective? Based on previous analyses (Elvik 1994, 2002) it is reasonable to assume that about 40 % of the saving in accident costs are external, and that 100 % of the environmental benefits are external from the motorists' point of view. If these assumptions are accepted, the benefits of lowering the speed limit vanish altogether – in fact they become negative. From the motorists' point of view, there are therefore not good enough reasons for lowering the speed limit from 90 to 80 km/h.

The following measures have been assessed with respect to whether they represent social dilemmas or not:

- Lowering speed limits from 90 to 80 km/h
- Upgrading pedestrian crossings
- Intelligent speed adaptation
- Design of front to protect pedestrians
- Front impact attenuators on heavy vehicles

As far as lowering speed limits are concerned, the answer is affirmative, since part of the societal benefits are external from the motorists' point of view and therefore do not enter motorist considerations of appropriate speed. If policy makers adopt a motorist point of view, they will not lower speed limits. The societal point of view only becomes apparent if a formal cost-benefit analysis is performed. Absent such an analysis, the motorist point of view is likely to prevail.

Upgrading pedestrian crossings essentially involves favouring one group of road users at the expense of another. Briefly put, motorists are required to reduce speed to make it safer for pedestrians to cross the road. In most pedestrian accidents, it is the pedestrian who sustains the most serious injuries. In fact, in most of these accidents, car drivers will be uninjured. Although striking a pedestrian is of course profoundly shocking and is an event most drivers will remember for the rest of their lives, it remains undisputable that pedestrians suffer the most serious and long-lasting impacts of pedestrian accidents. If most of the cost of pedestrian accidents is treated as external from the motorists' point of view, then the benefits to motorists of upgrading pedestrian crossings become negative and they may oppose the measure. A similar point of view applies to modifying the front and bumper design of cars to offer pedestrians better protection.

Intelligent speed adaptation is obviously a case of a social dilemma. Again, while the cost-benefit analysis finds that benefits greatly exceed costs, most motorists will adopt a different point of view. In the first place, part of the benefit in terms of reduced accidents is external, since some of the accidents prevented are not accidents in which the motorist would be injured and since society pays part of the bill for accidents (treatment in hospitals is, in general, free of charge for the patient in Norway, and the bill is not passed on to those who caused the injury). In the second place, environmental benefits of lowered speed are external from the motorists' point of view. Finally, motorists will probably count all additions to travel time as losses, not making the distinction made here between losses attributable to the prevention of illegal speeds and losses attributable to small reductions in legal speeds. In the cost-benefit analysis, only the latter were included as an added cost of travel time.

As far as impact attenuators on heavy vehicles are concerned, the case closely parallels that of front and bumper design to protect pedestrians. Owner of heavy vehicles will pay the full cost, but obtain only a minor share of the benefits. A social dilemma thus arises.

Social dilemmas can be overcome. However, their presence makes it less likely that a road safety measure will be introduced. In particular, this will be the case if a road safety measure giving rise to a social dilemma is not widely sported by the public.

10.1.5 Public acceptance of road safety measures

The SARTRE survey (Dahlstedt 2006) provides information concerning public acceptance of a number of road safety measures in many European countries. Norway did not take part in SARTRE, but there is no reason to believe that attitudes towards road safety measures in Norway differ very much from those found in other European countries.

There is, in general a high level of public support for more police enforcement, publicity campaigns for road safety, improving the standards of roads (not further specified), making penalties for speeding more severe, making penalties for drink-driving more severe and using speed cameras to enforce speed limits. Opinions are more divided with respect to making alcolocks mandatory and requiring event data recorders in cars. Lower speed limits on rural roads are opposed: a huge majority state that current speed limits should be kept.

ISA gets a surprisingly high level of support in many countries. Opinions are, however, somewhat divided, and a sizable proportion of motorists in some countries are opposed to ISA.

Thus, some of the measures that represent social dilemmas are, as one would expect, opposed by many motorists.

10.1.6 Power and path dependence

As already noted, the power to introduce road safety measures is shared between three levels of government: the international level, the national level and the regional or local level. This is a problem, as few or no formal coordination mechanisms between these levels of government exist. Moreover, action at the international level normally requires unanimity or at least wide support. In practice, this means that European countries are no longer at liberty to set their own national vehicle safety standards.

Several new safety technologies for motor vehicles hold promise to improve road safety. These technologies cannot become mandatory safety standards unless all or most European countries agree to it. Some of the technologies will probably spread by the market mechanism. But not all new safety technologies are in great demand. Relying on the market mechanism to introduce ISA systems or alcolocks may result in a very slow introduction of these technologies.

In the meantime, some governments may be tempted to step up the use of other road safety measures. A massive increase in police enforcement may, however, undermine the potential benefits of an ISA system to such an extent as to make the measure cost-ineffective. In general, path dependence is a problem, in that the benefit-cost ratio of a specific road safety measure depends on which other road safety measures are introduced.

