Report
490/2000

Improving Road Safety in Sweden

An Analysis of the Potential for improving Safety, the Cost-Effectiveness and Cost-Benefit Ratios of Road Safety Measures

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Project: 2441 Analysis of the potential for improving road safety, the cost effectiveness of road safety measures, and the relationship to other policy objectives

Project manager: Rune Elvik

Quality manager: Marika Kolbenstvedt

Key
Road safety; Measure; Cost-benefit analysis; Vision Zero; Sweden

Summary:
The report presents an analysis of the potential for improving road safety in Sweden, the cost-effectiveness of road safety measures, and the effects of these measures with respect to other policy objectives. The analysis shows that there is a huge potential for improving road safety in Sweden. Benefits are greater than costs for measures that can reduce fatalities by about 50% and the number of injured road users by about 25%, The costs of trying to reduce fatalities and injures even more are, however, very high. A programme designed according to the principles of Vision Zero leads to conflicts with other policy objectives, especially mobility.

Tittel: Bedre trafikksikkerhet i Sverige - Hovedrapport

Forfatter(e *Rune Elvik; Astrid Helene Amundsen*

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Prosjekt: 2441 Analyse av potensialet for å bedre trafikksikkerheten, trafikksikkerhetstiltaks kostnadseffektivitet og forhold til andre trafikkpolitiske mål

Prosjektleder: Rune Elvik

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Emneord:
Trafikksikkerhet; Tiltak; Nytte-kostnadsanalyse; Nullvisjonen; Sverige

Sammendrag:
Rapporten gir en analyse av mulighetene for å bedre trafikksikkerheten i Sverige, ulike trafikksikkerhetstiltaks kostnadseffektivitet, og hvordan trafikksikkerhetstiltakene virker i forhold til andre trafikkpolitiske mål. Analysen viser at det er et stort potensiale for å bedre trafikksikkerheten i Sverige. Det er samfunnsøkonomisk lønnsomt å iverksette trafikksikkerhetstiltak som vil redusere antallet drepte med rundt regnet 50% og det totale antallet skadde og drepte med ca 25%. Tiltak som kan gi ytterligere reduksjon av antallet skadde og drepte er imidlertid uforholdsmessig dyre. Et trafikksikkerhetsprogram som bygger på Nullvisjonen medfører konflikt med andre trafikkpolitiske mål, særlig knyttet til framkommelïghet.

Language of report: English

The report can be ordered from:
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Rapporten kan bestilles fra:
Transportøkonomisk institutt, Biblioteket
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Preface

This report presents an analysis of the potential for improving road safety in Sweden. Sweden has officially adopted Vision Zero, which embodies a long-term ambition of totally abolishing death and serious injury in road traffic, as the basis for road safety policy. This report shows that it is possible to substantially reduce the number of road accident fatalities and injuries in Sweden.

The project was commissioned by the Swedish National Roads Administration. The principal contact person was Jan Ifver. He has been very helpful in providing data needed for the project. He also gave detailed and helpful comments to an earlier draft of the report. The assistance given by Hans Rydgren, Thomas Lekander and Östen Johansson is also gratefully acknowledged. They also provided constructive comments to the first draft of the report.

Rune Elvik has been project manager at the Institute of Transport Economics. Astrid Amundsen also worked on this project. Astrid Amundsen collected and systematised most of the data used in the project, and has prepared Appendix 2 in the report. She also updated the report based on the comments given to the first draft.

Lasse Fridstrøm has performed the final quality check of this report. The responsibility for any remaining errors rests, however, with the authors solely.

Oslo, October 2000
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Table of Contents

TØI rapport490/2000
Forfattere: Rune Elvik, Astrid Helene Amundsen
Oslo 2000, 201 sider

Sammendrag:

Bedre trafikksikkerhet i Sverige

Rapporten inneholder en analyse av mulighetene for å bedre trafikksikkerheten i Sverige. Tre hovedspørsmål behandles i rapporten:

- Hvor mye kan antallet skadde og drepte i trafikken maksimalt reduseres, dersom man bruker alle trafikksikkerhetstiltak i maksimalt tenkelig omfang?
- Hvilke trafikksikkerhetstiltak er mest kostnadseffektive, det vil si hvilke tiltak kan gi størst nedgang i antallet skadde og drepte regnet i forhold til hvor mye det koster å gjennomføre tiltakene?
- Hvilke trafikksikkerhetstiltak er samfunnsøkonomisk lønnsomme, det vil si gir en nytte, regnet i kroner, som er større enn kostnadene til å gjennomføre tiltakene? I nytten inngår både trafikksikkerhet, framkommelighet og miljøforhold.

Her oppsummeres kun de viktigste resultatene av analysene. Et mer utførlig sammendrag finnes i en egen sammendragsrapport (TØI-rapport 489/2000).

Trafikksikkerhetsproblemer i Sverige

Svenske myndigheter har utarbeidet en liste over viktige trafikksikkerhetsproblemer. I rapporten er det gjort et forsøk på å tallfeste hvor mye hvert av disse problemene bidrar til antallet skadde og drepte i trafikken i Sverige. Bidraget er tallfestet ved å beregne hvor stor nedgang i antallet skadde og drepte man i teorien kunne oppnå, dersom problemet ikke fantes. Beregningene viser at overtredelser av fartsgrensene er det viktigste trafikksikkerhetsproblemet i Sverige i dag. Omlag 50% av trafikken foregår i ulovlig fart. Dersom fartsgrensene ble overholdt, kunne antallet drepte reduseres med 38% og antallet skadde og drepte med 21%. Andre viktige problem er blanding av ubeskyttede og beskyttede trafikanter på samme trafikkareal og blanding av motorkjøretøy med svært ulik masse og varierende nivå på innebygd kollisjonssikkerhet. Betegnelsen beskyttede trafikanter omfatter alle som sitter i bil, betegnelsen ubeskyttede trafikanter omfatter alle andre grupper.

Det er beregnet at dersom alle trafikksikkerhetsproblemer på en liste over 20 slike problemer ble løst, i den forstand at den økning av skaderisiko hvert problem innebærer ble eliminert, kunne antallet drepte i trafikken reduseres med 89% og antallet skadde og drepte med 73%.

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Transportøkonomisk institutt, Postboks 6110 Etterstad, 0602 Oslo
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Trafikksikkerhetsmål og dagens tiltaksprogram

Nullvisjonen er offisielt vedtatt som et langsiktig ideal for trafikksikkerheten i Sverige. Nullvisjonen går ut på at ingen skal bli drept eller alvorlig skadet i trafikken når de ferdes innenfor lovens rammer (det vil blant annet si overholder fartsgrenser og promillegrenser og bruker bilbelte). Det er satt tallfestede mål for det høyeste antall drepte i trafikken i år 2000 og år 2007. Målet er 400 i år 2000 og 270 i år 2007. Et trafikksikkerhetsprogram, som fortsatt gjelder, ble utarbeidet i 1994. I tillegg til dette programmet ble en særskilt trafikksikkerhetsplan (11 punkts programmet) lagt fram våren 1999. Beregninger svenske myndigheter har gjort, tyder på at dagens tiltaksprogram for trafikksikkerhet i Sverige ikke er tilstrekkelig til å nå målet om høyst 270 drepte i år 2007. Fra 1994 til 2000 har det ikke vært noen nedgang i antallet drepte i trafikken i Sverige.

Mulige alternative trafikksikkerhetsprogram og deres effekter

For å anslå hvor store muligheter det er for å bedre trafikksikkerheten i Sverige, ble 139 trafikksikkerhetstiltak gjennomgått. 77 av disse ble av ulike grunner ikke inkludert i beregningene av potensialet for å bedre trafikksikkerheten, 62 tiltak ble inkludert. Disse 62 tiltakene ble satt sammen til fire alternative programmer for bedring av trafikksikkerheten. Programmene gjelder perioden 2002-2011. Programmene er:

- Videreføring av dagens trafikksikkerhetspolitikk
- Et program der kun samfunnsøkonomisk lønnsomme tiltak inngår
- Et program som bygger på Nullvisjonen
- Et program der alle tiltak brukes maksimalt.

Rapporten anbefaler ikke et bestemt trafikksikkerhetsprogram. De alternative programmene er kun ment å vise hvilke muligheter som foreligger og belyse fordeler og ulemper ved ulike hovedinnretninger i trafikksikkerhetspolitikken.

Det maksimale potensialet for å bedre trafikksikkerheten i Sverige er beregnet til vel 75% reduksjon av dagens antallet drepte og vel 55% reduksjon av dagens antall skadde og drepte. Dersom man viderefører dagens bruk av trafikksikkerhetstiltak, vil antallet drepte i trafikken kun bli ubetydelig redusert i år 2012 sammenlignet med gjennomsnittet for årene 1994-1998. Det var i 1994-1998 i gjennomsnitt 554 drepte i trafikken i Sverige. Ved en videreføring av dagens politikk forventes dette redusert til ca 530 i 2012. Det er da forutsatt en trafikkvekst på 1% per år fra 2000 til 2012. Det er videre forutsatt at antallet drepte, alt annet likt, øker med 0,64% for hvert 1% trafikkvekst.

Ved å satse på samfunnsøkonomisk lønnsomme trafikksikkerhetstiltak kan antallet drepte reduseres til 316 i 2011. Et program som bygger på Nullvisjonen gir et forventet antall drepte på 230 i 2011. Brukes alle tiltak maksimalt, kommer man ned i 180 drepte i 2011.

Målet på høyst 270 drepte som er satt for 2007 kan ikke nås med noen av programmene. Dette målet kan bare nås ved at man satser sterkt på tiltak som gir rask effekt i perioden fram til 2007. Økt politikontroll er det mest aktuelle tiltak som kan gi kortsiktige gevinster.

Utviklingen av antallet skadde og drepte i trafikken er usikker

Det må understrekes at resultatene av beregningene er usikre. Dersom man viderefører dagens bruk av tiltak, kan antallet drepte i 2011 bli mellom 473 og 587, gitt antakelsen om 1% trafikkvekst per år. Satser man samfunnsøkonomisk lønnsomme tiltak, kan antallet drepte i 2011 bli mellom 215 og 467. Et program som bygger på Nullvisjonen gir mellom 135 og 396 drepte i år 2011. Maksimalt potensiale for på bedre sikkerheten gir mellom 72 og 337 drepte i 2011.

På bakgrunn av disse resultatene synes det, tross den store usikkerheten, klart at en videreføring av dagens trafikksikkerhetspolitikk i Sverige ikke er tilstrekkelig til å nå de mål som er satt for denne politikken.

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Summary:

Improving Road Safety in Sweden

This reports presents an analysis of the potential for improving road safety in Sweden. Three main problems have been studied:

- What is the maximum potential for improving road safety in Sweden by applying all known road safety measures to the maximum conceivable extent?
- Which are the most cost-effective road safety measures, that is measures that can prevent the greatest number of killed or seriously injured road users in relation to the costs of implementing the measures?
- Which are the road safety measures whose total benefits, expressed in monetary terms, exceed their costs? Total benefits include improvements with regard to safety, mobility and the environment.

This is a short summary of the main results of the analyses. A more extensive summary is given in a summary report (TØI report 489/2000).

Road safety problems in Sweden

The Swedish government has prepared a list of the most important road safety problems. An attempt was made to determine the relative importance of each problem, by estimating the risk attributable to the problem. Attributable risk denotes the size of the reduction in the number of killed or injured road users that could be attained by eliminating the added risk associated with a certain risk factor. The analysis shows that violations of speed limits is the most important road safety problem in Sweden today. About 50% of all driving exceeds the speed limit. If perfect compliance could be attained, the number of fatalities could be reduced by 38%, and the total number of road users injured could be reduced by 21%. Other important road safety problems include the mixture of unprotected and protected road users, and the mixture of cars of different mass and different performance with respect to crashworthiness. The term protected road users denotes all car occupants, the term unprotected denotes all other road users.

It has been estimated that by eliminating all road safety problems from a list of 20 problems, the number of road accident fatalities could be reduced by 89% and the total number of injured road users by 73%. To eliminate a road safety problem means to remove the entire risk attributable to it.

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Road safety targets and current road safety policy

Vision Zero has been officially adopted as the basis for road safety policy in Sweden. Vision Zero is a long-term ideal, stating that nobody shall be killed or injured in road traffic, provided they comply with road traffic law. Quantified road safety targets have been set for 2000 and 2007. The target for 2000 is not more than 400 fatalities. The target for 2007 is not more than 270 fatalities. A road safety programme, still in force, was passed in 1994. In addition to this programme, a special traffic safety plan was presented in 1999. Estimates made by the Swedish government, show that the current road safety programmes are insufficient to realise the target of 270 fatalities set for 2007. Between 1994 and 2000, the number of road accident fatalities in Sweden was not reduced.

Alternative road safety programmes and their effects

In order to estimate the potential for improving road safety in Sweden, a survey was made of 139 road safety measures. 77 of these were, for various reasons, omitted from further consideration. A formal analysis of maximum potentials for contributing to safety, cost-effectiveness and cost-benefit ratio was made for the remaining 62 measures. Four alternative road safety programmes were developed by combining the measures. These programmes applied to the ten year period 2002-2011. The alternative road safety programmes were:

- Business-as-usual, meaning that current road safety policy is continued until 2012
- Cost-benefit strategy, consisting of those measures whose benefits are greater than their costs
- Vision Zero strategy, designed to implement the main principles of Vision Zero
- Maximum safety potentials strategy, in which all measures are applied to the maximum conceivable extent.

This report does not recommend any of these strategies. They have been developed solely for the purpose of indicating the opportunities for improving road safety, and the range of choices for road safety policy.

The maximum potential for improving road safety has been estimated to a reduction of more than 75% in the current number of fatalities and more than 55% in the current total number of injured road users. If current road safety policy in Sweden is continued until 2011, there will be only a minor reduction of the number of killed road users by 2012. The mean annual number of road accident fatalities during 1994-1998 was 554. The mean annual number of people injured was 21,721. The predicted number of road accident fatalities for 2012, if current road safety policy goes on, and there is a traffic growth of 1% per year, is about 530. It has been assumed that, ceteris paribus, the number of fatalities increases by 0.64% for each 1% increase in traffic volume.

By adopting the cost-benefit strategy, the number of killed road users can be reduced to 316 by 2011. the Vision Zero strategy gives a predicted number of fatalities of 230 by

2011. The maximum safety potentials strategy gives a predicted number of 180 fatalities in 2011.

The target set of a maximum of 270 fatalities in 2007 cannot be realised, no matter which strategy is chosen. The only way of realising this target is to considerably increase the use of measures that have effects in the short term, before the year 2007. Increasing police enforcement is an example of a measure that has short term effects.

Predicting the number of killed or injured road users is difficult

It is important to stress the fact that the estimates are highly uncertain. If, for example, current road safety policy is continued, and traffic grows by 1% per year, the predicted number of fatalities in 2011 is between 473 and 587. Corresponding lower and upper limits are 215 and 467 for the cost-benefit strategy, 135 and 396 for the Vision Zero strategy, and 72 and 337 for the maximum safety potentials strategy.

Based on these results it seems clear, despite the considerable uncertainty involved, that a continuation of current road safety policy in Sweden is not sufficient to realise the targets that have been set for this policy.

1 Background and Objectives

The Swedish Parliament has set ambitious targets for improving road safety. The long-term vision for road safety is that no one shall be killed or seriously injured in road traffic accidents. This long-term vision is known as Vision Zero (Vägverket 1997). Vision Zero is not meant as a policy objective in the short term. The current targets for improving road safety in Sweden are:

- Not more than 400 fatalities in the year 2000
- Not more than 270 fatalities in the year 2007

The number of road accident fatalities in Sweden in 1999 was 580. The number of fatalities has remained stable from 1995. For the year 2007 a quantified target has been set for fatalities only. A quantified target has been set for persons with serious injury in the year 2000 to not more than 3 700 (reported by the police).

In order to develop an effective road safety programme, the Swedish National Road Administration granted a research project to the Institute of Transport Economics entitled: “Assessing the road safety potential, cost-effectiveness and relationship to other policy objectives of road safety measures”. This report presents the results of this project.

The objective of the report is to identify the road safety measures that can:

- Bring about the greatest reduction in the number of road accident fatalities and injuries,
- Reduce the number of road accident fatalities and injuries at the lowest possible direct costs of implementation,
- Reduce the number of road accident fatalities and injuries with the least amount of conflict with respect to other policy objectives.

These three objectives refer to three stages of the research project. The first stage is to identify the road safety measures that have the greatest potential for improving road safety, not taking their costs of implementation or effects on other policy objectives into account. The second stage is to identify the most cost-effective road safety measures. At this stage, the costs of implementing the measures are taken into account, but their effects on other policy objectives are not included. The third stage is to identify those road safety measures that both promote safety and other policy objectives, or involve the least amount of conflict with respect to other policy objectives. This is done both by means of a cost-effectiveness analysis and a cost-benefit analysis.

2 Statement of Research Problems

The main research problems to be discussed in the report are:

- What is the maximum number of fatalities and injuries in road traffic that can prevented by applying road safety measures?
- Which are the most cost-effective road safety measures, that is the measures that give the greatest reduction in the number of road users killed or injured in relation to the costs of implementing the measures?
- What are the effects of road safety measures with respect to other policy objectives? How can conflicts between policy objectives be minimised?

In order to answer these main questions, we need to discuss a number of other issues. These include:

- What are the major current road safety problems in Sweden? Which factors contribute to the occurrence of accidents and injuries and to what extent is it possible to control these factors by means of road safety measures?
- Which are the road safety measures that are currently applied in Sweden? What is the best estimate of the effects on road safety of these measures?
- How can potentially effective road safety measures be identified? What are the criteria that should be applied in screening measures for inclusion in a road safety programme?
- What are the relevant policy objectives for the road sector in addition to improving road safety? How can various policy objectives be traded off against one another when they conflict?
- How can alternative road safety programmes be developed, to show the range of choices and the measures that are needed in order to realise the road safety objectives set for the years 2000 and 2007?
- Which approaches can be taken to priority setting for road safety measures according to the three study objectives of (1) estimating the maximum potential for safety improvement, (2) identifying the most cost-effective measures to realise road safety objectives, and (3) identifying those measures that to the highest possible extent promote both road safety and other policy objectives?

These issues are discussed in the subsequent chapters.

3 Current road safety problems in Sweden

3.1 An epidemiological approach to the definition of road safety problems

It has sometimes been claimed that there is no rational way of defining road safety problems and assessing how easily these problems can be solved. Thus, for example, Pedersen, Elvik and Berard-Andersen (1982, page 29) state:

> "What do we mean by a road safety problem? There are many answers to this question that all make sense. The risk that children run on their trip to school is a road safety problem. Drinking and driving is a road safety problem, driving in the dark is a road safety problem, and young driver risk is a road safety problem. By making such lists of problems, it is possible to cover all areas of road safety. The snag is that the various problems on such a list tend to overlap. Children are at risk when travelling to school partly because young drivers have a high risk of accident involvement, partly because there is drinking and driving, and partly because driving in the dark increases the risk of accident. Drinking and driving is a major problem partly because it takes place in the dark and on roads where there are pedestrians and cyclists. These examples show how difficult it is to define road safety problems in an orderly and logical way. This difficulty is particularly relevant when we want to give an exhaustive definition of road safety problems."

It is obviously correct that the risk factors that contribute to accidents and injuries interact in complex ways that are not fully known. It is equally true that there does not exist any scientifically "correct" way of defining road safety problems, at least not in a strict sense of the term. But it is wrong to conclude that any list of road safety problems is arbitrary and therefore of no use for the purpose of developing an effective road safety programme. A rational approach to the definition of road safety problems can be developed by relying on concepts taken from epidemiology, combined with policy objectives and principles and a classification of factors contributing to accidents and injuries with respect to how easily they can be controlled or removed.

One of the basic notions of epidemiology is that of *attributable risk*, also known as etiologic fraction (Kleinbaum, Kupper and Morgenstern 1982). Attributable risk is simply the fraction of accidents or injuries that is attributable to a certain risk factor, or – to put it differently – the size of the reduction in the number of accidents or injuries that would be achieved by removing the risk factor.

Attributable risk is generally expressed as a fraction and can take on values in the range from 0 to 1. A risk factor is any factor that, ceteris paribus, increases the probability of sustaining an accident or worsens the severity of injuries. To illustrate the concept, consider the case of unprotected road users. Unprotected road users are all road users who are not enclosed by a deformable structure absorbing energy in case of an accident. They include pedestrians, cyclists and riders of mopeds and motorcycles. Protected road users are drivers and passengers of cars and buses. Trucks are not included.

Table 1 shows the number of fatalities, the number of injuries recorded by the police, the annual amount of travel and the relative fatality and injury rate of unprotected and protected road users in Sweden according to the 1992 national household travel survey (Thulin and Nilsson 1994).

Table 1: Number of fatalities, police reported injuries, amount of travel and relative risks of fatality and injury for unprotected and protected road users in Sweden. Source: Thulin and Nilsson 1994.

Injuries, travel and risk	Unprotected road users	Protected road users	All road users
Killed road users	259	466	725
Injured road users	6,454	14,633	21,087
Mill person km of travel	6,661	114,861	121,522
Relative fatality rate	9.58	1.00	1.47
Relative injury rate	7.61	1.00	1.36
Attributable fatality risk	0.896	Reference	0.320
Attributable injury risk	0.869	Reference	0.266

The table is based on information from about 1992 when the number of people killed in traffic in Sweden was higher than it is today. This is unimportant, as the Table is used only to illustrate a concept. It is seen that unprotected road users run a risk of being killed that is nearly ten times higher than the risk run by protected road users. To bring down the fatality risk run by unprotected road users to the same level as that of protected road users, a reduction of nearly 90% would be needed. This is the attributable risk of a fatal injury for unprotected road users as shown in the Table (0.896), which is estimated simply as the ratio (9.58 – 1)/9.58. This measure of attributable risk will be referred to as *the target attributable risk*, that is as the reduction in risk that must be achieved within the target group, in this case unprotected road users, in order get the same risk level as the reference group, in this case protected road users.

The overall, or *population attributable* risk for unprotected road users is the contribution their enhanced risk level makes to the total number of people killed or injured. The overall attributable risk has been estimated to 0.320 for fatality risk and 0.266 for injury risk, as shown in the right column of Table 1.

To explain how population attributable risk is estimated, denote by PE the proportion of exposure to the risk factor of interest. In Table 1, this proportion is 6,661/121,522 = 0.055, that is the proportion of all travel done by unprotected road users. Denote by RR the relative risk run when exposed to the risk factor of interest. In Table 1, this is 9.58 for fatality risk. In computing relative risk, the safest category of any risk factor is always used as reference. Population attributable risk (PAR) is then defined as:

Overall attributable risk (PAR) = $\frac{PE(RR-1)}{(PE(RR-1))+1}$ (1)

For fatality risk in Table 1, the numerator comes to 0.055 x 8.58 = 0.47. The denominator is 0.47 + 1 = 1.47. Attributable risk is 0.47/1.47 = 0.32.

To check if this estimate is correct, one can do the following: Estimate the expected number of killed unprotected road users if their risk were the same as that of protected road users. The fatality risk for protected road users (per million personkm of travel) is 466/114,861 = 0.004. If unprotected road users had the same risk level, the expected number of fatalities would be 0.004 x 6,661 = 27. The actual number of fatalities was 259. There would in other words be a saving of 232 fatalities (259 – 27). This saving amounts to 32% of the total number of fatalities (232/725 = 0.32).

By estimating the risks attributable to various risk factors, it is possible to get a quantified notion of their importance in contributing to accidents and injuries. This makes it possible, in principle, to rank various risk factors in order of their importance as contributing factors to accidents and injuries. In this report, an attempt has been made to quantify the importance of various road safety problems in Sweden by estimating the risks attributable to them.

Several notes of caution with respect to the use of attributable risks as a measure of the importance of various road safety problems are in order:

- There are many important risk factors for which no meaningful estimate of attributable risk is possible. Inattention on the part of road users is a case in point. There is little doubt that inattention causes many accidents. However, trying to quantify the contribution of this risk factor to accidents is very difficult, because exposure to it is virtually impossible to measure (what is the proportion of kilometres driven by inattentive drivers?).
- Risk factors tend to be correlated, but these correlations are not very well known. It is in most cases probably not correct to add the risks attributable to two risk factors in order to find their joint contributions to accidents or injuries. How to estimate the total contribution of a set of risk factors will be discussed in a subsequent section of the report.
- Some road safety problems are not adequately described in terms of enhanced risk. Children, for example, do not have an excessive risk of injury in traffic compared to adults. However, it is a policy objective to provide a higher level of safety for children than for other groups of road users. As long as it remains possible to reduce the risk of injury to children, this policy objective has not been fully attained, despite the fact that estimates of attributable risk will not identify children as a particularly vulnerable group.
- Accidents and injuries are not fully reported in official accident statistics. If the level of reporting is associated with a risk factor, an estimate of the risk attributable to that factor will be biased. This may apply to the risk attributable to being an unprotected road user, at least as far as injuries is concerned. Injuries to unprotected road users, especially cyclists, are known to be more incompletely reported in official statistics than injuries to car occupants. An estimate of attributable risk based on official accident statistics will then be an underestimate of the true risk attributable to being an unprotected road user.

Despite these limitations, the concept of attributable risk is fruitful when trying to assess the importance of various road safety problems. Attributable risks serve as indicators only, they are not exact and have to be supplemented by other considerations. They are nevertheless a useful starting point.

3.2 Problem perceptions underlying current road safety policy and Vision Zero as guideline in defining road safety problems

The current road safety programme for Sweden was adopted in 1994. It contains a list of eighteen road safety problems. This list is reproduced in Table 2. The various problems have been put in five main categories. The reason for doing so will be explained shortly.

Table 2: Current road safety problems in Sweden. Source: Kommunikationskommittén 1997.

Main areas of current road safety problems	Specific problems listed in road safety programme
A Poor design of the road system and of vehicles	1 Risks are too high in built-up areas
	2 The standard of roads is poor in many places
	3 Too many roads and vehicles are poorly designed with respect to crashworthiness
	4 Road users get too little guidance and support
	5 Heavy vehicles are over represented in serious accidents
	6 Some junctions have too high risks
B Environmental risk factors	7 Accident risk is too high at night
	8 Accident risk is too high during winter
	9 There are too many accidents involving animals
C Vulnerability of road users	10 The safety of children is insufficient
	11 The safety of unprotected road users is insufficient
	12 Young drivers run too high risks
	13 Older road users run too high risks
D Unsafe road user behaviour	14 Speeding is too common
	15 Drinking and driving is too widespread
	16 Behaviour is too often inconsiderate
	17 There is too much car driving in towns
E Provision of medical services	18 Medical services and rescue are insufficient

The relative importance of the various road safety problems has not been fully quantified in the road safety programme, although the programme discusses the importance of the road safety problems partly in purely verbal terms, partly by trying to quantify the various problems.

Vision Zero does provide a useful framework for assessing the importance of the road safety problems listed in Table 2. Vision Zero embodies a set of principles for designing road safety policy that can be applied to put the various road safety problems into main groups. The most important principles of Vision Zero can be stated as follows:

- The level of violence that humans can sustain without getting killed or seriously injured constitutes the basic design parameter for the road transport system. This means that no accident should expose those involved to an amount of biomechanical energy that exceeds the threshold for sustaining a serious injury.
- Vehicle speed is the most important regulating factor for road traffic. The permitted maximum speed of travel should be determined so as not to exceed the injury severity threshold described above.
- The designers of roads and vehicles are responsible for designing roads and vehicles so as to comply as closely as possible with the injury severity design parameter.
- Road users are responsible for complying with the rules for using the road system set by the system designers.
- If road users fail to comply with the rules set by the system designers, the system designers are required to take further action in order to counteract people being killed or injured.

These principles imply the following lexicographic ordering of risk factors contributing to road safety problems:

1 Factors contributing to fatal and serious injuries are more important than factors contributing to slight injuries.

2 Of the factors contributing to fatal and serious injuries, those that can be removed or controlled by action taken by the system designers are more important than factors that are primarily controlled by each road user.

3 Speed is the single most important risk factor both for accident occurrence and injury severity.

In Table 2, problems that can be reduced by a better design of roads or vehicles (group A) have been put on top of the list. Progress in solving these problems does not necessarily depend on changes of road user behaviour. One can, for example, make roadsides more forgiving without requiring road users to change behaviour at all. System designers are completely in control of the design of roads and vehicles. The second group of risk factors (group B) consists of environmental risk factors. These factors are partly beyond human control, but can to some extent be controlled both by system designers and by road users.

The third category of road safety problems (group C) has been labelled vulnerable road users. Vulnerable road users share at least two of the following three characteristics: (1) They are unable to control their own risk by taking appropriate action, due, for example to an inadequate understanding of risk (children). (2) They run a higher risk of accident involvement than other groups of road users. (3) They are less protected and hence more likely to be killed or seriously injured when involved in an accident than other groups. Vision Zero implies that system designers have to pay more attention to vulnerable road users than to protected road users. The fourth category of road safety problems (group D) concerns road user compliance with the rules made by the system designers. Progress in solving these problems does not necessarily require changes to be made in the design of the system, but it does require road users to change behaviour to the extent they currently violate the rules regulating road user behaviour. Finally, category E refers to the medical treatment and first aid rescue aid given to accident victims and is a responsibility of the system designers.

3.3 Levels of intrusion into road user liberty in road safety policy

Vision Zero puts a major emphasis on the responsibility system designers carry for road safety. Roads, vehicles and other components of the road transport system ought to be designed according to the basic safety principle on which Vision Zero is based, which is to control the amount of biomechanical energy in a way that prevents death or serious injury from occurring. Attention is focussed on injuries rather than accidents. It is recognised that human fallibility makes it impossible to prevent accidents from occurring altogether.

This approach to injury prevention does not absolve road users of their responsibility for preventing injuries. It does, however, put the responsibilities of the system designers above those of road users. Roughly speaking, one can distinguish between the following levels of intrusion into individual liberty involved in implementing road safety measures.

1 Injury control

In pure form, injury control involves measures that do not affect the probability of accident occurrence and that do not require road users to change behaviour. The amount of travel and the choice of mode of travel is not affected.

2 Accident prevention by system design

Accident prevention by system design includes any measure that changes the system, but does not require road users to change behaviour in any way. Installing road lighting is an example of this kind of road safety measure.

3 Accident prevention by enforcement of current rules and regulations

Accident or injury prevention measures belonging to this group involve the enforcement of current rules and regulations. This may involve changes of behaviour to the extent that road users violate current rules and regulations.

4 Accident prevention by introducing new rules and regulations

This may involve, for example, lowering speed limits to make them comply with the principles of Vision Zero. This is more intrusive than enforcing current rules, in that it may force even those who comply with current rules to alter their behaviour.

5 Accident prevention by exposure control

This is the most intrusive approach to accident and injury prevention, in that it may force road users to travel less or limit their choice of mode of travel, for example by prohibiting highly risky modes like motorcycle travel.

Within the framework of Vision Zero, the highest preference is given to measures belonging to group 1, the lowest preference to measures belonging to group 5. Injury prevention policy should, in other words, intrude as little as possible into the liberty of road users with respect to the amount of travel, the mode of travel and behaviour when travelling.

3.4 The treatment of correlations between risk factors – uncertainties in attributable risks

When the contributions of various risk factors to current road safety problems are to be assessed, it is important to try to account for the correlations between risk factors. Otherwise, one may double count the contributions of a set of risk factors to injuries and thereby overestimate the potential for injury reduction by removing or controlling the risk factors. This can be illustrated by means of a numerical example.

Consider the data given in Table 3. These data are fictitious and are used only to illustrate how the existence of correlations between risk factors may bias estimates of the risks attributable to them. In the Table, the risks attributable to two risk factors are considered. It is assumed that each risk factor increases risk by 50%, which gives a relative risk of RR = 1.50 for those exposed to the risk factor. Relative risk when exposed to both risk factors is 1.5 x 1.5 = 2.25. Moreover, it is assumed that 20% of all road users are exposed to each factor.

If exposure to one of the risk factors is independent of exposure to the other, it can easily be worked out that 64% of all road users will not be exposed to any of the two factors (0.8 x 0.8 = 0.64). 32% will be exposed to one factor only [2 x (0.8 x 0.2 = 0.16)], and 4% will be exposed to both factors (0.2 x 0,2 = 0.04). This distribution of exposure is shown in the first row of Table 3, for the case in which there is no correlation in exposure to the two risk factors. In this case the risk attributable to the first factor is estimated to 0.091, and the risk attributable to the second factor to the same value, 0.091. The total risk attributable to both risk factors is 0.174. Attributable risks are shown in boldface italics in Table 3.

When exposure to the two risk factors is uncorrelated, total attributable risk can be estimated by multiplying the residuals of the individual attributable risks and subtracting the obtained value from 1 in order to obtain the joint residuals. This will be referred to as *the method of joint residuals*. It works like this:

Risk attributable to factor 1 = 0.091; residual = 1 – 0.091 = 0.909.
Risk attributable to factor 2 = 0.091; residual = 1 – 0.091 = 0.909.
Product of residuals = 0.909 x 0.909 = 0.826. (joint residuals)
1 – 0.826 = 0.174.

Table 3: Illustration of how the existence of correlations between risk factors may bias estimates of risks attributable to them. Fictitious data.

		Risk factors present in exposure and injuries				
Correlation in exposure	Exposure and risk	None	Factor 1	Factor 2	Both	Total
None (0.00-0.15)	Exposure	640	160	160	40	1000
	Injuries	640	240	240	90	1210
	Relative risk	1.00	1.50	1.50	2.25	
	Risk attributed to factor 1	1.00	1.50			*0.091*
	Risk attributed to factor 2	1.00		1.50		*0.091*
	Total attributable risk				1.58	*0.174*
Moderate (0.15-0.50)	Exposure	700	100	100	100	1000
	Injuries	700	150	150	225	1225
	Relative risk	1.00	1.50	1.50	2.25	
	Risk attributed to factor 1	1.00	1.76			*0.133*
	Risk attributed to factor 2	1.00		1.76		*0.133*
	Total attributable risk	1.00			1.75	*0.184*
Strong (0.50-0.85)	Exposure	760	40	40	160	1000
	Injuries	760	60	60	360	1240
	Relative risk	1.00	1.50	1.50	2.25	
	Risk attributed to factor 1	1.00	2.05			*0.173*
	Risk attributed to factor 2	1.00		2.05		*0.173*
	Total attributable risk	1.00			2.00	*0.194*
Perfect (0.85-1.00)	Exposure	800	0	0	200	1000
	Injuries	800	0	0	450	1250
	Relative risk	1.00			2.25	
	Risk attributed to factor 1	1.00	2.25			*0.200*
	Risk attributed to factor 2	1.00		2.25		*0.200*
	Total attributable risk	1.00			2.25	*0.200*

This procedure does not work when exposure to the two risk factors is correlated. A correlation of exposure denotes a situation in which those who are exposed to risk factor 1 are also exposed to risk factor 2 more often than chance alone implies.

Looking first at the case of a moderate correlation, the simple estimates of attributable risk are 0.133 for each risk factor, summing to 0.266. These are the estimates of attributable risk for each risk factor that can be derived from a simple two way tabulation of exposure and risk for each factor, not taking into account the correlation in exposure to the two factors. It should be noted that summing of attributable risks does not make much sense. However, the total risk attributable to both factors amounts to 0.184, which is substantially less than the sum of the risks attributed to each factor. The correlation can, in this case, be estimated to

0.375, according to a binomial effect size display for a two-by-two table (Rosenthal 1994).

The bias in simple estimates of attributable risk becomes greater the higher is the correlation in exposure to the two risk factors. In the case where exposure is perfectly correlated, that is everyone who is exposed to one risk factor is also exposed to the other, adding the risks attributed to each risk factor counts their contribution to injuries twice.

In the limit, then, not accounting for the correlation between risk factors may lead to complete double counting of their effects on the number of injuries. Unfortunately, there is little knowledge about correlations between risk factors.

Ideally speaking, estimates of the risks attributable to specific risk factors ought to be derived from multivariate analyses in which the partial effects of each risk factor have been estimated while controlling for as many other risk factors as possible. Very few multivariate analyses of this nature, based on Swedish data, are available (Fridstrøm et al 1993, Tegnér and Loncar-Lucassi 1996). Besides, the results of those few studies have not been presented in a format that easily allows attributable risks to be estimated. It must therefore be concluded that studies allowing well controlled estimates of the contributions of various risk factors to injuries in road accidents in Sweden do not exist. Any estimate based on available data is likely to be incomplete and possibly misleading. It has nevertheless been concluded that it is better to try to make the best use of current data, rather than not attempting to quantify the contributions of various risk factors to current road problems.

The approach taken in textbooks in epidemiology to estimating uncertainty for an attributable risk is to estimate the uncertainty of the relative risk used in estimating attributable risk. This approach is not applicable to the estimates presented here. Attributable risk has in some cases been estimated informally, in other cases by using methods that do not utilise information about relative risks. Hence, another approach has been taken.

The risks attributable to each risk factor can be interpreted as a potential safety effect, that is an effect of removing the risk factor entirely. An attributable risk of 0.034, for example, corresponds to a potential safety improvement of 3.4%. Interpreted this way, uncertainties can be estimated by relying on the log odds method applied in meta-analysis. Each estimate of attributable risk is related to the mean annual number of traffic injuries in Sweden for 1994-1998. This was 554 for fatalities and 21,721 for injured road users in total. The value of the statistical weights is determined by estimating the prevented number of injuries corresponding to each estimate of attributable risk. Thus, an estimate of 0.034 for fatalities, for example, corresponds to 0.034 * 554 = 18.8 prevented fatalities. The statistical weight assigned to this estimate then becomes:

Weight (w) = 1/(1/554 + 1/18.8)

These weights are inversely proportional to sample size, which will in turn minimise the variance of the weighted estimate. The log odds estimate of attributable risk is:

$$\text{Attributable risk} = \exp\left(\frac{\sum_{i=1}^{g} w_i\, y_i}{\sum_{i=1}^{g} w_i}\right) \qquad (2)$$

in which y_i is the natural logarithm of the first order estimate of attributable risk. The 95% confidence interval for attributable risk is estimated according to:

$$\text{95\% confidence interval} = \exp\left[\left(\sum_{i=1}^{g} w_i\, y_i / \sum_{i=1}^{g} w_i\right) \pm 1.96 \cdot 1/\sqrt{\sum_{i=1}^{g} w_i}\right] \qquad (3)$$

This method of estimation is strictly analogous to the one used in meta-analysis employing the log odds method (Fleiss 1981). Table 5 gives the estimated 95% confidence intervals for first order attributable risks. Two main tendencies are apparent in the table:

1. There is greater uncertainty about attributable risks for fatal injury than for injured road users in total.
2. There is greater relative uncertainty about the risks attributed to risk factors that make a comparatively small contribution than to the risks attributed to factors that make a greater contribution to fatalities and injuries.

3.5 A preliminary quantification of important road safety problems in Sweden

The contribution of various factors to current road safety problems in Sweden has been estimated in stages. Details of the estimation are given in Appendix 1.

The following points are important to note with respect to the interpretation of the estimates that are presented:

- The attributable risks refer to the risks of sustaining a fatal injury or an injury reported to the police. No account has been taken of incomplete accident reporting.
- Two problems have been added to the list, compared to the list given in Table 2. Poor crashworthiness of roads and cars has been divided into two problems, one referring to roadside obstacles, the other to vehicle crashworthiness. Non-use of seat belts has been added to the list of problems, making the total number of problems 20.
- The estimates of attributable risk represent the contributions of the various factors as of the early or mid nineteen nineties. The contribution of a specific risk factor to fatalities and injuries may change over time. If, for example, there is a decline in drinking and driving, this factor may become relatively less important for road accidents.

Simple first order attributable risks. The first stage of analysis was to estimate the *first order attributable risks* of the risk factors representing the twenty road safety problems listed in Table 2 in a set of simple two way tabulations. These estimates did *not* account for *overlaps* between the problem categories or *correlations in exposure* to the various risk factors. The results of this first stage of estimation are given in Figure 1. To keep the figure simple, confidence intervals are not shown. Confidence intervals can be found in Appendix 1.

Bad system design, vulnerability of road users, and road user behaviour are the three most important main categories of roads safety problems as evidenced in the first order risks attributable to these problems. Each of these problems account for about 60% of fatalities and about 40% of all injuries. If violations of road traffic law did not occur, the number of fatalities could be reduced by 63% and the total number of injuries could be reduced by 37% (Figure 1).

The sum of all first order attributable risks is 2.36 for fatalities and 1.56 for injuries. This simply shows the widely known fact that more than one risk factor may contribute to each accident. This fact is known from in-depth studies of accidents, which usually list several factors that may have contributed to each accident. Hence, if one simply adds the contributions of a set of risk factors to accidents, one will nearly always come to more than one hundred percent. In fact, if more factors had been included in the analysis, the sum of the first order contributions would have been greater than the numbers given in Figure 1.

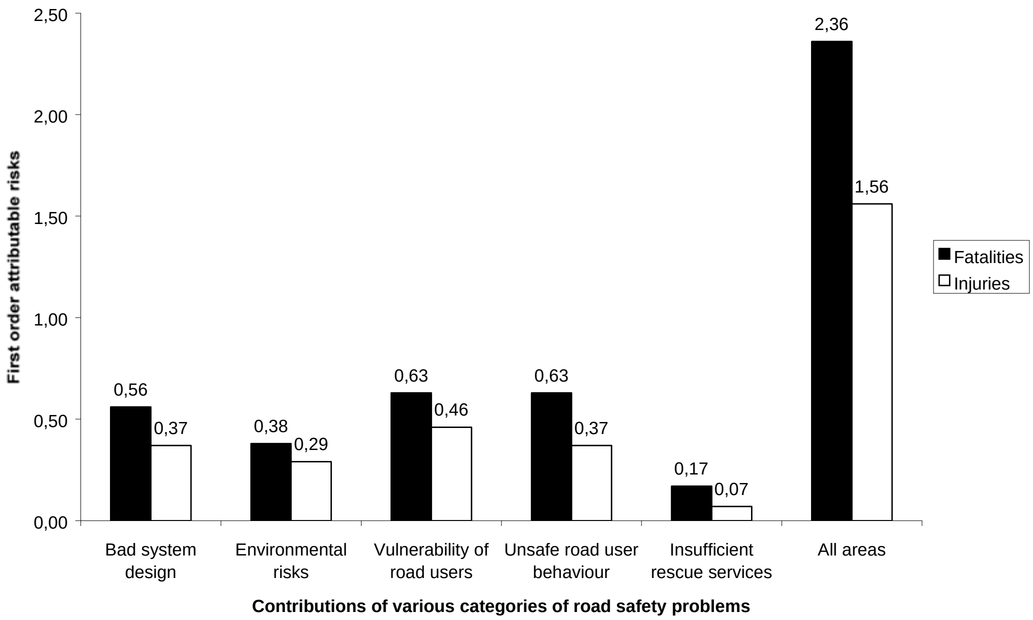

Figure 1: First order attributable risks of major road safety problems in Sweden

The single most important problem of the twenty that were included in the analysis is violation of speed limits. Speeding represents an attributable risk of 0.38 for fatalities and 0.21 for injuries. This means that the number of road accident fatalities in Sweden could be cut by nearly 40% if drivers simply complied with current speed limits. This result is so remarkable that it deserves a more careful discussion.