Thus, in policy option A, optimal use of road safety measures, the overall benefit cost ratio of road-related measures is reduced from 1.90 according to first order effects to 1.42 when these measures are part of a programme consisting of several other road safety measures. A similar pattern is found in all policy options: benefit-cost ratios are lowered substantially when road safety measures are combined into a package of measures.

This creates a problem of path dependence: the efficiency of specific measures depends on the order in which they are introduced. ISA is more cost-effective than traditional police enforcement. If police enforcement is increased, the cost-effectiveness of ISA is reduced and it may no longer be more cost-effective than other road safety measures – even if it would be the measure of choice if first best choices could be made at the national level of government.

10.2 Prospects for improving road safety in Norway: a summary

What all the points discussed above add up to, is that the real prospects of improving road safety in Norway are probably not as bright as the most attractive policy option analysed in this road safety impact assessment suggests. On the contrary, the prospects are considerably more bleak and give few reasons for optimism. Table 19 provides a summary of the policy options discussed in this report with respect to potential effects on road accident fatalities.

Table 19: Prospects for improving road safety in Norway. A critical analysis of four policy options

Expected annual number of road accident fatalities – contribution of main categories of road safety measures to reducing fatalities					
Baseline values and main contributing factors	**Policy option A: optimal use of road safety measures**	**Policy option B: optimal use of measures controlled by the Norwegian government**	**Policy option C: continue present policies**	**Policy option D: strengthen present policies**	**Comments on prospects of implementation**
Mean 2003-2006	250	250	250	250	
Expected in 2020 as a result of traffic growth	285	285	285	285	
Contribution of main categories of measures to reducing fatalities					
Exogenous vehicle safety features	49	55	58	55	Is likely to occur
New vehicle safety features	42	0	0	0	Beyond national power
Road related measures	26	28	34	39	Inefficient site selection may diminish effect
Enforcement related measures	24	29	3	43	Substantial increase unlikely
New legislation	4	0	0	5	Unlikely
Road user related measures	2	2	0	0	Unlikely
Total contribution of all measures	147	114	95	142	
Expected in 2020 as a result of policy option	138	171	190	143	

Policy option A is unrealistic for several reasons. Based on the discussion in section 10.1, the most realistic policy option is option C, although its likely effects will be smaller than estimated here. The reason for expecting smaller effects, is that the selection of sites for treatment is likely to remain somewhat inefficient. The effects that may be expected from road related measures are thus smaller than shown in Table 20. A rough estimate of the expected number of road accident fatalities in 2020 is 200, which is considerably more than the target number of

125. The following points summarise the main findings of the road safety impact assessment:

1. A survey was made of 139 potentially effective road safety measures. 45 of these were selected for a formal impact assessment, including a cost-benefit analysis.
2. 39 of the 45 road safety measures included in the impact assessment were cost-effective, i.e. produced benefits greater than the costs.
3. Based on the 45 road safety measures included in the impact assessment, four policy options were developed for road safety policy in Norway. These options refer to the period before 2020 and were developed in order to assess the prospect of realising the target set of halving the number of road accident fatalities and seriously injured road users by 2020 compared to annual mean numbers for the years 2003-2006.
4. The four policy options developed were:
    a. "First best" optimal use of road safety measures, i.e. using all road safety measures optimally without regard to current budget limits and without regard to who has the power to introduce the measures.
    b. Optimal use of road safety measures that the Norwegian government can control ("Norwegian" optimal use of road safety measures).
    c. Continuing present policies, i.e. not introducing any new legislation of any new motor vehicle safety standards.
    d. Strengthening present policies, i.e. continuing to use the road safety measures that are used today, but increasing the use of some of these measures, in particular police enforcement, considerably.
5. Estimates of the likely effects of road safety measures show that the policy targets for 2020 are unlikely to be realised. The target is to reduce road accident fatalities from 250 (annual mean 2003-2006) to 125 and seriously injured road users from 980 to 490. These targets are not realised in any of the four policy options whose impacts have been assessed. The best option is optimal use of road safety measures. This policy option results in 138 fatalities in 2020 and 652 seriously injured road users.
6. The policy options as developed in this impact assessment are unlikely to be realised. Possibly the most realistic option is continuing present policies. Yet, even this policy option may be slightly optimistic, in that it assumes a perfectly efficient selection of sites for treatment. The selection of sites for treatment on public roads in Norway is the result of a complex process of negotiations that will not result in a maximally efficient selection. Thus, a realistic estimate for the expected number of road accident fatalities in 2020 is about 200. The expected number of seriously injured road users in 2020 is about 850.
7. The results of the impact assessment are highly uncertain. It is, at the current state of knowledge, not possible to meaningfully quantify all

sources of uncertainty. However, the standard errors of the estimated effects on fatalities, amount to about 30 % of the best estimate in all policy options, considering only random variation in the number of fatalities and random variation in the total effect of all measures. This is clearly a lower bound estimate of uncertainty. True uncertainty will be greater.

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