Data on current driving speeds and violation rates were taken from two sources: A research note issued by VTI (Andersson, et al 1998) and a report issued by the Swedish National Road Administration (Isaksson 1997). The assumption was made that speeds are normally distributed around the mean speed. The mean speed corresponds to the 50th percentile speed in a cumulative speed distribution. It was further assumed that the entire speed distribution is contained within plus or minus three standard deviations from the mean speed (spanning a range of six standard deviations).

Perfect compliance with speed limits was defined as a speed distribution in which 90-95% of all drivers keep to the speed limit. The critical value for perfect compliance was defined as the following speed:

Speed equal to posted speed limit = Mean speed + 1.5 standard deviations

93.3% of the normal distribution is located to the left of the mean plus 1.5 standard deviations, implying that a violation rate of about 7% was tolerated. Figure 2 illustrates the procedure used in estimating the mean speed that corresponds to perfect compliance with speed limits thus defined.

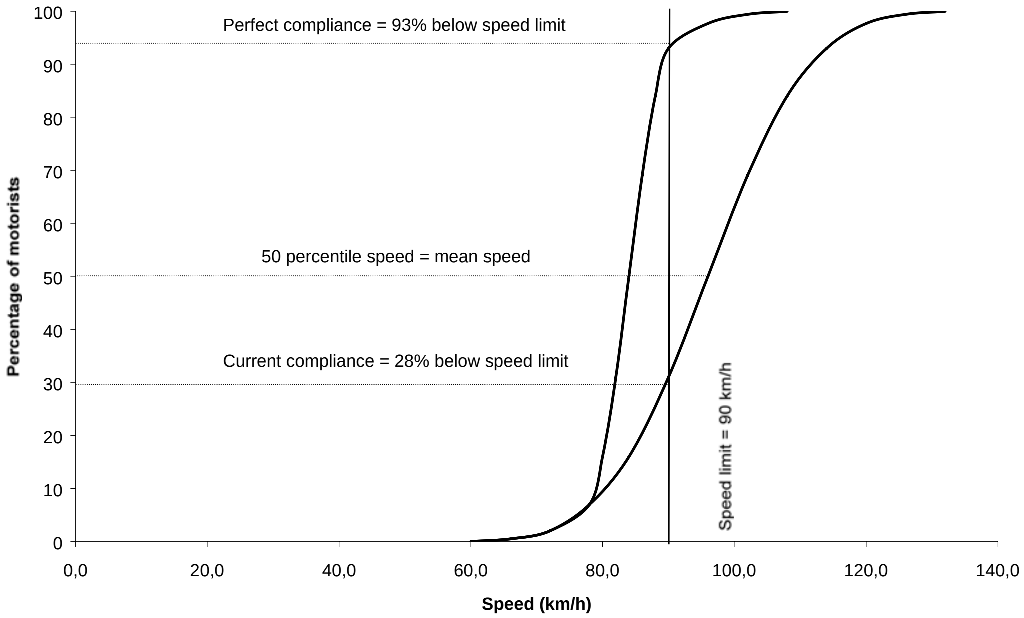

Figure 2: Illustration of perfect compliance with speed limits. Motor traffic roads with speed limit 90 km/h

Motor traffic roads with a speed limit of 90 km/h have been used as an illustration. The current mean speed on these roads is 96 km/h. The violation rate is 72%. The current distribution of speeds is shown by the S-curve to the right in Figure 2. The solid vertical line represents the speed limit of 90 km/h. It was assumed that drivers who at present believe that they comply with the speed limit will not further reduce their speed. Hence, the speed distribution that applies in case of perfect compliance starts at the same minimum speed as the current speed distribution. It starts deviating from the current speed limit at a speed about 10% lower than the posted speed limit, because some drivers will adapt to the speed indicated by their speedometers, although most speedometers show a speed which is higher than the actual speed. This means that the speed distribution applying to perfect compliance with speed limits is considerably more peaked around the mean speed than the current speed distribution. The new mean speed is worked out by relying on the approximation to the normal distribution and comes to 84 km/h for the speed limit of 90 km/h. Mean speed in case of perfect compliance will always be below the posted speed limit, since it corresponds to the 50^{th} percentile speed.

The assumptions used to derive the safety implications of perfect compliance with speed limits are debatable. A simpler approach would be to assume that everybody kept exactly to the posted speed limit. However, until everybody uses a perfect speed adapter for motor vehicles, which communicates with speed limit signs, it seems unrealistic to assume that speed variance will disappear altogether. As long there is speed variance, perfect compliance implies that the mean speed will be below the speed limit. It is not claimed that perfect compliance with speed limits is a realistic objective in the short run. The estimate presented here merely shows the importance of driving speed for the number of injuries.

Adjusting for overlapping problem definitions and correlations among risk factors. The second stage of analysis was to adjust the simple first order attributable risks for overlapping problem definitions and the presence of correlations in exposure to the various risk factors. The following categories of road safety problems partly overlap:

1 High risk in built-up areas and high risk for unprotected road users

Since most unprotected road users are injured in built-up areas, the higher risk in built-up areas compared to the countryside is partly attributable to the presence of more unprotected road users in built-up areas. The overlap between these problems was removed by subtracting 0.144 from the first order attributable risk of a fatal injury to an unprotected road user and subtracting 0.178 from the first order overall attributable risk of injury to an unprotected road user. This subtraction was based on the proportion of accidents involving unprotected road users that occurs in built-up areas.

2 High risk in built-up areas and high risk in some junctions

Most accidents in junctions occur in built-up areas and thereby contribute to the high risk in those areas. The overlap between the two problems was removed by subtracting 0.014 from the fatality risk attributed to junctions and 0.015 from the injury risk attributed to junctions. This subtraction was based on the proportion of junction accidents that occur in built-up areas.

3 Roads standards are low and some roads are poor with respect to crashworthiness

These problems partly overlap. The overlap was removed by subtracting 0.014 from the fatality risk attributed to roadside objects and subtracting 0.003 from the injury risk attributed to roadside obstacles. These subtractions reflect the fact that hitting a roadside obstacle is more likely on narrow roads with poor alignment than on wider and more straight roads, even if the roadside obstacles are located at the same distance from the edge of the road.

4 High risk for unprotected road users and safety problems of children

These problems overlap to the extent that children are injured as unprotected road users. Risks attributable to children as unprotected road users were subtracted from the overall risk attributed to children to remove the overlap between the problems. The subtractions were 0.005 for fatality risk and 0.014 for injury risk.

5 High risk for unprotected road users and for older road users

These problems overlap to the extent that older road users are injured as pedestrians and cyclists. Removing the overlap involved subtracting 0.110 from the overall fatality risk attributed to being an older road user and subtracting 0.026 from the overall injury risk attributed to being an older road user.

It was assumed that exposure to darkness and to winter road conditions are correlated. This assumption is reasonable, since there is less daylight in winter than in summer. A correlation of .5 was assumed and the first order attributable risks from darkness and winter conditions were, somewhat conservatively, reduced by 30% each.

Violations of road traffic law, except for speeding, were assumed to be correlated. A three way (multiple) correlation of .3 between drinking and driving, not wearing seat belts and other violations was assumed. The risk attributable to reach of these violations was reduced by 10%.

Once these adjustments had been made, the marginal effect of each risk factor was estimated by applying the method of joint residuals. As explained in section 3.4, this method is based on the assumption that exposure to the risk factors is uncorrelated. Figure 3 shows the results of the estimation.

Adjusting for overlaps and correlations reduces the sum of the attributable risks from 2.36 to 1.95 for fatalities and from 1.56 to 1.23 for injuries. The sum of the marginal effects of the risk factors is 0.89 for fatalities and 0.73 for injuries. By definition, the sum of marginal effects cannot exceed 1, since it is logically impossible to reduce the number of injuries by more than 100% (which equals a proportion of 1). Figure 3 shows that by removing all risk factors included in this analysis, it is in theory possible to reduce the number of fatalities by 89% and the total number of injuries by 73%. In practice, of course, the potentials for reduction are smaller. It is almost never possible to entirely remove a risk factor. No safety measure is one hundred percent effective. It is nevertheless clear that a substantial reduction in the current number of killed and injured road users should be possible by introducing measures that remove or control the risk factors whose contributions to current problems have been assessed.

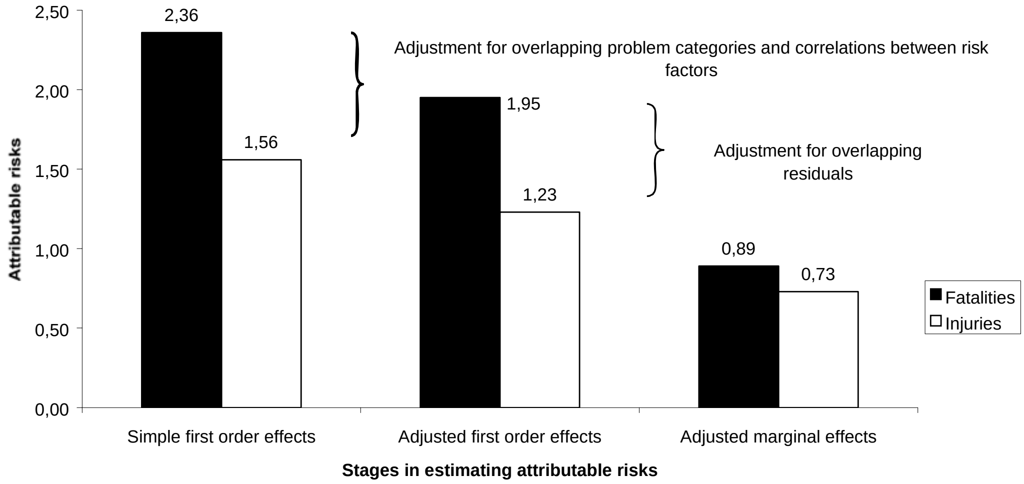

Figure 3: Adjustments in first order attributable risks

Marginal contributions of various risk factors. Table 4 presents estimates of the marginal contributions of various risk factors to current road safety problems in Sweden. Confidence intervals are given in Appendix 1. The *marginal contribution* of a risk factor to fatalities and injuries denotes the *partial contribution it represents in a set of risk factors whose combined effects have been estimated according to the method of joint residuals* explained in section 3.4.

If the problems are ranked according to the size of their contributions to fatalities and injuries, the following five problems are on top of the list:

1 Speed limit violations (0.172 for fatalities; 0.125 for injuries)

2 Poor vehicle crashworthiness (0.156 for fatalities; 0.039 for injuries)

3 High risks of unprotected road users (0.081 for fatalities; 0.052 for injuries)

4 Insufficient medical and rescue services for accident victims (0.076 for fatalities; 0.042 for injuries)

5 Roadside obstacles (0.070 for fatalities; 0.021 for injuries)

The problems have been ranked according to their contributions to fatal injuries. High risk in built-up areas makes a major contribution to injuries in general, but is actually a safety factor for fatalities. This means that the risk of injury is higher in built-up areas than outside, but that the risk of fatal injury is lower in built-up areas than outside.

Table 4: Adjusted marginal attributable risks for various risk factors in Sweden. Sources: See Appendix 1

		Marginal attributable risk	
Exposed group	Comparison group	Fatalities	Injuries
1 Roads in built-up areas	All roads outside built-up areas	-0,06	0,127
2 Poor road standard	Motorway road standard	0,016	0,006
3 Roadside obstacles	Clear side zones	0,070	0,021
4 Poor vehicle crashworthiness	Best performing cars	0,156	0,039
5 Erroneous highway signs	Correct highway signs	0,005	0,009
6 Heavy vehicles	Light vehicles	0,049	0,003
7 High risk junctions	Low risk junctions	0,010	0,004
A Bad system design (total)	*Good system design*	*0,245*	*0,210*
8 Risk at night	Risk during daytime	0,053	0,045
9 Risk in winter	Risk in summer	0,063	0,061
10 Risk of animal crashes	Zero risk of animal crashes	0,007	0,023
B Environmental risks (total)	*Less hazardous environment*	*0,123*	*0,128*
11 Children's traffic risks	Safest age group (any mode)	0,005	0,005
12 Unprotected road users	Protected road users	0,081	0,052
13 Young drivers' traffic risks	Safest age group of drivers	0,039	0,060
14 Older road users' traffic risks	Safest age group (any mode)	0,044	0,025
C Vulnerable road users (total)	*Safest groups of road users*	*0,169*	*0,142*
15 Speed limit violations	Legal speed	0,172	0,125
16 Drinking and driving	Sober driving	0,030	0,026
17 Not wearing seat belts	Wearing seat belts	0,035	0,017
18 Other violations of traffic law	Behaviour complying with the law	0,038	0,033
19 Excessive driving in towns	Removal of 3% of urban driving	0,002	0,009
D Unsafe behaviour (total)	*Safe road user behaviour*	*0,277*	*0,209*
20 Standard of medical services	Ambulance helicopters	0,076	0,042
E Current rescue services (total)	*Best available service level*	*0,076*	*0,042*
All problem areas	*Best currently available safety*	*0,890*	*0,730*

The high risk of injury run by unprotected road users is clearly related to driving speed. By reducing speed limit violations, one will at the same time reduce the risks to which unprotected road users are exposed. It is therefore important to determine the speed at which motor vehicles are allowed to travel on different types of road and in different kinds of traffic environment.

A principle of Vision Zero is to reduce the number of people who are killed or injured with as little intrusion into the liberty of road users as possible. In section 3, five levels of intrusion were defined. Applying these, Table 5 presents a preliminary priority setting of the five biggest road safety problems in terms of their importance as targets for policy interventions based on Vision Zero.

Table 5: Preliminary priority setting based on Vision Zero for possible policy interventions designed to solve the five most important road safety problems in Sweden

Problem	Contribution to fatalities	Contribution to injuries	Intrusiveness of possible policy interventions	Preliminary priority ranking of interventions
Speed limit violations	1	1	3 or 4	1
Vehicle crashworthiness	2	4	1 or 2	2
Unprotected road users	3	2	2 or 3	4
Medical and rescue services	4	3	1	3
Roadside obstacles	5	5	1 or 2	5

The possible policy interventions with respect to speed limit violations include police enforcement of current speed limits (level of intrusiveness = 3) and adoption of a new speed limit system based on Vision Zero. The new speed limit system would in most cases lead to lowered speed limits, which has been assigned a score of 4 for intrusiveness. Vehicle crashworthiness can be improved by system design and does not necessarily require road users to change their behaviour in any way. System design (score 2 for intrusiveness) as well as stricter enforcement appear to be the most promising approaches to improving the safety of unprotected road users. Medical and rescue services can be improved without changing the road transport system at all, and roadside obstacles can be removed or made less hazardous by system design.

The preliminary priority ranking was determined by multiplying the scores. The score for speed limit violations was 1 x 1 x 3.5 = 3.5 (3.5 is the midpoint between the two scores given for intrusiveness). The lower the score, the higher the priority ranking. In case of ties, the score for contribution to fatalities was used to determine the ranking.

Interventions designed to reduce speed limit violations got the highest ranking. Improving vehicle crashworthiness got the second highest ranking. In subsequent chapters of this report, these rankings will be adjusted to take account for the costs of policy interventions and their possible effects on other policy objectives.

3.6 Speed limit system and classification of road network in Vision Zero

Within Vision Zero, the thresholds for the amount of biomechanical energy that can lead to serious injury form the basis for determining speed limits. These thresholds have been set by studying the relationship between the probability of sustaining a fatal injury and impact speed for three types of accident:

1 Accidents in which pedestrians are struck by motor vehicles

2 Accidents that involve side impacts between cars

3 Head-on crashes between cars of similar mass

Figure 4 shows smoothed curves for the probability of being killed as a function of impact speed for these three types of accident.

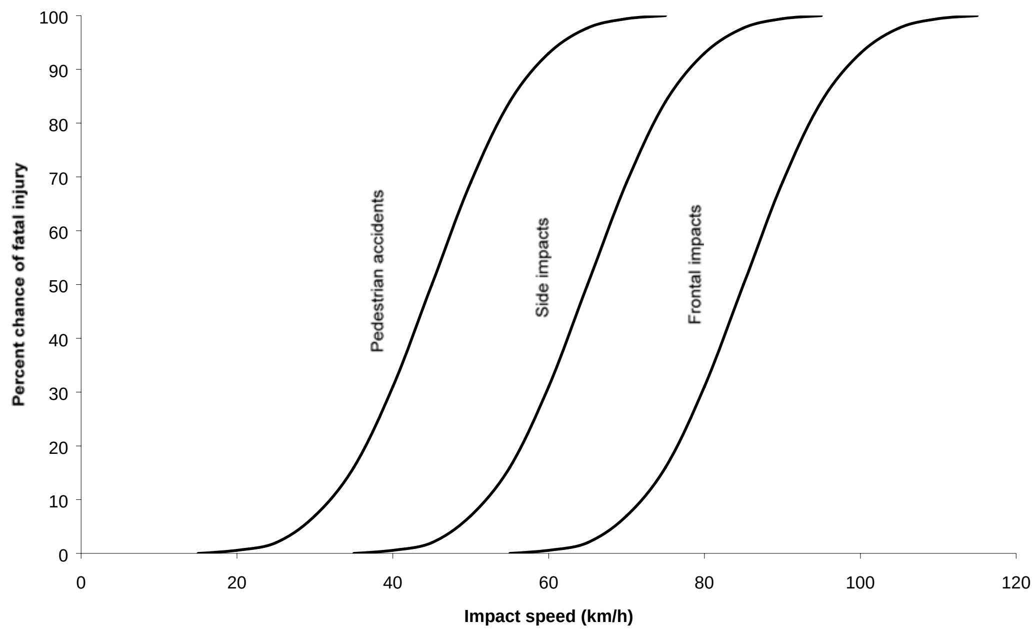

Figure 4. Probability of being killed in various types of accident as a function of impact speed. Source Brandberg, Johansson and Gustafsson 1998

The leftmost curve in Figure 4 refers to pedestrian accidents. The probability of being killed when struck by a car increases rapidly when impact speed exceeds 30 km/h. The curve in the middle refers to side impacts involving cars. For this type of accident, the chances of being killed rise sharply when impact speed exceeds 50 km/h. Finally, the rightmost curve applies to frontal impacts between cars of similar mass. It has been assumed that seat belts are worn. For this type of impact, the chance of sustaining a fatal injury rises sharply above an impact speed of about 70 km/h.

Based on these curves, the following classification of roads in Sweden with respect to maximum speed has been developed (Wramborg 1998):

1 ***Motorways and other divided highways***: On motorways and other roads with a high design standard outside built-up areas, a maximum speed of more than 70 km/h is allowed. It is assumed that on these roads there is: (a) a median sufficiently wide to (virtually) eliminate frontal impacts, (b) no roadside obstacles close to the road, (c) no at-grade junctions with other roads, and (d) no pedestrians or cyclists are allowed.

2 ***Motor traffic roads and 13 metre roads***. On these roads, a maximum speed of more than 70 km/h is allowed if there is: (a) a wire guard rail between traffic in opposite directions, (b) guard rails to protect against roadside obstacles, (c) no at-grade junctions with other roads, (d) no pedestrians or cyclists are

allowed. It is assumed that the roads are wide enough to allow three traffic lanes, in an alternating 2 + 1 layout.

3 ***Minor rural road and major urban arterial road***. On smaller rural roads, as well as on major arterial roads in urban areas, a maximum speed of 70 km/h is allowed. There is no median guard rail on these roads. In junctions, the speed limit is lowered to 50 km/h. It is assumed that pedestrians and cyclists who travel along the road are separated by means of at least a safety fence, vegetation or a sufficiently wide traffic separation area. Crossing facilities for pedestrians and cyclists are assumed to be grade separated.

4 ***Urban main street***. On urban main streets, a general speed limit of 50 km/h is assumed, lowered to 30 km/h at crossing facilities for pedestrians and cyclists. The layout of urban main streets is characterised by wide pavements and cycle tracks and formal crossing facilities for pedestrians and cyclists.

5 ***Urban Collector and Residential streets***. These are streets with a mixed function, serving partly an access function and partly a collector/distributor function. The streets have mixed traffic and a maximum speed limit of 30 km/h is therefore proposed. Formal crossing facilities do not exist and pedestrians are allowed to cross the road anywhere.

6 ***Residential street***. On pure residential streets, the street has other functions besides just providing mobility. It is a place for people to meet and talk and where children should be allowed to play. This means that driving can only be allowed at walking speed, about 7 km/h. Street layout has to be changed in order to achieve this low speed, by applying suitable speed reducing devices.

Table 6 shows a preliminary classification of public roads in Sweden. It is based on the national road data bank and other sources. The table shows the assumptions that have been made in this report about the amount of traffic, the number of accidents and the number of injured road users on different types of road in Sweden.

Table 6: Classification of public roads in Sweden. Lengths in kilometres. Rounded values. Mean values for the years 1994-1998

	Road characteristics					Killed or injured road users			
Type of road	Speed limit	Length (km)	Mean AADT	Mill veh kms	Acci-dents	Killed	Serious	Slight	Total
Motorway A	110	1050	19309	7400	446	21	112	547	680
	90	290	18895	2000	196	5	33	261	299
	70	140	18591	950	260	3	36	349	388
All motorways		*1480*	*19160*	*10350*	*902*	*29*	*181*	*1157*	*1367*
Motor traffic road	110	100	14247	520	66	9	27	83	120
	90	200	6164	450	75	7	23	88	118
	70	70	6262	160	42	1	9	55	65
All motor traffic roads		*370*	*8367*	*1130*	*183*	*17*	*59*	*226*	*303*
Rural 110	110	4180	1675	2555	300	34	130	329	493
Rural 90	90	26410	1890	18215	2613	198	956	3073	4227
Rural 70	70	58680	463	9920	2638	111	786	3059	3956
Total rural		*91120*	*1268*	*42170*	*6636*	*389*	*2112*	*7844*	*10345*
Urban 70	70	1700	2949	1830	575	20	148	661	829
State 50	50	6880	1573	3950	1625	39	379	1777	2195
Municipal 50	50	21800	1993	15860	5667	80	1068	5858	7006
Urban 50	50	28680	1892	19810	7293	119	1447	7635	9202
Municipal 30	30	15000	168	920	142	2	31	168	201
Total urban		*45380*	*1362*	*22560*	*8010*	*141*	*1626*	*8464*	*10231*
All public roads		136500	2630	64730	14645	530	3738	16308	20576
Other roads				2700	975	24	230	891	1145

4 Current Policies for Road Transport and Road Safety in Sweden

This chapter contains a description of current road transport policy in Sweden. Policy objectives are presented. As far as road safety is concerned, progress towards current targets is briefly discussed, based on recent trends in the number of fatalities and injuries. The road safety measures that are currently applied are briefly described and an estimate of their potential effects in the years 1994-2000 is presented.

4.1 Policy Objectives for Road Transport Policy in Sweden

Objectives for road transport policy in Sweden are discussed in the report of the transport policy commission (Kommunikationskommittén 1997). The report of this commission is used as the basis for describing current policy objectives.

The overall policy objective for road transport policy in Sweden is stated in the following terms:

> *The aim of transport policy is to provide good, environmentally benign and safe transport to citizens and business in all parts of the country in a way that is economically efficient to society and environmentally sustainable.*

A set of sub-targets and indicators to measure progress in realising them has been formulated. These sub-targets and the set of indicators that has been developed is shown in Table 7. Table 7 shows that indicators designed to measure progress in goal achievement have so far not been developed for all sub-targets. However, the desired direction of changes has been indicated for all sub-targets.

It is recognised that there may be conflicts between the policy objectives (Kommunikationskommittén 1997). Guidelines for the resolution of conflicts between policy objectives have been developed and will be discussed more in detail in a subsequent chapter of this report. At this stage, it is sufficient to note that the main objectives in addition to improving road safety include:

1 More efficient transport

2 Improving the environment

3 More accessible transport

4 Regional development

These are the policy objectives against which the objective of improving road safety must be traded off, preferably in a manner that does not directly counteract these objectives.

Table 7: Objectives of road transport policy in Sweden and indicators of goal achievement. Source: SOU 1997:35

Main objective	Sub-target	Indicator of progress	Current target
More efficient transport	Shorter travel time	Travel time	Not quantified
	Axle load standard	Permitted axle loads	Not quantified
Better environment	Less air pollution	CO_2 emissions	-15% (1990 to 2020)
		NO_x emissions	-50% (1980 to 2005)
		SO_2 emissions	-45% (1980 to 2005
		VOC emissions	-70% (1988 to 2005)
	Less adverse health impacts	Ambient air quality	Not quantified
	Reduced traffic noise	Ambient noise levels	L_{eq} 55 dBA outdoors
		Population affected	Not quantified
	Natural and cultural values	To be developed	Not quantified
	Conservation of resources	To be developed	Not quantified
Improving road safety	Reducing number of fatalities and injuries	Number of killed	Max 400 killed 2000
		Number of seriously injured	Max 3700 seriously injured 2000
			Max 270 killed 2007
More accessible transport	Accessible public transport	To be developed	Not quantified
Regional development	Shorter travel time	Travel time within and between regions	Not quantified

4.2 Road Safety Targets and Progress towards Them

Figure 5 shows the current targets for the years 2000 and 2007 for the maximum number of traffic accident fatalities in Sweden. The actual number of fatalities is shown for the year from 1990 to 1999.

It can be seen from Figure 5 that the decline in the number of road accident fatalities has stopped in recent years. There was good progress towards the target for the year 2000 in the early nineteen nineties. This progress has now stopped. It does not seem likely that the target for the year 2000 can be attained. Reducing the number of fatalities to 270 by the year 2007 is even more difficult. A critical examination of current priorities in road safety policy is therefore called for, if the targets are to be maintained and more rapid progress made towards them. The next section will give a brief overview of the effects of current road safety policy in Sweden.

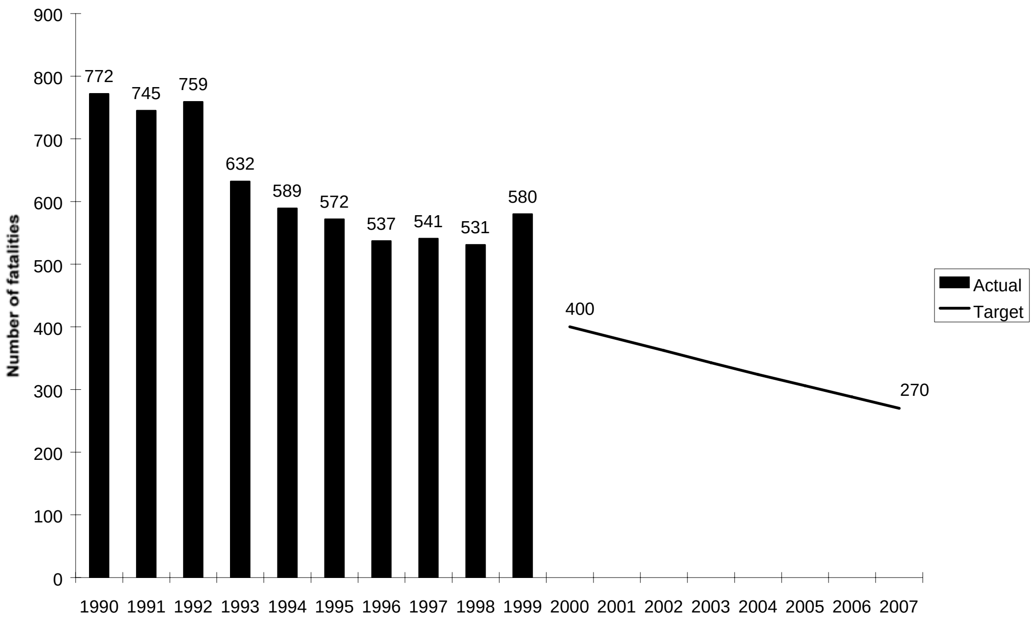

Figure 5: Road safety targets for Sweden for the years 2000 and 2007 and actual number of killed road users for the years 1990-1999

4.3 Effects of Current Road Safety Policy in Sweden

VTI (Andersson, Brüde, Larsson, Nilsson, Nolén and Thulin 1998) has estimated the expected effects of current road safety policy in Sweden for the years 1994-1996. The estimate also includes an assessment of whether it will be possible to realise the target for the year 2000 by implementing the policy reforms that constitute the core of current road safety policy in Sweden. These policy reforms include:

1 Higher valuation of road safety

2 Improving the urban traffic environment (road design and traffic control)

3 Improving the rural traffic environment (road design and traffic control)

4 Improving visibility (target is 60% use of pedestrian reflective devices by the year 2000)

5 Improving vehicles (better crashworthiness)

6 A higher use of seat belts, child restraints and airbags (target is 95% use by the year 2000)

7 A higher use of bicycle helmets (target is 80% use by the year 2000)

8 Fewer speed limit violations (target is 35% reduction by the year 2000)

9 Less drinking and driving (target is 27% reduction by the year 2000)

10 Fewer other violations of road traffic law (target is 50% reduction by the year 2000)

11 More effective rescue services and medical care

Figure 6 shows the results of the estimates for the two years from 1994 to 1996. During these two years, the number of fatalities was reduced from 589 in 1994 to 537 in 1996. Figure 6 shows the marginal contributions of various factors to this decline. The marginal contributions of the factors listed in Figure 6 can be added to obtain their total effect.

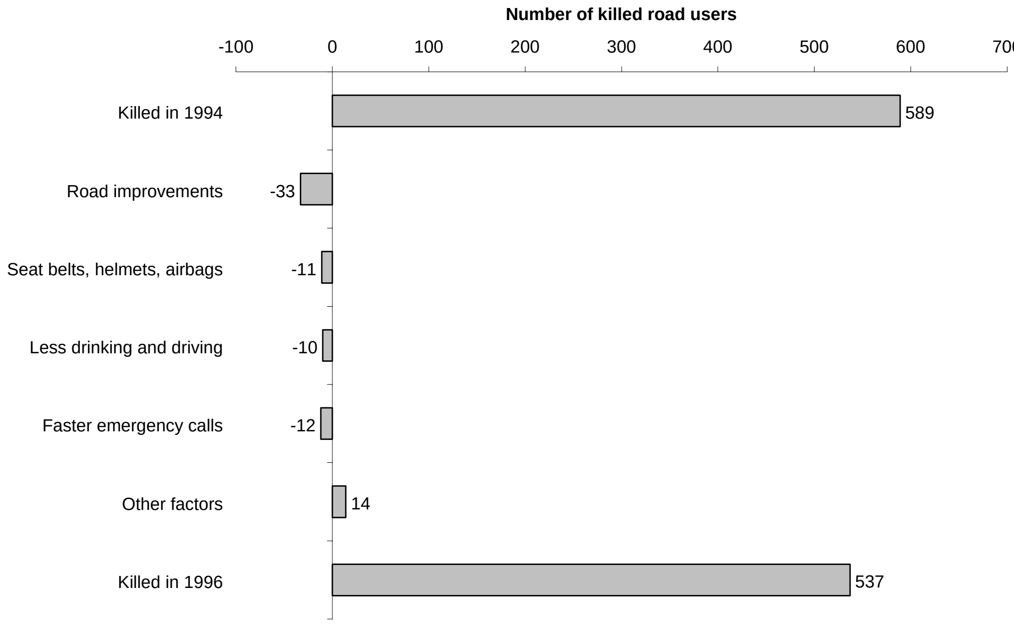

Figure 6: Contributions of various factors to changes in the number of road accident fatalities in Sweden from 1994 to 1996. Source: Andersson et al 1998

According to the estimates, various road improvements made the largest contribution to the decline in the number of fatalities, a reduction of 33. Increased wearing of seat belts and cycle helmets, and an increase in the proportion of cars having airbags were estimated to have prevented 11 fatalities. There was a reduction of drinking and driving, contributing to a reduction of 10 fatalities. Compliance with other regulations, especially speed limits, did not improve during 1994-1996. Increased use of mobile telephones resulted in faster emergency calls in accidents, contributing to a reduction of 12 fatalities. Other factors, including an increase in traffic volume, contributed to a net increase of 14 in the number of fatalities. The road safety measures that were carried out from 1994 to 1996 thus more than offset an increase in the number of fatalities that would otherwise have happened.

Extending the analysis to the years from 1994 to 2000 gave the results presented in Figure 7. A net decline of 190 in the number of fatalities, from 589 in 1994 to 399 in 2000, was estimated. Once more, the largest contribution to this decline was estimated to come from road improvements. Broadly speaking, all major factors were expected to affect the number of fatalities in the same manner during the years 1994-2000 as during the years 1994-1996. An exception is the category labelled “other factors”, which is expected to contribute to fewer fatalities during the years 1994-2000. This category of factors contributed to more fatalities during 1994-1996. The main reason for the change in the sign of the effect is that fuel prices are expected to increase substantially before the year 2000, leading to less traffic.

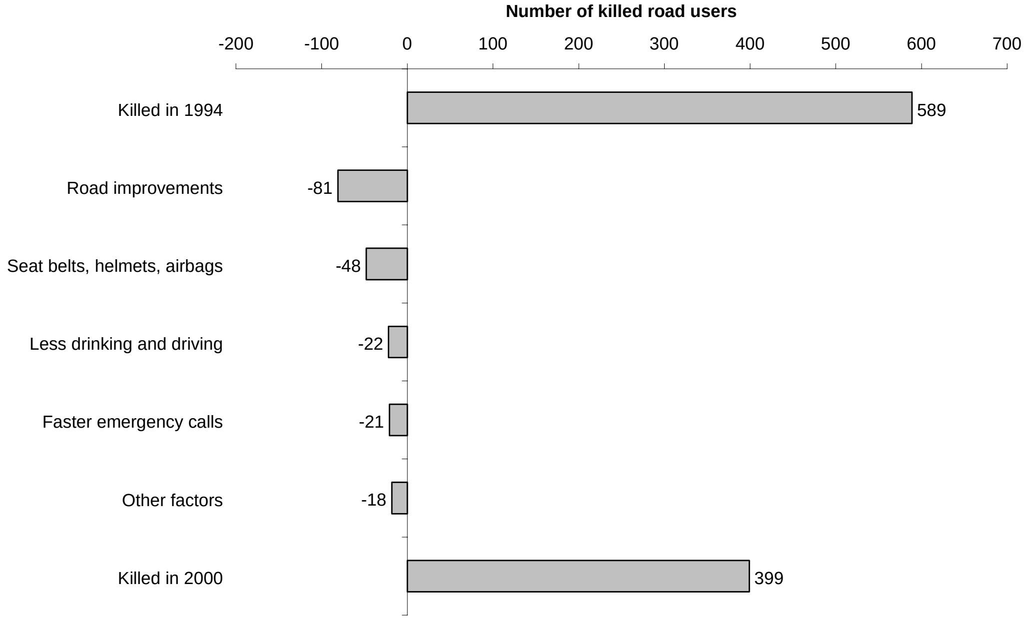

Figure 7: Contributions of various factors to expected changes in the number of road accident fatalities in Sweden from 1994 to 2000. Source: Andersson et al 1998

According to the estimates made by VTI, it is possible to realise the quantified target for fatalities in the year 2000. This estimate should not necessarily be taken as a prediction. It is based on a number of assumptions, the most important of which are:

1 All measures that contribute to improving safety are carried out to the extent assumed when estimating their effects.

2 The effects of these measures on safety are at least as great as assumed in the estimate.

3 Other factors affecting road safety continue to develop as assumed when estimating their effects.

If, for example, not all measures are carried out, or the measures become less effective, or there is a greater growth in traffic volume than assumed, the number of killed road users in the year 2000 may well exceed the target for that year. According to these estimates, the road safety target for the year 2000 is within reach, but there is no guarantee of reaching it. Based on recent accident experience, these estimates appear to be too optimistic.

Current road safety policy in Sweden is not making as great a contribution to improving safety as it in principle could do. This becomes apparent when the effects of current road safety policy is compared to the effects of fully implementing the ten policy reforms listed on page 25.

4.4 Effects of Fully Implementing Road Safety Policy Reforms

VTI has estimated the effects on the number of killed road users of realising the targets that have been set for implementing all the policy reforms listed on page 25 by the year 2000 (Andersson et al 1998). For each of these policy reforms, targets have been set for the year 2000 with respect to the implementation of the reforms. There is a target of, for example, reducing speed limit violations by 35% by the year 2000. This means that if 50% of road users currently violate the speed limit, the target for the year 2000 is to reduce the violation rate to 32.5% (a reduction of 17.5% corresponds to a 35% reduction of a violation rate of 50%).

Figure 8 shows the effects estimated by VTI if all policy reforms are implemented to their targeted level in the year 2000.

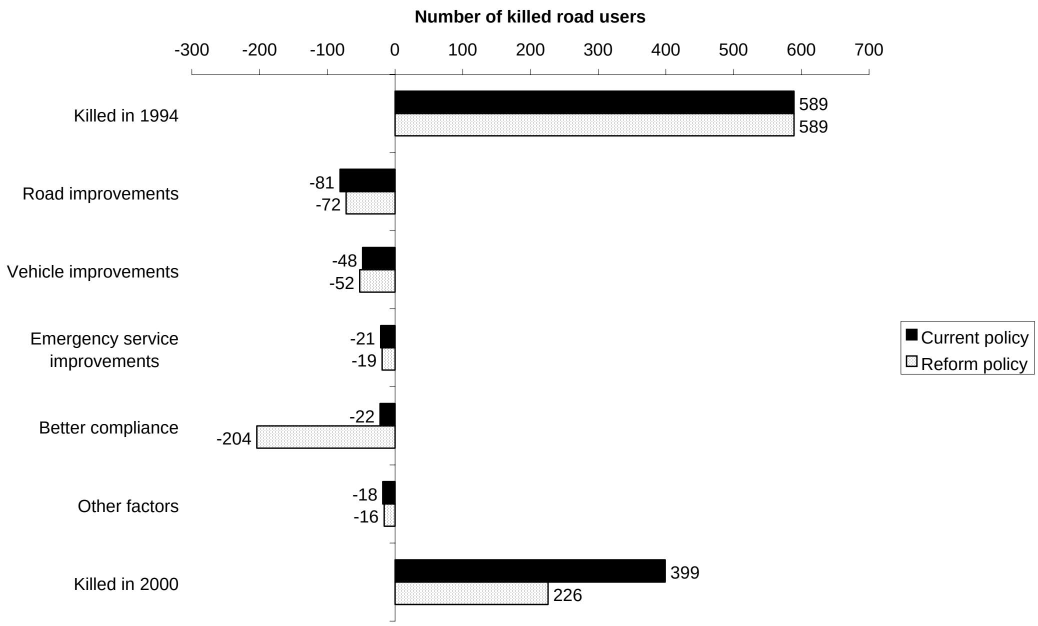

Figure 8: Estimated effects of implementing road safety policy reforms in Sweden to their targeted level by the year 2000

The expected effects of current road safety policy are indicated by the black bars. These effects are identical to those shown in Figure 7. The expected effects of fully implementing the road safety policy reforms are shown by the grey bars. By comparing these bars to those that indicate the effects of current policy, it becomes apparent that the main shortcoming of current road safety policy in Sweden is that not enough is done to improve road user compliance with road traffic law. This is the area where the largest road safety benefits can be harvested in the short term. Realising the target for speed limit compliance would alone reduce the number of fatalities by nearly 28%. This confirms the importance of speed for road safety, as discussed in chapter 3.

4.5 The special traffic safety plan presented in 1999

In the spring of 1999, a special traffic safety plan was presented by the Swedish Ministry of Industry (Näringsdepartementet 1999). This plan is known as the 11 point programme for road safety. It consists of road safety measures already proposed in the National Road Plan 1998-2007 as well as a number of additional measures. Measures in the National Road Plan are mainly road investments. The 11 points proposed in the plan include:

1 Identifying and treating the most hazardous road sections

2 Maker traffic safer in towns, by reconstructing streets according to the design principles of Vision Zero

3 A stronger emphasis on the responsibility of road users for road safety – this means that an increase in police enforcement is planned

4 Safer cycling, especially by means of promotoing helmet wearing

5 Safety audits of transport services purchased by the public sector

6 A law requiring the use of winter tyres on slippery roads in winter

7 Exploiting Swedish technology to make motor vehicles safer

8 Codifying the responsibility for safety of those who design the road transport system

9 Reassessing penalties for traffic law violations

10 Clarifying the role of voluntary associations and organisations working for road safety

11 Experimenting with new systems for financing new roads.

The effects of these measures have been assessed by the Swedish National Roads Administration (Vägverket 1999A). It was concluded that the 11 point programme would not be sufficient to realise the target set for 270 fatalities in 2007. An additional reduction of 70-160 fatalities would be needed, which means that the predicted number of fatalities in 2007 is around 340-430.

In this report, it has been assumed that most of the measures proposed in the 11 point programme will be carried out by 2007. This means that this plan forms part of the current road safety policy for Sweden.

5 Screening of Potentially Effective Road Safety Measures

5.1 A Survey of Potentially Effective Road Safety Measures

In order to develop a maximally 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. It is, for example, technically feasible to introduce a speed governor in all motor vehicles that makes it impossible to drive faster than the speed limit. The effects of such a system on accidents are so far not known, but possible effects on speed are known. The effects on speed give reason to believe that such a system would be effective in reducing the number and severity of accidents. The reason for believing so, is based on general knowledge about the relationship between speed and accidents.

The process of screening of potentially effective road safety measures for inclusion into a formal assessment of their safety potential, 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 Traffic Safety Handbook (Elvik, Mysen and Vaa 1997). The measures covered by this book has been taken as the basis for preparing an exhaustive list of road safety measures. The Traffic Safety Handbook covers 124 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. The measures that have been added include:

A Vision Zero speed limits

This measure includes introducing Vision Zero speed limits to the road system, but without altering the layout of the roads. It is not assumed that there will be perfect compliance with the new speed limits. It is assumed that mean speed will correspond to the speed limit, which implies a compliance of about 50%. This is virtually the same as the current compliance with speed limits in Sweden. A ten fold increase in police enforcement has been assumed. A reclassification of all public roads, as indicated in point B below, will serve as the basis for setting new speed limits.

B Reclassification and reconstruction of roads according to Vision Zero

Vision Zero implies certain standards for the design of roads. This measure comprises a reclassification of all public roads in Sweden according to the classification system developed as part of Vision Zero, and reconstructing the roads that need reconstruction in order to meet the designs standards developed within the framework of Vision Zero. More specifically, the following changes are assumed to be implemented:

- All motor traffic roads (370 km) will be reconstructed to motorways.
- 280 km of national road with AADT > 8,000 and speed limit 90 or 110 km/h will be reconstructed to 13m roads with a wire median guard rail.
- Wire median guard rail will be provided on 3,500 km of road with a width of 13 m and a speed limit of 90 or 110 km/h.
- 13,600 km of urban road with low traffic volume will be reconstructed according to the design principles for 30 km streets in Vision Zero.
- 9,000 km of urban road with moderate to large traffic volume will be reconstructed according to the design principles for 50/30 streets in Vision Zero (comparable to environmentally adapted through roads).
- 9,000 km of urban access roads with very low traffic volume will be reconstructed according to the design principles for walking speed streets in Vision Zero.

C New safety standards for motor vehicles

The following new safety standards for motor vehicles have been included in the survey of potentially effective safety measures:

- Requiring self-levelling headlamp systems for new cars from a certain date (retrofitting older cars with this kind of system is not realistic).
- Requiring a seat belt reminder in new cars from a certain date. This a device that gives a warning signal if a seat is occupied and the seat belt is not fastened.
- Requiring an ignition interlock system for seat belts in all new cars from a certain date.
- Introducing new requirements for front design and bumpers on light cars, in order to reduce injuries to pedestrians who are struck by cars (Lawrence, Hardy and Lowne 1993).
- Requiring an energy absorbing structure in the front of heavy cars, in order to reduce the severity of injuries in head on crashes (Riley, Farwell and Burgess 1987, Jones 1987).

D Integrated application of intelligent transport systems technology

The following applications of intelligent transport systems technology have been considered:

- Requiring an automatic *accident warning device* on all new cars from a certain date. This is a device that automatically sends a signal to an emergency warning centre when the car is involved in an accident where the airbag is deployed. The car can then be located more quickly by means of, for example, Global Positioning Systems (GPS).
- Requiring a *crash data recorder* in all new cars from a certain date. This is a small computer that records, for example, braking, steering wheel movements, and the use of direction indicators during the last few seconds before an accident. Information is deleted continuously and stored only in case an accident occurs (Wouters and Bos 1997).
- Requiring an *ignition interlock device* in the car to detect whether the driver is drunk. The device could take the form of a breathalyser unit, into which the driver would be required to blow in order to be able to switch on the ignition (Glad 1996).
- Requiring *intelligent cruise control* on new cars from a certain date. An intelligent cruise control device would warn the driver if the forward distance to other vehicles becomes too short.
- Requiring an *intelligent speed adaptation system* in cars. Such a system would probably have to be fitted in all cars from a certain date. Different designs of the system can be imagined. As a means of driver support, the system would give a warning if the speed limit is exceeded, but not otherwise act to prevent speed limit violations. As a fully integrated control system, the system would overrule driver attempts to exceed the speed limit, by means of a speed governor.

It will be assumed that these applications can be introduced both on an individual basis and jointly as an integrated application of all systems.

E Reforming driver education

Plans have been made to reform the system of driver education and training in Sweden for private cars (Grummas Granström 1998). Although not all details of these plan are ready, it is assumed that a new system will contain one or several of the following elements:

- It will be possible to start driver training at the age of 16 (as today), but the licensing age remains 18.
- A minimum number of kilometres of driving will be required before the driving test can be taken.
- A graduated training system will be introduced. The driving license itself will, however, not be graduated.
- Possibly some special regulations for novice drivers, for example a zero BAC limit.
- Possibly a system rewarding accident free driving, for example the type of insurance scheme introduced by Gjensidige in Norway (Vaaje 1991).

F Vehicle impoundment for drinking and driving

The possibility of using vehicle impoundment to prevent unlicensed driving has been included, based on recent experience in the United States (DeYoung 1999).

5.2 Criteria for Inclusion of Measures in a Formal Assessment of Costs and Benefits

The second stage of screening involves the selection of measures that are to be included in a formal analysis of safety potentials, cost-effectiveness and benefit-cost ratio according to the following criteria.

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 estimate of safety potential, cost-effectiveness and benefit-cost ratio. In order to estimate the safety potential of a measure, that is the maximum number of injuries it can prevent, its effect on safety 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 even 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 assessment of safety potential, cost-effectiveness or benefit-cost ratio. In a road safety programme there is no point in using measures that are not known to improve safety.

3 Overlap of other measures

Some of the measures described in the Traffic Safety Handbook 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 Sweden wear helmets. Hence, requiring helmets to be worn is a measure that has been implemented. In order to further increase wearing rates, more effective enforcement would be needed.

5 Measure is analytically intractable

Some measures are difficult to define in a way that permits meaningful calculations of the safety potentials, cost-effectiveness and cost-benefit ratio. 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, cost-effectiveness and cost-benefit ratio. 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 analysis of costs and effects.

These criteria are obviously somewhat discretionary. As far as the first screening criterion is concerned, it may be felt as excessively conservative to confine a road safety programme 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 in a safety programme. 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, Mysen and Vaa 1997). 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. The implications for a road safety programme of the finding that resurfacing roads increases the number of accidents are twofold. First, resurfacing roads should not be included in the programme as a safety measure. Second, measures that may counteract an increase in the number of accidents, like a temporary reduction of the speed limit, ought to be considered for inclusion in the safety programme.

5.3 Screening of Measures for Inclusion in Formal Analyses of Safety Potentials, Cost-Effectiveness and Benefit-Cost Ratio

Table 8 presents the results of screening 139 road safety measures, of which 124 were taken from the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997), for inclusion in a formal assessment of their safety potentials, cost-effectiveness and benefit-cost ratios.

Table 8: 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 audits	8	Yes	
Motor vehicle taxation	9	Yes	
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
Automatic accident warning and location (§)	14	Yes	
Tracks for walking and cycling	101	Yes	
Motorways	102	Yes	
Bypasses	103	Yes	
New urban arterial roads	104	No	Ineffective measure
Channelising junctions	105	No	Overlaps other measures
Roundabouts	106	Yes	
Geometric layout of junctions	107	No	Ineffective measure
Staggered junctions	108	Yes	
Interchanges	109	Yes	
Black spot treatment	110	No	Overlaps other measures
Cross section improvement	111	No	Overlaps other measures

Table 8: 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
Roadside safety treatment	112	Yes	
Improving road alignment	113	No	Overlaps other measures
General rehabilitation of roads	114	Yes	
Guard rails, including median guard rails	115	Yes	
Preventing accidents involving animals	116	Yes	
Curve treatment	117	Yes	
Road lighting	118	Yes	
Road tunnel safety measures	119	No	Overlaps other measures
Rest areas	120	No	Effects unknown
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	Yes	
Winter maintenance of walking areas	207	No	Not a road safety measure
Correcting erroneous highway signs	208	No	Overlaps other measures
Highway work zone safety devices	209	No	Effects unknown
Area wide urban traffic calming	301	Yes	
Environmentally adapted through roads	302	Yes	
Pedestrian streets	303	No	Fully implemented
Walking speed streets (7 km/h streets)	304	Yes	
Access control on existing roads	305	No	Ineffective measure
Priority roads	306	No	Ineffective measure
Yield signs at junctions	307	No	Ineffective measure
Stop signs at junctions (four way stop)	308	Yes	
Traffic signal control at junctions	309	Yes	
Traffic signal control of pedestrian crossings	310	Yes	
Speed limits, including Vision Zero limits	311	Yes	
Speed humps etc	312	Yes	
Road markings	313	No	Fully implemented
Traffic control for pedestrians and cyclists	314	Yes	
Parking regulations	315	No	Overlaps other measures
One way streets	316	No	Ineffective measure

Table 8: 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
Reversible lanes	317	No	Ineffective measure
Bus lanes (HOV-lanes)	318	No	Ineffective measure
Dynamic route guidance (§)	319	No	Effects unknown
Variable signs (partly an ITS application)	320	Yes	
Railroad-highway grade crossing	321	No	Fully implemented
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	Yes	
Daytime running lights on cars	405	No	Fully implemented
Daytime running lights on motorcycles	406	No	Fully implemented
Self levelling headlamp requirement	407	Yes	
Use of retro-reflective devices	408	Yes	
Steering, handling, stability of cars	409	No	Effects unknown
Bicycle helmets, campaign and law	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	Yes	
Seat belts in heavy vehicles	415	No	Effects unknown
Vehicle crashworthiness	416	No	Analytically intractable
Modifying car instruments and controls	417	No	Effects unknown
Intelligent cruise control (§)	418	Yes	
Regulating vehicle mass	419	No	Ineffective measure
Speed governor in motor vehicles (§)	420	Yes	
Motor power regulation of motorcycles	421	No	Ineffective measure
Improving under run guard rails on trucks	422	Yes	
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
Crash data recorder (§)	429	Yes	
Safety standards for front and bumper	430	Yes	

Table 8: 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 motor vehicle inspection	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
Reforming basic driver training	604	Yes	
Training of problem drivers	605	Yes	
Driver's license examination	606	No	Fully implemented
Training of motorcyclists	607	No	Ineffective measure
Training of bus and truck drivers	608	Yes	
Graduated driver's license - curfews	609	No	Overlaps other measures
Rewarding safe driving	610	No	Overlaps other measures
Regulation of driving and rest hours	611	No	Fully implemented
Safety regulation of emergency driving	612	No	Ineffective measure
School bus transport for children	613	No	Fully implemented
Training of pre-school children (age <6)	701	No	Ineffective measure
Training of school children (age 6-)	702	Yes	
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	
Automatic speed enforcement	806	Yes	
Automatic red light enforcement	807	Yes	
Simple traffic tickets	808	No	Ineffective measure
Ordinary traffic tickets and imprisonment	809	No	Overlaps other measures
Demerit point systems	810	Yes	
Motor vehicle insurance regulation	811	No	Effects unknown
Ignition interlock device (§)	812	Yes	
Vehicle impoundment for unlicensed driving	813	Yes	

(§) This measure is an ITS application

Some comments will be given with respect to this screening.

Measures with unknown effects. A total of fifteen (15) measures have been screened out because their effects on safety are unknown. These measures include measures whose causal relationship to accidents is very indirect in a way that 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 useful in the present project.

For measure 209, highway work zone safety devices, some estimates exist of the safety effects of various devices. However, all these estimates appear to be based on studies of major motorways works in the United States and Great Britain. Moreover, official Swedish accident statistics does not identify work zone accidents. Hence, it is not known how large the problem of work zone safety is.

As far as measure 428, hazardous goods transport safety is concerned, official Norwegian accident statistics indicate that the accident rate for trucks (tankers) carrying highly flammable goods is about 75% lower than the accident rate for trucks carrying other types of goods. A corresponding difference in accident rate has not been found in Sweden (Nilsson 1994A). Moreover, it is not known whether the difference in accident rate between transport of hazardous goods and transport of other goods found in Norway is attributable to the safety measures that have been introduced or to behavioural adaptation on the part of drivers.

Various aspects of motor vehicle insurance (measure 811) have been found to affect accident rates. The very existence of motor vehicle insurance may affect accident rates adversely, but this is not very well known, since no highly motorised country has ever had a system of no insurance. Studies of the effects of motor vehicle insurance on safety are riddled with uncertainties (Englund and Pettersson 1997). It has therefore been concluded that the effect of this measure on road safety is largely unknown.

Measures that are ineffective. A total of twenty five (25) 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 analysis of evidence from five towns (Elvik 1998B) 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 Traffic Safety Handbook (Elvik, Mysen and Vaa 1997), 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. Since the prevention of fatal injuries is given first priority in Vision Zero, this measure has been classified as ineffective.

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). This experiment is clearly the best controlled study of this measure and did not show 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 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. These campaigns tend to be combined with other measures, like new legislation or police enforcement, and tend to be targeted to specific types of accident or groups of road users, not accidents in general. In the present report, it has been assumed that information campaigns are always combined with other measures.

Simple traffic tickets have been classified as ineffective, mainly based on Swedish studies (Nilsson and Åberg 1986; Andersson 1989), despite the fact that a recent Norwegian study (Fridstrøm 1999) indicates that increasing tickets for not wearing seat belts in Norway did have an effect on wearing rates.

Measures that overlap other measures. A total of eighteen (18) 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, is indeed what this report is about, and therefore overlaps all the specific measures analysed in this report. Measure 4, safe communities, is omitted for the same reason. Safe communities is, in a sense, embodied in Vision Zero and will therefore be promoted to the extent that Vision Zero is promoted. Measure 5, exposure control, overlaps at least measures 9 (motor vehicle taxation) and 10 (road pricing), and possibly other measures as well. 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 audits. 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. Fifteen (15) measures have been left out because they are, for all practical purposes, fully implemented. 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. Four (4) 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. There is no doubt that many elements of urban and regional planning may contribute to improving road safety. On the other hand, such planning may sometimes have an adverse effect on safety, like when major new shopping malls accessible only by means of a car are developed in the outskirts of major cities. The chief effect of such developments is to generate more car driving.

6 System Description and Framework for Analysis

This chapter contains a description of the Swedish road transport system, with emphasis on travel exposure, the accident rate for various elements of the transport system and the injury rate of various groups of road users. Accident and injury rates have been estimated on the basis of police reported injury accidents. The second part of the chapter is a summary of the most important assumptions made in the analyses of the safety potentials, cost-effectiveness and benefit-cost ratio of the road safety measures.

6.1 Travel Exposure, Road Network and Modal Distribution of Travel

The number of accidents and injuries depends strongly on travel exposure. Two measures of the amount of travel exposure will be used in this report. *Vehicle kilometres of travel* are used to describe the amount of driving performed by motor vehicles on different types of road. *Person kilometres of travel* are used to describe the amount of travel done by different groups of road users in different types of traffic environment. Table 9 gives an overview of vehicle kilometres of travel, as estimated for the year 1999 (Hammarström 2000). It is seen that passenger cars dominate motorised travel. 65% of all travel takes place in rural areas, 35% in urban areas. The total amount of travel was nearly 69 billion vehicle kilometres.

Table 9: Vehicle kilometres of travel in Sweden 1999. Billion kilometres

	Amount of travel in billion vehicle kilometres		
Type of vehicle	Rural areas	Urban areas	Total
Passenger car	36.85	20.77	57.62
Van or pickup truck	3.22	1.79	5.01
Bus	0.65	0.47	1.12
Light truck (3.5-16 tons)	1.02	0.32	1.34
Heavy truck (16- tons)	2.45	0.40	2.85
Moped	0.03	0.14	0.17
Motor cycle	0.39	0.21	0.60
Total	44.61	24.10	68.71

The assumed distribution of travel between different types of road was given in Table 6. There are some minor discrepancies between these two tables. The two sets of data were taken from different sources and are close enough for the intended use in this report.

6.2 Injury rates of Road User Groups and Road Elements in Sweden

Figure 9 shows the injury rate of different groups of road users in Sweden, estimated from official accident records and the national household travel survey (Thulin and Nilsson 1994, Thulin and Kronberg 1998).

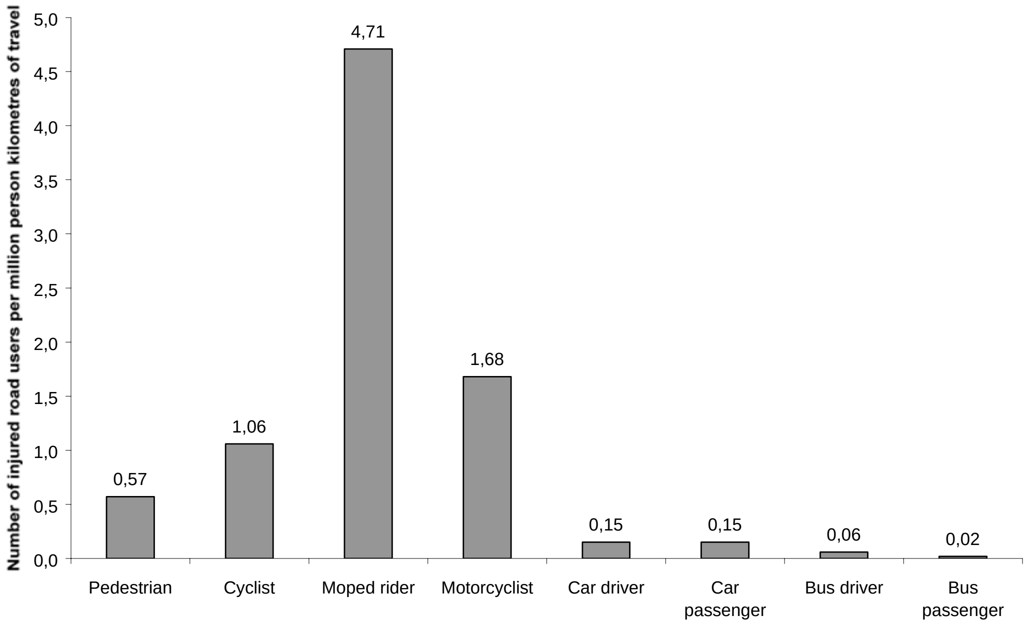

Figure 9: Injury rates for different groups of road users in Sweden. Based on Thulin and Nilsson 1994 and Thulin and Kronberg 1998

The high injury rate for pedestrians, cyclists, moped riders and motorcyclists, compared to drivers and passengers of cars is readily apparent from figure 9. It should be noted that there are some discrepancies in exposure data between the national household travel survey and the model estimated for emissions of noise and air pollution. More specifically, vehicle kilometres of driving for passenger cars amount to 66.7 billion according to the national household travel survey and to 62.6 billion according to the emissions model (when small vans are included). This difference, however, is not of major importance for the purposes of the analyses presented in this report.

6.3 Road User Behaviour and Compliance with Road Traffic Law

Table 10 summarises the current state of road user behaviour in Sweden for those aspects of behaviour that are regularly monitored. The data have been taken from various sources (Andersson et al 1998; Vägverket 1999; Thulin 1999; Eriksson 1997; Stenbäck 1997; Vägverket 2000A).

Table 10: Road user behaviour in Sweden. Compliance with road traffic law

Aspect of road user behaviour	Categories of roads or road users	Percent complying with the law or using safety devices
Speed	Motorway class A 110 km/h	53 (mean speed 109 km/h)
	Motorway class A 90 km/h	25 (mean speed 97 km/h)
	Motorway class A 70 km/h	14 (mean speed 82 km/h)
	Motorway class B 110 km/h	57 (mean speed 108 km/h)
	Motorway class B 90 km/h	28 (mean speed 96 km/h)
	Rural road 110 km/h	63 (mean speed 106 km/h)
	Rural road 90 km/h	34 (mean speed 95 km/h)
	Rural road 70 km/h	14 (mean speed 82 km/h)
	Mean for all rural roads	45
	Urban arterial road 70 km/h	70 (mean speed 63 km/h)
	Urban arterial road 50 km/h	45 (mean speed 48 km/h)
	Other urban roads 50 km/h	54 (mean speed 45 km/h)
	Mean for all urban roads	51
Stop signs	Stopping at stop signs	65 (overall rate)
Traffic signals	Compliance with red signal	97.7 (overall rate)
Seat belts and child restraints	Drivers of light cars	87 (overall rate)
	Adult passengers (15-years)	89 (overall rate)
	Child passenger (0-15 years)	96 (overall rate)
Drinking and driving	Results of random breath testing	98.7 (not testing positive)
Crash helmets for motorcyclists	Moped and motorcycle riders	99 (overall rate)
Cycle helmets	Children <10 years	53 (overall rate)
	School children	36 (overall rate)
	Adults	14 (overall rate)
	All cyclists	18 (overall rate)
Lights and reflective devices	Pedestrians in darkness	30 (overall rate)
	Cycles with headlamps	63 (overall rate
	Cycles with front and rear reflex	85 (overall rate)
	Cycles with side reflex	84 (overall rate)
High mounted stop lamps	Car with high mounted stop lamps	50 (all driving)
Airbags	Cars equipped with air bags	44 (all driving)
Seat belt reminders	Cars equipped with reminders	35 (all driving)

It is apparent that one the most serious traffic safety problems in Sweden today is speed limit violations. Roughly speaking 50% of all driving involves violating the speed limit. Compliance with most other regulations is somewhat better.

6.4 The Distribution of Roads and Junctions by Traffic Volume

For national roads, the road data bank provides information concerning the length of roads with different traffic volumes. For municipal roads, no exact information can be found on the distribution of roads according to traffic volume. An estimate has therefore been made. Table 11 presents this estimate for national roads, except motorways and motor traffic roads, and for municipal roads according to speed limit.

Table 11: Distribution of public roads in Sweden by traffic volume. Mean AADT in each class. Kilometres of road

	Mean annual average daily traffic (AADT) in each AADT class. Kilometres of road by AADT											
Km/h	0-250	250-500	500-1000	1000-2000	2000-4000	4000-8000	8000-12000	12000-15000	15000-20000	20000-30000	30000-	Total
						National roads						
50	1504	1330	1398	1164	702	346	96	29	11	4	1	6585
70	36788	9828	5975	3154	1612	867	237	85	62	13	2	58523
90	4324	3403	4988	4701	4828	2967	938	169	70	5	0	26393
110	256	776	1300	868	315	528	137	1	1	0	0	4182
Total	42872	15337	13661	9887	7457	4708	1408	284	144	22	3	95783
						Municipal roads						
30	9500	3500	1100	560	200	100	40	0	0	0	0	15000
50	2000	3400	5100	4200	3500	2200	900	410	60	26	4	21800
70	350	410	245	210	190	140	90	50	15	0	0	1700
Total	11850	7310	6445	4970	3890	2440	1030	460	75	26	4	38500

It is seen that the majority of roads carry rather small traffic volumes, less than 1,000 motor vehicles per day. Table 11 does not include motorways and motor traffic roads, nor national roads with a speed limit of 30 km/h. When these roads are included, the total length of national roads becomes 98,000 km. A similar distribution of junctions, admittedly very uncertain, is shown in Table 12. It has been assumed, based on Andersson et al (1998), that there are 192,500 junctions on public roads in Sweden, and that the total traffic volume in these junctions amounts to about 105,000 billion entering vehicles per year. The distribution assumed in Table 12 fits these totals, except for rounding errors, but this by itself does not guarantee that the estimated distribution is correct.

Table 12: Distribution of junctions in Sweden by traffic volume. Mean AADT in each class. Number of junctions

	Mean annual average daily traffic (AADT) in each AADT class. Number of junctions by AADT											
Km/h	0-250	250-500	500-1000	1000-2000	2000-4000	4000-8000	8000-12000	12000-15000	15000-20000	20000-30000	30000-	- Total
30	41800	15400	4840	2464	880	440	176	26	0	0	0	66026
50	9146	15266	22762	18748	15561	9760	3982	1811	357	155	28	97576
70	10001	4064	2452	1649	1207	815	451	240	130	31	4	21044
90	995	783	1147	1081	1110	682	216	99	26	6	2	6147
110	59	178	299	200	72	121	32	8	4	2	1	976
Total	62001	35691	31500	24142	18831	11819	4856	2183	517	194	35	191769

6.5 The Diffusion of New Technology in the Vehicle Fleet

If a new measure is introduced for motor vehicles, its rate of diffusion will depend on the turnover rate of the vehicle fleet. Official statistics (Bilindustriföreningen 1999) give information on the distribution of motor vehicles by age, and on the number of new motor vehicles registered every year. Official road accident statistics does, however, provide data on the percentage of registered cars by vintage and the percentage of cars involved in accidents by vintage. In Figure 10, these percentages (cumulative) have been plotted against each other.

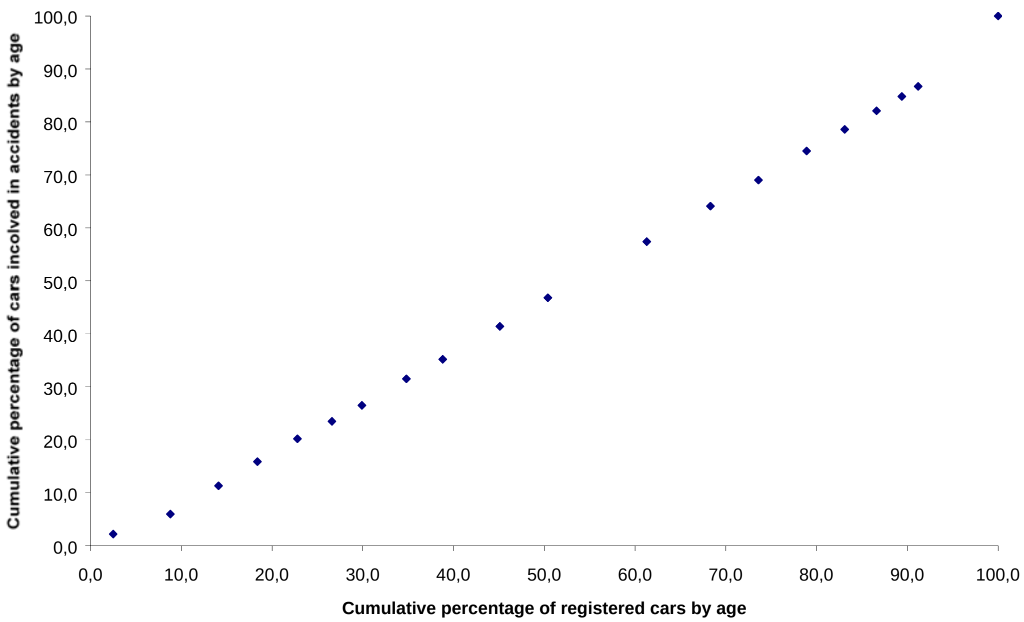

Figure 10: Percentage (cumulative) of registered cars by vintage versus percentage of cars involved in accidents by vintage.

New cars are closest to the origin, old cars are at the ends of the axes. It is seen that there is a strong linear proportionality between the percentage of registered cars by vintage and the corresponding percentage of cars involved in injury accidents. For example, 50% of all cars are less than ten years old. These cars constitute 47% of all cars involved in injury accidents. For the purpose of estimating the effects on accidents and injuries of measures introduced in new cars, it has been assumed that such measures affect 5.5% of all cars and all accidents the first year, 50% of all cars and all accidents within ten years, and at most 95% of all cars and all accidents.

6.6 Economic Valuation of Impacts of Road Safety Measures

Road safety measures can have a number of impacts, in addition to their effects on accidents or the number and severity of personal injuries. Table 13 lists the economic valuation that has been applied in this project for the various impacts of road safety measures (Hansson 1997; Lindberg et al 1997; Nylander et al 1999, Vägverket 2000B).

Table 13: Economic Valuation of Impacts of Road Safety Measures. Amounts in SEK 1999 prices

Main policy objective	Unit of valuation	Valuation per unit (SEK 1999 prices)
General parameters	Annual discount rate, fixed prices	4.0%
	Annual real growth rate, fixed prices	1.5%
	Cost multiplier for general taxation of consumption	1.23
	Cost multiplier for opportunity cost of taxes	1.30
	Total opportunity cost multiplier for public expenditure	1.53
Length of effects (years)	New roads	40
	Targeted road safety investments in roads	15
	Rehabilitation of existing roads	15
	Highway signs, traffic control devices	10
	Safety standards for new cars	15
	Retrofitting safety devices on all cars	7
	Crash helmets, reflective devices	5
	Police enforcement	1
Road safety	1 fatality	14,300,000
	1 police reported serious injury (adjusted for incomplete reporting)	6,200,000
	1 police reported slight injury (adjusted for incomplete reporting)	360,000
Travel time	1 vehicle hour of travel passenger car	120
	1 vehicle hour of travel freight truck	241
	1 vehicle hour of travel for a bus (including passengers)	770
Transport cost	Vehicle operating cost per kilometre – car	1.00
	Vehicle operating cost per kilometre – heavy vehicle	5.60

Table 13: Economic Valuation of Impacts of Road Safety Measures. Amounts in SEK 1999 prices, continued

Main policy objective	Unit of valuation	Valuation per unit (SEK 1999 prices)
Environmental impacts	1 kg emission of CO_2	1.50
	1 kg emission of SO_2 in urban areas	40[1]
	1 kg emission of SO_2 in rural areas	20
	1 kg emission of NO_x in urban areas	72[1]
	1 kg emission of NO_x in rural areas	60
	1 kg emission of NMVOC in urban areas	50[1]
	1 kg emission of NMVOC in rural areas	30
	1 kg emission of PM10 in urban areas	3523[1]
	1 kg emission of PM10 in rural areas	180
	Noise emission per vehicle kilometre – light cars rural areas	0.008
	Noise emission per vehicle kilometre – heavy cars rural areas	0.040
	Noise emission per vehicle kilometre – light cars urban areas	0.067
	Noise emission per vehicle kilometre – heavy cars urban areas	0.617

[1] The numbers are calcutated, and give the valuation per unit for a urban area with a ventilation factor of 1.1 and 95 000 inhabitants (mean value of Sweden's 40 largest cities).

Some comments will be given with respect to the sources of these valuations. Most of them have been taken from a recent SIKA report (Nylander et al 1999) containing recommendations for the valuation of various items in cost-benefit analysis. Two sets of values were provided for environmental effects. The values that have been used in the strategic long term planning (inriktningsplanering) were used. Road accident costs refer to injured persons in police reported accidents, but have been adjusted for incomplete reporting in official accident statistics.

Obviously, all these valuations are uncertain. However, no official recommendations with respect to the treatment of uncertainty have been found. A discussion is given in chapter 9.

6.7 Models for estimating Effects of Measures

A set of models has been developed to estimate the effects of measures on road safety, mobility, transport costs, and the environment.

Effects on road safety. The effects of a measure on road safety are stated in terms of the number of prevented persons injured at a given level of injury severity. The basic model used to estimate the effects of a measure on road safety is:

Number of prevented injured persons = Exposure x Injury risk x Effect of measure

Exposure denotes:

- For road sections: the number of motor vehicle kilometres per year

- For junctions: the number of entering motor vehicles per year
- For motor vehicles: the number of newly registered motor vehicles per year
- For education and training: the number of people in each age cohort
- For enforcement: the whole road system, or specific roads
- For sanctions: the number of violators who are sanctioned per year

Injury risk denotes the number of injuries at a given level of severity per unit (million units) of exposure. Three levels of severity are distinguished in the calculations:

- Fatal injuries
- Serious injuries
- Slight injuries

For each level of injury severity the definition used in official accident statistics is applied.

The effect of a measure is stated as the percentage reduction in the number of injured persons. A numerical example showing how effects on safety are calculated is given in a subsequent section.

Effects on road safety from changes in speed. Some road safety measures affect the number and severity of injuries by affecting speed. The relationship of changes in speed to changes in the number of injured road users has been assessed by applying the following power functions:

$$\frac{\text{Number of killed after}}{\text{Number of killed before}} = \left(\frac{\text{Mean speed after}}{\text{Mean speed before}}\right)^4$$

$$\frac{\text{Number of seriously injured after}}{\text{Number of seriously injured before}} = \left(\frac{\text{Mean speed after}}{\text{Mean speed before}}\right)^3$$

$$\frac{\text{Number of slightly injured after}}{\text{Number of slightly injured before}} = \left(\frac{\text{Mean speed after}}{\text{Mean speed before}}\right)^2$$

The function for fatal injuries implies, for example, that a reduction in mean speed of 10%, results in a reduction in the number of killed road users of 34% ($0.9^4 = 0.656$, i e 34.4% reduction). The functions closely resemble functions given by Andersson et al (1998). The functions given by Andersson et al (1998) are defined in terms of the number of accidents, and contain an additional term that accounts for the effect of speed changes on the number of injured road users per accident. This additional term has been omitted in this report, and the functions as originally derived for accidents have been applied without modifications to injured road users as well. This is a conservative approach, intended to make sure that the effects of changes in speed are not overstated.

Effects on mobility. The term mobility refers to travel time. Effects on travel time are estimated by relying on changes in mean speed. The effects are stated as changes in the number of vehicle hours of travel:

Change in mobility = Vehicle hours of travel before – Vehicle hours of travel after

If the number of vehicle hours of travel is reduced, this expression is positive, and the change is counted as a gain for mobility. If the number of vehicle hours of travel increases, the change becomes negative and counts as a loss of mobility. This estimate is applied both to existing traffic and induced traffic, treated separately.

Effects on vehicle operating costs. Changes in the direct costs of transport are approximated by changes in vehicle operating costs. These costs are assumed to depend on speed as shown in Figure 11. Figure 11 shows one curve for rural areas and one for urban areas. Both curves are an average for light and heavy vehicles, weighted according to the mixture of light and heavy vehicles in rural and urban areas. The percentage of heavy vehicles is higher in rural areas, hence the mean cost is slightly higher in rural areas than in urban areas.

The effects of a measure on vehicle operating costs has been assumed to depend on speed only. However, vehicle operating costs depends not just on speed, but on the quality of the road surface and on the smoothness of speed. The curves in Figure 11 refer to a constant driving speed. If you drive at a constant speed of 30 km/h, costs are higher than if you drive at a constant speed of 50 km/h. This changes, however, if you compare a constant speed of 30 km/h to a highly variable speed of 50 km/h. Frequent stops and accelerations increase fuel consumption and thus vehicle operating costs. The complexity introduced by this is discussed in a subsequent section.

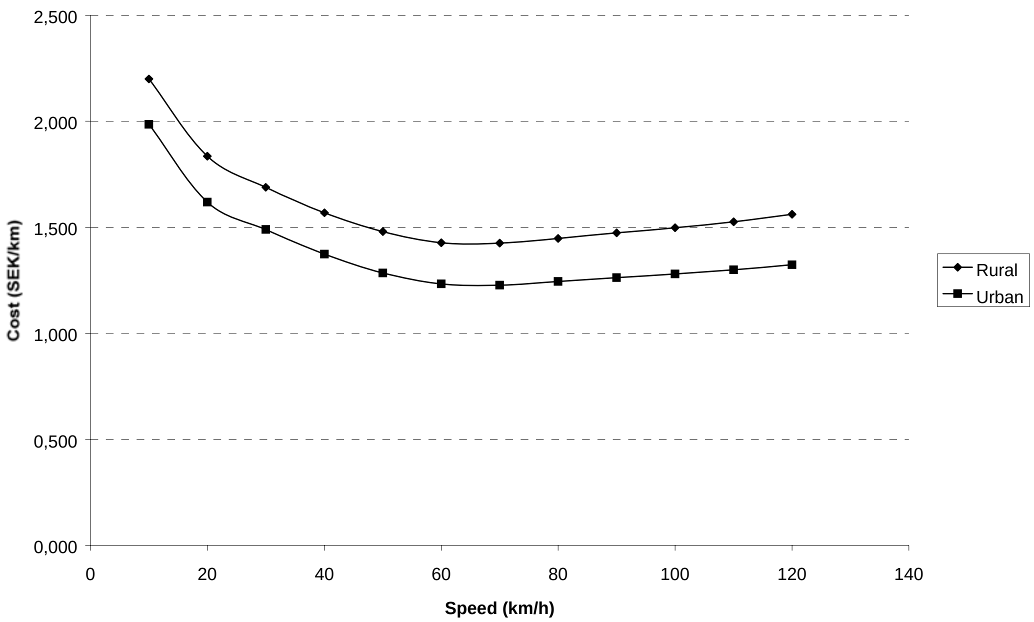

Figure 11: Vehicle operating costs in rural and urban areas. SEK/km

Effects on the environment. The approach taken to estimating effects on the environment is similar to the one chosen for vehicle operating costs. The costs of noise and pollution were estimated as a function of speed for urban and rural areas, applying the valuations given in table 13 and emission factors taken mainly from a Norwegian model (Statens forurensningstilsyn 1999). Figure 12 shows the results of these estimates.

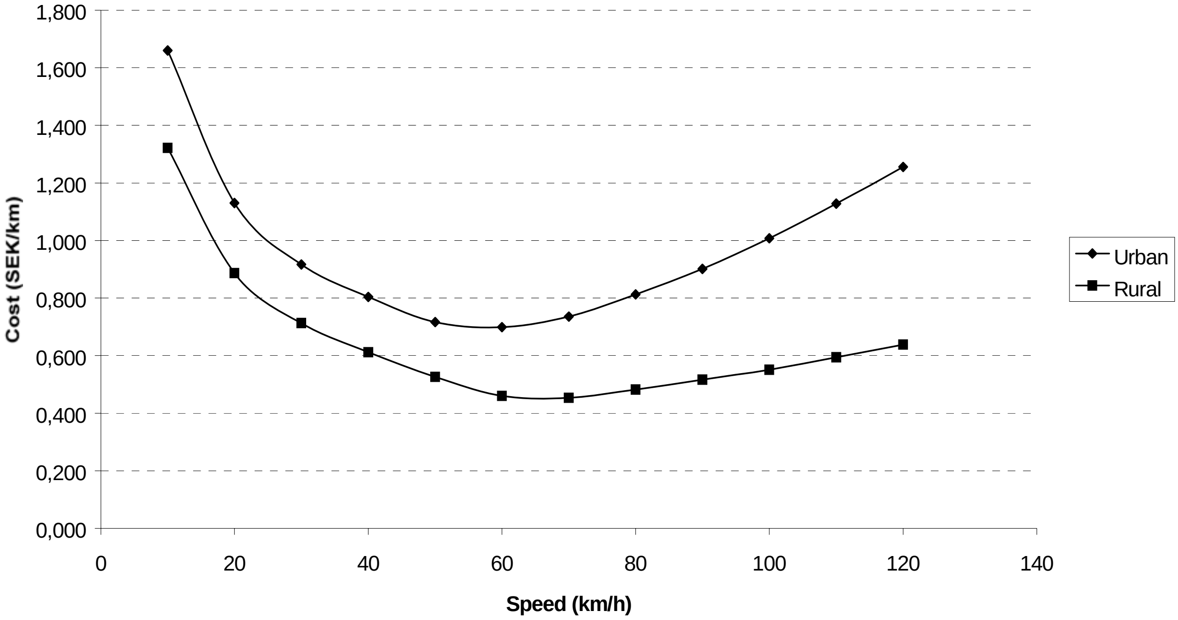

Figure 12: Environmental costs of urban transport in urban and rural areas. SEK/vehiclekm

The costs form a U-shaped curve as a function of speed. The environmental costs of motor traffic are higher in urban areas than in rural areas, and depend more strongly on speed in urban areas than in rural areas. An assumption of constant speed was used in estimating the curves. This assumption is not always correct, and the need for adjusting it is discussed below.

The shape of the relationship between speed and environmental costs differ for different types of effects. The costs of traffic noise increase exponentially as speed increases, and does not exhibit the U-shape of the curves shown in Figure 12. Most components of pollution emissions, are, on the other hand, closely related to fuel consumption, which is in turn related to speed.

6.8 A Numerical Example of a Cost-Benefit Analysis

To show how the models described above function, a numerical example is given. The example chosen concerns reconstructing urban main streets according to the design principles for 50/30 streets in Vision Zero. This measure closely resembles constructing an environmentally adapted through road.

It was assumed that this measure could be introduced for a maximum of 9,000 km of urban street. Three alternative levels of use for the period 2002-2011 were defined: 1,500 km, 4,500 km, and 9,000 km. The highest level of use corresponds to the maximum potential use of this measure. The lowest level of use corresponds to what, according to the Special Traffic Safety Plan, is expected to be implemented before the year 2007. The example given here refers to the lowest level of use.

It was assumed that the measure is first introduced in streets with a large traffic volume. Annual exposure for the first 1,500 km of street was assumed to be 4,000 million vehicle kilometres per year. This corresponds to assuming a mean AADT of 7,306. The total risk of injury was estimated on the basis of Table 6 in this report to 0.464 injured road users per million vehicle kilometres. The distribution of these by injury severity was also estimated on the basis of Table 6. Based on this, it was estimated that the measure can have an effect on 24 fatalities, 292 serious injuries, and 1,540 slight injuries per year.

The effects of this measure on accidents are a function of the effects on speed. Mean speed was assumed to be reduced from 50 to 42 km/h. The expected changes in the number of fatal, serious and slight injuries was estimated by relying on the following functions:

Effect on fatal injuries = $1 – [(42/50)^4] = 1 – 0.498 = 0.502$

Effect on serious injuries = $1 – [(42/50)^3] = 1 – 0.593 = 0.407$

Effect on slight injuries = $1 – [(42/50)^2] = 1 – 0.706 = 0.294$

In other words, a reduction of about 50% in the number of fatalities, about 40% in the number of serious injuries and about 30% in the number of slight injuries was assumed. This translated into 12 prevented fatalities, 119 prevented serious injuries, and 453 prevented slight injuries per year. Applying the costs in Table 13, and a present value factor of 12.415 (referring to 15 years, 4% annual discount rate and 1.5% annual real growth), this translated into an estimated saving in accident costs of 13,320 million SEK.

The effect on travel time was estimated as follows:

Effect on travel time = (4,000/50) – (4,000/42) = – 15.24 million vehicle hours

This increase in travel time was estimated to represent an additional cost of travel time of 25,729 million SEK, using the same assumptions as for accident costs.-

Based on the function given in Figure 11, vehicle operating costs were assumed to increase by 0.07 SEK per vehicle kilometre. This results in an additional cost of operating vehicles (present value) of 3,476 million SEK. Based on Figure 12, environmental costs were assumed to increase by 0.07 SEK per vehicle kilometre, resulting in an additional environmental cost of 3,476 million SEK (present value).

Reconstructing streets was assumed to cost 8.0 million SEK per kilometre, and increase annual costs of maintenance and operation by 500,000 SEK per kilometre of street. The results of the cost-benefit analysis can now be added up. Table 14 shows the results of this addition.

The analysis shows that the total benefits of this measure are negative. The most important reason for this, is the huge increase in the costs of travel time. However, there are several troublesome aspects of this analysis. There are reasons to believe that the results are biased and need to be adjusted.

In the first place, the analysis – at least broadly speaking – takes a motorist’s point of view. Additional travel time and added vehicle operating costs count as losses.

But a reduction of vehicle speed may well be perceived as a gain by non-motorised travellers (pedestrians and cyclists) and by residents or people who are working next to a street, like shopkeepers. The gain to these groups is not included in an analysis that considers time spent driving only.

Table 14: Case illustration of a cost-benefit analysis of constructing 50/30 streets

Effects	Million SEK (present values)
Reduction of traffic injuries	13,320
Increase in travel time	-25,729
Increase in vehicle operating costs	-3,476
Increase in environmental costs	-3,476
Total benefits	-19,361
Investment costs	12,000
Operation and maintenance	9,311
Taxation costs	11,295
Total costs	32,606

In the second place, the assumption made that speed changes from one constant level to another constant level is unlikely to be correct. A reduced mean speed may be associated with a reduced variability of speed. This could have important implications for the effects on fuel consumption and pollution emissions. Unfortunately, only a few studies have tried to evaluate the actual effects of speed reducing measures in urban areas on fuel consumption and pollution emissions. These studies have nevertheless been reviewed and are discussed below.

6.9 Modifying the Conventional Framework for Cost-Benefit Analysis for Speed Reducing Measures in Urban Areas

Modification of assumptions concerning vehicle emissions. Three studies have been found that assess the effects of speed reducing measures in urban areas on fuel consumption or pollution emissions. These studies are:

- A report on environmentally adapted through roads in Denmark (Treumer Andersen and Michelsen 1997)
- A report summarising several studies by Hedström (1999)
- A report on an experiment in Växjö (Hydén and Várhelyi 2000)

The results of these reports are summarised in Table 15, which in addition compares them to the model employed in this report.

The results presented in Table 15 are quite diverse, but on the whole the studies of Treumer Andersen and Michelsen (1997), Hedström (1999) and Hydén and Várhelyi (2000) do not confirm the results of the model used in this report. The most important explanation for this, is probably that the variability of speed is reduced as mean speed is reduced. Reduced variability of speed, in the form of less frequent and more moderate accelerations and decelerations, offsets the increase in fuel consumption and vehicle emissions associated with a lower mean speed.

Table 15: Effects of speed reducing measures in urban areas on fuel consumption and pollution emissions. Light cars in urban areas

Study	Speed reduction	Type of effect	Percent change
Model used in this report	50 to 42 km/h	CO2 emission	+18
		NOx emission	+5
		PM10 emission	+21
		VOC emission	+29
Treumer Andersen and Michelsen 1997	56 to 50 km/h	CO2 emission	+5
		NOx emission	+0
		PM10 emission	+2
		VOC emission	+9
Model used in this report	39 to 30 km/h	CO2 emission	+18
		NOx emission	+4
		PM10 emission	+12
		VOC emission	+30
Hedström 1999	31 to 27 km/h	CO2 emission	-4
	(Tempo 30 Graz)	NOx emission	-32
		VOC emission	-17
	Not stated	NOx emission	-30
	(Buxtehude)	VOC emission	-7
	Not stated	CO2 emission	+7
	(VTI-model)	NOx emission	-26
		VOC emission	-3
Hydén and Várhelyi 2000	50 to 40 km/h	NOx emission	+4
		NOx emission	-21

Hedström (1999) remarks that this effect is likely to be most clearly evident for 30 km/h streets. 50/30 streets are likely to have a greater variance of speed. The studies he quotes, do not show what the effects of a very low driving speed, close to 10-20 km/h would be. When speed becomes this low, one may perhaps assume that emissions start to increase again, despite the fact that speed variability may be even more reduced. Driving at a low gear (first or second) is associated with an increase in fuel consumption.

On the basis of the studies reviewed above, it was decided to modify the assumptions made regarding the effects of speed reducing measures in urban areas as indicated in Table 16.

Table 16: Modification of assumptions made in analyses of speed reducing measures in urban areas to account for the effects of reduced variability of speed in addition to reduced mean speed

Measure	Original assumptions regarding savings in cost per vehicle kilometre		Modified assumptions regarding savings in cost per vehicle kilometre	
	Vehicle operating costs	Environmental costs	Vehicle operating costs	Environmental cost
30 km/h streets	-0.100	-0.10	0.000	0.000
50/30 km/h streets	-0.070	-0.070	-0.015	-0.020
7 km/h streets	-0.120	-0.210	-0.030	-0.050

It has been assumed that introducing 30 km/h streets has no effect on vehicle operating costs or on environmental costs. This is a conservative assumption, considering the fact the many of the studies quoted by Hedström (1999) actually indicated a reduction in fuel consumption and vehicle emissions. For the other two speed reducing measures, the effects on vehicle operating costs and environmental costs have been reduced to roughly 20% of the original values.

Although these adjustments are clearly ad hoc, it is hoped that they more adequately reflect the combined effects of changes in mean speed and changes in the variability of speed than the original assumptions, which were based on an assumption of constant speed (e g a change from a constant speed of 50 to a constant speed of 42 km/h).

Effects on travel time for pedestrians and cyclists. The effects on travel time have been estimated for motorised traffic only. It is, however, likely that speed reducing measures in urban areas can benefit mobility for pedestrians and cyclists. The reconstruction of crossing facilities makes it easier for pedestrians and cyclists to enforce their right of way when crossing the road. A general slowing of motor traffic makes it easier to find gaps in traffic to cross the road at leisure.

The extensive study made in Växjö (Hydén and Várhelyi 2000) confirms this. In give way junctions that were converted to roundabouts, each pedestrian gained on the average 1.3 seconds when crossing the road, and each cyclist gained on the average 2.2 seconds. In a previously signal controlled junction, gains were even bigger: 12.5 seconds per pedestrian and 3.4 seconds per cyclist. Gains of this magnitude can, however, only be expected on streets with a quite heavy volume of motor traffic.

According to Thulin (1999) about 70% of pedestrian exposure occurs in urban areas. Among cyclists, the corresponding proportion is around 75%. Pedestrian exposure amounts to about 2,700 million kilometres per year, cyclist exposure amounts to about 3,300 million kilometres per year. This means that exposure in urban areas is 1,890 million kilometres, and 2,475 million kilometres, respectively. Pedestrians on the average cross the road 3.75 times per kilometre in urban areas, making for a total of 7,090 million crossings per year. Cyclist on the average cross the road about 1.6 times per kilometre, resulting in a total of about 3,960 million crossings per year.

The number of crossings in each type of road is not very well known. For the purpose of estimating the gain in travel time, it has been assumed that crossings are distributed in proportion to the amount of motor traffic. It has further been assumed that there is an average gain of 6 seconds per pedestrian and cyclist on 50/30 km/h streets and 2 seconds on 30 km/h streets. The amount of crossings on 7 km/h streets has been assumed to be negligible. The total number of crossings in urban areas is 11,050 million per year. It has been assumed that 65% are on streets that are eligible for conversion to the 50/30 design, 15% are on streets eligible for conversion to the 30 design, 15% are on streets eligible for the 70/50 design (mainly grade separated crossing facilities), and 5% are on streets eligible for the 7 km/h, walking speed design.

The value of travel time for a pedestrian or cyclist has been set equal to that for an average passenger car (120 SEK per hour). This means, for example, that on streets eligible for conversion to the 50/30 design, it is assumed, in the maximum potentials alternative, that there are 11,050 x 0.65 = 7,182.5 million crossings per year. The present value of the gain in travel time works out as:

7,182.5 x (6/3600) x 120 x 12.415 = 17,834.1 million SEK

in which:

7,182.5 is the number of crossings per year in millions,

6/3600 is the gain in travel time in hours (3 seconds to 3,600 seconds per hour),

120 is the value in SEK of travel time per person per hour, and

12.415 is the present value factor for 15 years at 4% annual discount rate and 1.5% real growth per year.

Values for all other alternatives were worked out the same way. The results of the modified analyses are summarised in Table 17, in which they are also compared to the original results.

Table 17: Comparison of results of cost-benefit analysis of 50/30 in original and modified framework for analysis

	Present values in million SEK by framework for analysis	
Effects	Original framework	Modified framework
Reduction of traffic injuries	13,320	13,320
Increase in travel time for motorists	-25,729	-25,729
Gain in travel time for pedestrians/cyclists	0	4,280
Increase in vehicle operating costs	-3,476	-745
Increase in environmental costs	-3,476	-993
Total benefits	-19,361	-9,866
Investment costs	12,000	12,000
Operation and maintenance	9,311	9,311
Taxation costs	11,295	11,295
Total costs	32,606	32,606

The original results are identical to those reported in Table 14. It can be seen that, although the modifications made in the assumptions have a major impact on some items, the overall outcome of the analysis remains unchanged. It would therefore seem that one would have to rely on very optimistic assumptions about effects on safety in order for these outweigh the expected loss from an increase in travel time. In fact, benefits would be smaller than costs even if the value of travel time for motorists was set equal to zero.

This does not mean that the trade off between mobility and safety made within the framework of a cost-benefit analysis represents the truth and cannot be challenged. It is, however, the result one gets by applying the current official Swedish valuations of safety and travel time. To the extent that one wants the introduction of the design principles for urban streets embodied in Vision Zero to be supported by cost-benefit analyses, it is necessary to change the framework for such analyses, by either:

- Changing the items that are included, for example by including road user security as an additional item, or
- Modify the monetary valuations applied in such analyses. Modifying these values would, however, affect all road projects, not just the reconstruction of certain urban streets.

6.10 Modifying the Conventional Framework for Cost-Benefit Analysis for Police Enforcement and Intelligent Speed Adaptation

The conventional framework for cost-benefit analysis relies on the tradeoffs made by road users to determine the values of non-marketed goods, like changes in the number of accidents, travel time or environmental factors. Taken literally, this means, for example, that any additional travel time should be counted as a loss, even if it is the results of police enforcement designed to curb illegal speed.

The treatment in cost-benefit analysis of gains obtained by violating the law has been discussed in detail in another report (Elvik 2000D). It was concluded that benefits that road users obtain by violations should not be counted as losses in cost-benefit analyses of enforcement. It follows, for example, that the additional travel time imposed on speeders by forcing them to obey speed limits is not counted as a loss in cost-benefit analyses. Any gain obtained by complying with speed limits, such as reducing vehicle operating costs, is, on the other hand, included as a benefit.

The decision not to include benefits obtained by violations in cost-benefit analyses of enforcement measures also has implications for the cost-benefit analysis of an intelligent speed adaptation system for motor vehicles. Basically, systems for intelligent speed adaptation are intended to help drivers keep to current speed limits. To the extent that this prevents violations, there is no loss of any legitimate societal gain. It must be assumed, however, that imperfections in the technology means that the average speed once all vehicles have systems for intelligent speed adaptation will be slightly below the speed limit.

There would therefore be a slight increase in legitimate travel time associated with the use of an intelligent speed adaptation system, equal to the difference between the speed limit and the actual mean speed. Figure 13 illustrates how the additional costs of travel time have been estimated for the case of an intelligent speed adaptation system.

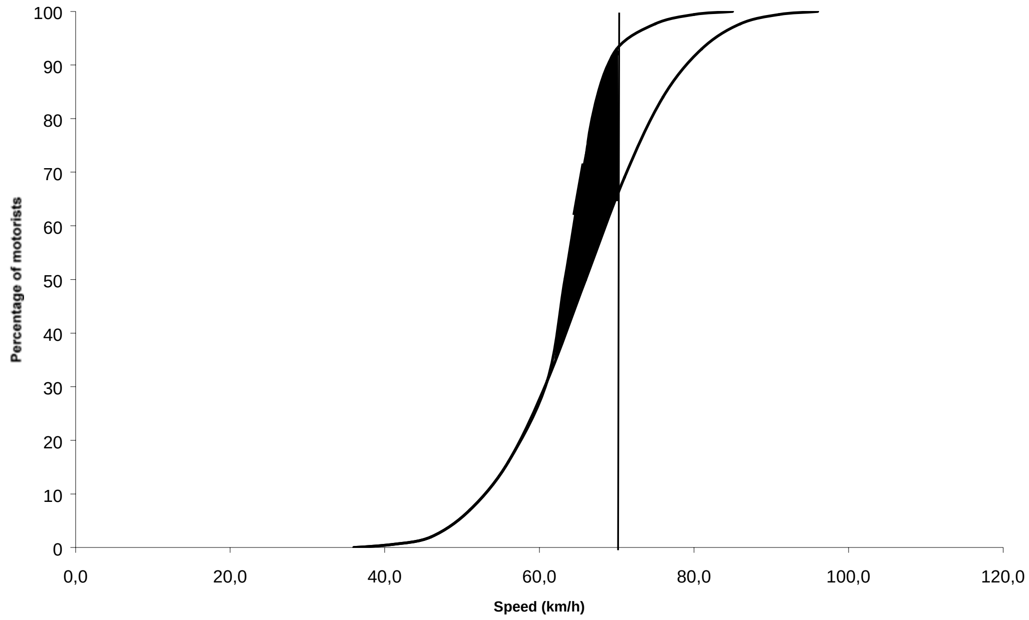

Figure 13: Additional costs of travel time in case an intelligent speed adaptation system is introduced. Shaded area represents additional costs

The additional travel time for which costs are estimated corresponds to the shaded area in Figure 13. This area shows the reduction in mean speed imposed on those who drove at or below the speed limit before the system was introduced. The size of this speed reduction has been estimated to between 1 and 4 km/h for different types of road. The proportion of drivers affected by this speed reduction has been estimated to between 53% and 77% for different types of road. The example given in Figure 13 concerns urban streets with a speed limit of 70 km/h. Current mean speed is 66 km/h. It has been estimated that this will be reduced to 63.3 km/h when all cars use intelligent speed adaptation.

6.11 Estimating the Combined Effects of Multiple Measures

The alternative road safety strategies developed in the next chapter all consist of a combination of several road safety measures. Some of these measures will be carried out at different geographical locations, and will therefore not affect the same accidents. At the national level, however, it is more correct to assume that different measures all affect the same groups of accidents. This means that their first order effects, that is the effects each measure has when implemented on an individual basis cannot be added, but has to be estimated by the method of joint residuals (see chapter 2). The following example shows how this method works.

Let E_i denote the zero order effect of each measure in terms of the number of fatalities or injuries it prevents. Let R_i denote the “residual” of measure i, that is the number of fatalities or injuries it does not prevent. Both quantities are measured as proportions of the total number of fatalities or injuries. Thus, for example a measure reducing 300 accidents by 30%, E_i is:

90/300 = 0.30,

and R_i is:

(300 – 90)/300 = 210/300 = 0.70.

The combined effect of all measures was estimated as:

$$\text{Combined effect} = 1 - \prod_{i=1}^{n} R_i$$

that is as one minus the product of the residuals of all measures included in a policy alternative.

7 Developing Alternative Road Safety Strategies

This chapter develops alternative road safety strategies. A road safety strategy consists of a set of road safety measures, put together according to a certain rule or principle for setting priorities. The strategies are assumed to apply to the ten year period from 2002 to 2011 (both years included).

7.1 Road Safety Strategies

Four alternative road strategies have been developed. The strategies are:

1 The Business as usual Strategy

This strategy consists of road safety measures as they are currently applied in Sweden. This means that no new reforms are introduced, except for those that have already been decided upon, but are not yet fully implemented. It has been assumed that measures currently used continue to be used to the same extent as the average during the last five years (1994-1998). It has further been assumed that at least some of the measures proposed in the Special Traffic Safety Plan presented in 1999 will be implemented before 2011. These are:

- Reconstruction of some urban roads according to the design principles of Vision Zero
- A reform of basic driver training, to encourage more behind the wheel practice before passing the driving test
- Increased random breath testing of drivers
- Introduction of speed cameras at about 1,200 km of road.

2 The Cost-Benefit Strategy

In this strategy, measures are implemented if their first order marginal benefits are greater than their first order marginal costs. The benefits include the total monetary benefits for safety, mobility and the environment. First order benefits are assessed in terms of the first order effects of the measures.

3 Vision Zero Strategy

The Vision Zero strategy consists of applying, in as consistent a way as possible, the road design principles of Vision Zero, and Vision Zero speed limits. Measures are prioritised according to cost-effectiveness, however, with the main emphasis put on cost-effectiveness in terms of reducing the number of fatalities and serious injuries.

4 Maximum Safety Potential Strategy

This strategy consists of implementing all safety measures to the maximum conceivable extent. This strategy is included mainly to serve a benchmark function, by indicating the theoretically maximum improvement in road safety that is conceivable by applying currently known road safety measures.

7.2 Description of Current and Maximum Use of Measures

For each of the measures included in the formal assessment of costs and benefits, a short description will first be given of their current use in Sweden.

Measure	***Road safety audits (8)***
Description	Road safety audits are supposed to be conducted on existing roads. A road safety audit consists of a systematic assessment of safety standard.
Current use	A trial road safety audit has been performed for 92 km of road in region West (Hvoslef 1998)
Maximum use	All national roads with AADT >2,000 (14,000 km) (Hvoslef 1998).

Measure	***Motor vehicle taxes (9)***
Description	Taxation of the use of motor vehicles, designed to internalise marginal, societal costs.
Current use	According to Hansson (1997), the current marginal tax rate is, on the average, 0.40 SEK per vehicle kilometre of driving.
Maximum use	An increase of 0.14 SEK per vehicle kilometre, to 0.54 SEK, would be sufficient to internalise external costs of road transport. This is an increase of about 35%. This is assumed to result in 10% less vehicle kilometres of travel.

Measure	***Automatic accident warning system (14)***
Description	A transmitter sending a signal to an emergency phone number is attached to the airbag. When the airbag is deployed, the signal is transmitted, permitting rapid location of the car by means of global positioning systems (satellite location).
Current use	The system is not currently used.
Maximum use	Mandatory on all new cars equipped with airbags as of 2002.

Measure	***Grade separated crossing facilities for pedestrians (101)***
Description	Construction of bridges or tunnels to provide crossing of arterial roads for pedestrians and cyclists.
Current use	Some 3,500 grade separated crossings exist in Sweden. About 70 new ones are constructed every year (Wramborg 2000)
Maximum use	A study of the implications of Vision Zero for urban arterial roads (Linderholm et al 1997) concludes that about 0.2 additional grade separated crossings are needed per kilometre of road. It is estimated that by 2010, there will be about 8,600 km of urban arterial roads. This means that about 1,750 new grade separated crossings are needed (making the total 5,250).

Measure	***Motorway class A (102)***
Description	Construction of new motorways of class A (at least two lanes in the same direction of travel and a median barrier)
Current use	There is currently about 1,480 kilometres of motorway in Sweden. 75 km of new motorway are opened every year.
Maximum use	All rural (speed limit 70 km/h or more) main highways (not classified as motorways) with an AADT in the year 2002 of more than about 8,000. This amounts to about 1,720 km of road.

Measure	***Reconstructing motor traffic roads into motorways (102)***
Description	Reconstructing all motor traffic roads into motorways.
Current use	It can be estimated that about 9 km of motor traffic road are reconstructed to motorways every year.
Maximum use	All motor traffic roads are reconstructed, amounting to 370 km of road.

Measure	***Bypasses (103)***
Description	Construction of bypass roads to lead long distance traffic outside towns and villages.
Current use	There are about 275 bypass roads around 450 towns in Sweden with a population of more than 2,000. 1-3 new bypass roads are opened every year (mean length about 5 km per road) (Nilsson 1994B).
Maximum use	Constructing bypass roads around all towns with a population of at least 2,000 that do not currently have bypasses, amounting to 175 bypass roads.

Measure	***Roundabouts (106)***
Description	Reconstructing junctions to roundabouts, with yield signs on the approaches.
Current use	There are about 1,500 roundabouts in Sweden. About 150 new ones are built every year.
Maximum use	All junctions with an AADT of at least 5,000 vehicles, except junctions in central business districts in towns where lack of space makes it impossible to build a roundabout. This amounts to about 2,000 additional junctions, of which 1,200 are three leg and 800 four leg junctions.

Measure	***Staggered junctions (108)***
Description	The measure consists of staggering a four leg junction, turning it into two three leg junctions.
Current use	There are currently about 300 staggered junctions in Sweden (projected from Brüde and Larsson 1987). It will be assumed that about 2 new ones are built every year.
Maximum use	It is not possible to estimate very precisely the maximum number of junctions that might be suited for staggering. It will be assumed that an additional 50 junctions are suited (in addition to the 300 that already exist).

Measure	***Interchanges (109)***
Description	Reconstruction of an at-grade junction to a grade separated interchange.
Current use	There are about 800 interchanges in Sweden. About 1-3 new ones are built every year.
Maximum use	It has been assumed, based on Andersson et al (1994) that about 25 junctions are suitable for reconstruction to interchanges.

Measure	***Roadside safety treatment (112)***
Description	Treating hazardous roadsides, by means of removal of objects or flattening of side slopes. Putting up guard rails is not included in this measure, but listed separately (measure 115 below).
Current use	It is estimated that at least 30% of all rural roads (about 30,000 km) contain hazards close to the roadside. A systematic programme for treating these roads does not currently exist.
Maximum use	All rural roads judged to have hazardous road sides and a traffic volume of more than 2,000 vehicles (4,000 km). It is assumed that less expensive measures, in particular guard rails, are preferred on roads with a smaller traffic volume.

Measure	***Reconstructing roads to the new 13m design (114)***
Description	Widening rural roads (with speed limit 90 and 110 km/t and AADT of at least 8,000 vehicle), and improve the standard according to new design standards for 13m roads. This involves an alternating 2 + 1 design with wire median guard rail.
Current use	It is estimated, on the basis of the National Road Transport Plan, that about 11 km of road are reconstructed every year.
Maximum use	The maximum potential is estimated to about 280 km of road.

Measure	***General rehabilitation of roads (114)***
Description	The measure consists of a general upgrading of both cross section, alignment and pavement surface on existing roads.
Current use	According to the National Road Transport plan 1998-2007, about 70 kilometres of road is going to be rehabilitated.
Maximum use	All roads with a 70 km/h speed limit and an AADT of more than 2,000 vehicles. This amounts to about 2,850 km of road. It is assumed that about half of these roads have already been reconstructed, making the maximum potential 1,400 km.

Measure	***New guard rails on embankments (road sides) (115)***
Description	The measure consists of putting up new guard rails on roads with hazardous roadsides.
Current use	About 4,600 km of road have guard rails. About 100 km of new guard rails are installed each year (Vägverket 1999A).
Maximum use	It is judged that guard rails can be effective on about 30% of roads outside built up areas (except motorways). When roads that have already got guard rails, and roads where road side safety treatment is proposed are subtracted, the maximum potential comes to 18,300 km of road.

Measure	***Median guard rails (wire) on wide roads (115)***
Description	The measure consists of putting up a median wire guard rail to separate opposite traffic directions on roads with a total width of at least 13 m.
Current use	According to the National Road Transport Plan, it is estimated that median guard rails will be introduced on about 15 km of road per year.
Maximum use	The maximum potential use of this measure on the current road system in Sweden is about 3,500 km.

Measure	***Preventing accidents involving animals (116)***
Description	The chief measure is to cut down trees and put up game fences along roads passing through areas with a high density of moose.
Current use	Game fences have been put up on about 2,000 kilometres of road. It is assumed that new fences are put up on 10 kilometres of road every year.
Maximum use	It is judged that game fences can be effective on about 4,000 kilometres of road, that is 2,000 in addition to those that already have these fences.

Measure	***Curve treatments (117)***
Description	The measure comprises putting up warning signs, directional signs, and advisory speed limits in hazardous curves.
Current use	It is assumed that about 4,000 curves have already been treated.
Maximum use	It is assumed that the treatment is suitable in an additional 4,000 curves. This estimate is very uncertain, but also conservative, compared to the potential use of this measure in Norway (which was used as a reference to determine potential use in Sweden).

Measure	***New road lighting (118)***
Description	The measure consists of installing new road lighting on previously unlit roads.
Current use	The are about 2,000,000 lamps for road lighting in Sweden (Svenska kommunförbundet 1999). Assuming that there is, on the average, 40 lamps per kilometre of road (equivalent to a mean distance of 25 metres between each lamp), this means that 50,000 km of road are lit. It is assumed that 46,500 km is public road. About 500 km of new road lighting is installed each year.
Maximum use	All public roads are eligible for installation of public lighting (136,500 km - 46,500 km = 90,000 km).

Measure	***Improving winter maintenance of roads (206)***
Description	The measure consists of improving winter maintenance of roads, by means of a combination of a quicker response to changes in weather, extending the use of chemical de-icing and more effective snow clearance.
Current use	All roads are maintained in winter, but the standard adopted depends on traffic volume.
Maximum use	It is assumed that a higher standard of winter maintenance can be adopted on all roads.

Measure	***Area wide urban traffic calming (30 km/h zones) (301)***
Description	This measure is assumed to involve reconstructing roads to conform to the design standards of 30 km/h roads within Vision Zero. The roads concerned are assumed to be access roads in urban residential areas.
Current use	Area wide traffic calming has been implemented in a number of areas in Sweden. It is assumed that all municipal roads currently having a speed limit of 30 km/h conform to Vision Zero design standards.
Maximum use	About 25% of all urban roads are assumed to be eligible. This amounts to about 12,600 km of road. AADT is assumed to be less than 2,000, with a mean of about 500.

Measure	***Redesigning urban main streets (50/30 streets) (302)***
Description	Urban main streets are assumed to be redesigned along the lines of environmentally adapted through roads. This includes improving pedestrian crossing facilities (raised pedestrian crossings) and providing cycle lanes (Wramborg 1998).
Current use	A few roads have been redesigned along these lines, but their total length is negligible.
Maximum use	Eligible roads constitute about 20% of road length in urban areas, amounting to about 9,000 km of road (Wramborg 1998). AADT is assumed to be more than 2,000, with a mean of about 5,000.

Measure	***Walking speed streets (woonerfs) (304)***
Description	These are streets redesigned in order to permit driving only at walking speed. These streets correspond to the design standards of walking speed streets in Vision Zero.
Current use	A few roads have been reconstructed as walking streets, but their total length is negligible.
Maximum use	Eligible roads make up about 20% of total road length in urban areas (Wramborg 1998), corresponding to about 9,000 km of road, of which 8,000 is assumed to be suitable. Mean AADT is assumed to be very low, about 150.

Measure	***Four way stop at urban junctions (308)***
Description	Introduction of stop sign on all approaches to four leg junctions in urban areas.
Current use	A limited experiment has been reported (Carlsson et al 1991), but the measure is not used today in Sweden.
Maximum use	Eligible junctions are those urban junctions that serve motor traffic in all directions, have restricted sight conditions and cannot be redesigned as raised junctions or roundabouts or served by traffic signals. It is estimated that there are 900 eligible junctions in Sweden.

Measure	***Traffic signal control at junctions (309)***
Description	Introducing traffic signal control at junctions
Current use	New traffic signals are less common today than a few years ago. Some traffic signals have been dismantled and replaced by roundabouts. There are about 2,700 signalised locations in Sweden, of which it is assumed that 2,500 are junctions and 200 are pedestrian crossings. Very few new signals are installed every year.
Maximum use	It will be assumed that there are still some locations where providing traffic signals could be the best solution. It will be assumed that there are 20 such locations, of which 10 three leg junctions and 10 four leg junctions.

Measure	***Traffic signal control at mid block pedestrian crossings (310)***
Description	Introducing new traffic signals at pedestrian crossings not located at a junction.
Current use	It is assumed that 200 pedestrian crossings outside junctions are signalised in Sweden.
Maximum use	It is assumed that the measure is suitable at a further 50 locations.

Measure	***Seasonal speed limits (311)***
Description	Introduction of reduced speed limits in the winter, for example from November 1 until April 1 (five months).
Current use	Seasonal speed limits are already in force on about 2,240 km of road in Sweden the winter 1999/2000.
Maximum use	In principle, seasonal speed limits could comprise the entire road network. It will be assumed however, that within the current speed limit system, the measure will be limited to roads with a speed limit of 90 or 110 km/h (see Ragnøy and Fridstrøm 1999). It will be assumed that seasonal speed limits are 20 km/h below general speed limits. 27,190 km of road are eligible for this measure.

Measure	***Optimal speed limits (311)***
Description	Setting speed limits in order to minimise the total costs to society of traffic operations. These costs include accident costs, costs of travel time, vehicle operating costs, and environmental costs.
Current use	Current speed limits are based on a mixture of criteria, that do not necessarily result in optimal speed limits.
Maximum use	The entire public road system could be subject to optimal speed limits (136,500 km of road). If the system is introduced, it is assumed that speed enforcement is increased by a factor of ten.

Measure	***Vision Zero speed limits (311)***
Description	Setting speed limits according to the criteria for human injury tolerance embodied in Vision Zero.
Current use	Current speed limits are not based on Vision Zero criteria.
Maximum use	All public roads will be included (136,500 km of road). It is assumed, however, that reconstructing roads according to Vision Zero has been carried out. Moreover, speed enforcement will be increased by a factor of ten. 103,000 km of road are then eligible for Vision Zero speed limits.

Measure	***Upgrading pedestrian crossings (314)***
Description	Improving ordinary marked pedestrian crossings by means of, for example, lighting, refuges, raised crossings, or fences.
Current use	It is assumed that there are 55,000 marked pedestrian crossings in Sweden, based on a report by Thulin (1999) about the number of times per kilometre walked that pedestrians cross the road at formal crossing locations in urban areas. This number may now have been reduced, but no statistics show by how much.
Maximum use	All marked pedestrian crossings could be improved. It is assumed that 1,000 crossings are already improved, and 54,000 in need of improvement.

Measure	***Road markings for cyclists at junctions (314)***
Description	The measure consists of marking advanced stop lines and cycle lanes through urban junctions, especially signalised junctions.
Current use	The extent of current use of the measure is not known, but is likely to be quite limited.
Maximum use	All signalised junctions (2,500 junctions).

Measure	***Cycle lanes (314)***
Description	The measure consist of providing cycle lanes in urban areas by means of road markings. It is an integral part of measure 302, but is in addition listed as a separate measure.
Current use	The length of roads in Sweden that have cycle lanes is not known. An additional 270 km of new lanes are opened each year (Wramborg 2000).
Maximum use	All urban main roads or collector roads (25,800 km of road).

Measure	***Feedback signs (320)***
Description	Variable message signs that give individual or collective feedback on selected aspects of driving behaviour. Applications that have been tested include speed, following distance, queue warning and yielding to pedestrians at crossings.
Current use	Current use of feedback signs is negligible.
Maximum use	The most promising application is feedback signs for speed at roads with high traffic volume. Maximum application includes all roads with an AADT with a speed limit of 90 km/h and a traffic volume above 2,000 vehicles. This amounts to 4,490 km.

Measure	***High mounted stop lamps (404)***
Description	Requiring high mounted stop lamps on all cars.
Current use	It is assumed that about 50% of all driving by light cars is performed by cars having high mounted stop lamps (Andersson et al 1998).
Maximum use	The maximum potential use of this measure is to require retrofitting of high mounted stop lamps on all cars as of 2002. Even without such a requirement, the proportion of cars with high mounted stop lamps will grow in the coming years.

Measure	***Self levelling head lamp requirement (407)***
Description	A self levelling head lamp is one that automatically adjusts correctly, depending on how the car is loaded. This will eliminate the problem of head lamps aiming too high or too low.
Current use	Very few cars are likely to have self levelling head lamps.
Maximum use	Requiring the system in all new cars as of 2002. Retrofitting on older cars is not realistic.

Measure	***Use of retro-reflective devices (pedestrians) (408)***
Description	Law requiring pedestrians walking in the dark on unlit roads to wear retro reflective devices to enhance conspicuity.
Current use	About 30% of pedestrians walking in the dark wear some reflective device.
Maximum use	Requiring use of reflective devices as of 2002. This is assumed to result in a wearing rate of 75% at the end of 2011.

Measure	***Reflective devices on bicycles (law) (408)***
Description	Requiring more reflective devices and light on all bicycles.
Current use	About 63% of all bicycles have reflective devices of some sort.
Maximum use	Requiring use of reflective devices as of 2002. This is assumed to results in a usage rate of 85% in 2011.

Measure	***Bicycle helmets, campaign and law (410)***
Description	Public information campaign and law requiring the use of bicycle helmets.
Current use	About 15% of all cyclists wear helmets.
Maximum use	A target has been set for 80% of cyclists to wear helmets. It has been stated, that a law requiring helmets to be worn will not be introduced until wearing rates have increased. The most radical alternative is for a law to be introduced as of 2002.

Measure	***Seat belt reminder in light cars (412)***
Description	A device in the car reminding drivers to put on their seat belts. This could, for example, be a buzzer that goes on buzzing until the seat belt is put on.
Current use	About 35% of cars have seat belt reminders (Volvo and Saab cars).
Maximum use	Requiring more effective seat belt reminders to be installed in all new cars as of 2002. Retrofitting reminders in older cars is not regarded as realistic.

Measure	***Ignition interlock device for seat belts (412)***
Description	An integrated circuit for the seat belt buckle and the ignition switch, making it impossible to start the car before the seat belt is firmly attached in the buckle.
Current use	Negligible, very few cars (if any) have got the system.
Maximum use	The most radical alternative is to require ignition interlocks on all new cars as of 2002. Retrofitting interlocks in older cars is not regarded as realistic.

Measure	***Air bags (414)***
Description	Air bags fitted to various seat and positions in light cars.
Current use	It has been estimated that about 44% of all cars have driver side air bags (Vägverket 2000).
Maximum use	No regulation of this measure is assumed to be introduced. However, the proportion of cars with air bags will grow even if no regulation is introduced.

Measure	***Intelligent cruise control (headway control) (418)***
Description	A system that monitors the distance to the car immediately ahead in the traffic stream and sends a warning to the driver if the distance is closing rapidly or is below a certain threshold.
Current use	The system has been tested experimentally (Nilsson 1996), but its regular use is so far negligible.
Maximum use	Required on all new cars as of 2002.

Measure	***Intelligent speed adaptation for cars (420)***
Description	A system that makes it impossible – or at least very difficult - to drive faster than the speed limit, by cutting off fuel supply, applying a blocking force to the gas pedal, or some other technical solution.
Current use	A large test of an intelligent speed adaptation system, involving 6,000 cars, is currently taking place in four cities in Sweden. Technically reliable systems exist, but are not in regular use.
Maximum use	Required on all cars as of 2002. It is assumed that it will be possible to retrofit the system in older cars. More moderate alternatives are to require the system on new cars only as of 2002, or on new cars as of 2011.

Measure	***Improving under run guard rails on trucks (422)***
Description	Current rear and side under run guard rails on trucks can be improved (Knight 1998) if made to the highest design standards. The highest design standards are technically superior to the under run guard rails that are currently mounted on most trucks.
Current use	No statistics has been found regarding the percentage of trucks that have under run guard rails and their quality.
Maximum use	Requiring an improved design of under run guard rails on new trucks as of 2002. Retrofitting on older trucks is not regarded as realistic.

Measure	***Front impact protection on trucks (423)***
Description	Modifications to the front design and front under run guard rails on trucks can significantly reduce the maximum decelerations for light car occupants in frontal crashes (Jones 1987; Riley et al 1987).
Current use	The system envisaged is not currently used.
Maximum use	Requiring front impact protection on all new trucks and buses as of 2002. Retrofitting the system on older trucks and buses is not considered to be realistic.

Measure	***Crash data recorder (429)***
Description	A data recorder that records, for example, speed, braking, steering wheel movements, and gear shifts for the last few seconds. This information is continually deleted, but is stored for future analysis when a crash occurs.
Current use	A system has been tested in Belgium (Wouters and Bos 1997), but is not currently in regular use.
Maximum use	Required for all new car as of 2002. Retrofitting the system in older cars is not regarded as realistic.

Measure	***New standards for front and bumper on light cars (430)***
Description	Modifications to the design of bumpers and the front of cars to reduce the severity of injuries to pedestrians struck by cars (Lawrence et al 1993).
Current use	A new design standard for the European Union has been proposed, but not adopted.
Maximum use	Required for new light cars as of 2002. Retrofitting on older cars is not realistic.

Measure	***Roadside motor vehicle inspections (503)***
Description	Random roadside technical inspections of cars, especially trucks.
Current use	A total of 65,000 random roadside inspections of trucks were made in 1998.
Maximum use	Inspecting, on the average, every heavy vehicle twice per year.

Measure	***Reforming basic driver training (604)***
Description	A number of reforms to basic driver training have been introduced in recent years. It is assumed that these reforms will be extended in the form of (a) incentive systems to encourage more on-the-road training, (b) a new insurance system for young drivers (first five years), (c) zero BAC limit for new drivers (first two years of driving), (d) a graduated license, including a curfew on night driving during the first year after the license is obtained (Grummas-Granström et al 1998)
Current use	Some elements of the system described above have been or are being introduced.
Maximum use	Introducing the whole set of measures as of 2002.

Measure	***Training of problem drivers (605)***
Description	A compulsory short training scheme for drivers who have been caught repeatedly for traffic violations. The training given will be targeted at those traffic violations for which the driver has been caught most often.
Current use	Systems like this exist in the United States, and do seem to have a modest impact on accidents. No such system exists in Sweden.
Maximum use	The system is introduced as of 2002. “Problem drivers” are, roughly speaking, 7.5% of all drivers (Spolander 1997).

Measure	***Training of bus and truck drivers (608)***
Description	Reforming the system of driver training for bus and truck drivers by (a) emphasising defensive driving, (b) requiring retraining every ten years, and (c) encouraging the introduction of reward systems for safe driving in bus and truck companies
Current use	A system like the one described above is not currently in use.
Maximum use	Introducing the new system for new drivers as of 2002. Retraining of older drivers is offered on a voluntary basis only.

Measure	***Training of school age children (6- years) (702)***
Description	Systematic practical training of school children in how to cross a road correctly in their everyday environment.
Current use	No statistics has been found describing the extent to which such training is given today.
Maximum use	Annual training of all children from the first to the sixth grade in school at the start of school every autumn. Children are assumed to be trained in a class, both on road and in the classroom. Total amount of training is assumed to require 1 hour of teachers work per pupil for those who are six years old, somewhat less for older children.

Measure	***Stationary speed enforcement (801)***
Description	Speed enforcement by means of radar and patrols that stop speeding drivers to give them traffic tickets or other sanctions.
Current use	Police enforcement currently costs about 670 million SEK per year. It is assumed that about 200 million SEK refer to stationary speed enforcement.
Maximum use	Ten times the current level of enforcement.

Measure	***Random breath testing (804)***
Description	Stopping drivers to test for alcohol in breath.
Current use	About 1 million drivers are tested every year. Totals costs are assumed to amount to 200 million SEK per year.
Maximum use	Ten times the current level of enforcement.

Measure	***Seat belt enforcement (805)***
Description	Checking the use of seat belts.
Current use	The amount of enforcement done today is not precisely known, but is assumed to amount to 50 million SEK per year.
Maximum use	Ten times the current amount of enforcement.

Measure	***Automatic speed enforcement (speed cameras) (806)***
Description	Speed enforcement by means of inductive loops and cameras that measure speed and take pictures of driver violating the speed limit.
Current use	This measure has been tested in Sweden (Nilsson 1992), but the current use is negligible.
Maximum use	All roads with a speed limit of 90 or 70 km/h and an AADT of more than 2,000. This amounts to 11,850 km of road.

Measure	***Automatic red light enforcement (red light cameras) (807)***
Description	Cameras taking pictures of drivers going against red traffic signals in signalised junctions (and pedestrian crossings).
Current use	The system has been tested in Sweden, but the current use is negligible.
Maximum use	In principle, all signalised junctions (about 2,500) could have the system.

Measure	***Demerit point system (810)***
Description	A system in which penalty points are given to traffic offences. The driver's license is suspended if a number of points have been accumulated within a certain period.
Current use	Demerit point systems exist in many countries, but not in Sweden.
Maximum use	Introducing a demerit point system as of 2002.

Measure	***Ignition interlock system for alcohol (812)***
Description	An ignition interlock system for alcohol has been developed and tested (Glad 1996). The system makes it impossible to start the car unless and breathalyser test is passed.
Current use	The system is not currently used in Sweden, except as part of an ongoing experiment.
Maximum use	Requiring the system to be installed in the cars of recidivist drinking drivers, that is drivers who have been convicted more than once for drinking and driving. It is estimated that there are about 5,000 new cases of recidivism in Sweden every year.

Measure	***Vehicle impoundment to prevent unlicensed driving (813)***
Description	Many drivers who have had their licenses suspended, for example as a result of drinking and driving, go on driving unlicensed. Impounding (confiscating) their vehicles may reduce the incidence of unlicensed driving.
Current use	The measure is not currently used in Sweden.
Maximum use	Vehicle impoundment is used routinely in cases of license revocation as of 2002. About 22,000 licenses are suspended in Sweden each year.

7.3 Developing Alternatives for the Use of each Measure

In general, for measures that are currently used, four alternatives have been developed for their use:

1 The measure is not used at all

2 The measure is used to the same extent as today

3 The measure is used to a somewhat higher extent than today

4 The measure is used to the maximum conceivable extent

These alternatives all refer to the use of a measure during a period of ten years, starting in 2002 and ending in 2011. It will be assumed that the annual use of a measure remains constant during these ten years. This means that if, for example, a total of 9,500 km of road are eligible for a measure, it is assumed that the measure is introduced on 950 km per year for ten years (950 km the first year, 1,900 km the first two years, 2,850 km the first three years, and so on).

For measure that are not currently used, or used only to a very minor extent, the alternatives for their use are generally:

1 The measure is not introduced at all

2 The measure is introduced at the start of the last year of the period, 2011, and has an effect during 1 year

3 The measure is introduced at the start of the first year of the period, 2002, and has an effect during 10 years

4 The measure is introduced retroactively at the start of the first year of the period, 2002, and is retrofitted on all older vehicles in the same year.

Alternative 1 is the most conservative one, alternatives 3 or 4 the most radical ones. Appendix 2 gives detailed information concerning the definition of alternative levels of use for each measure.

7.4 Developing Alternative Road Safety Strategies

Road safety strategies were developed by combining measures. Table 18 shows the use of the measures in each road safety strategy. As noted before, levels of use refer to the total use during the period 2002-2011. If, for example, enforcement is increased to ten times the current level, that means that enforcement will be ten times the current level every year during the period 2002-2011.

Table 18. Use of road safety measures in each strategy

	Use of measure in each road safety strategy – refers to period 2002-2011			
Measure	Business as usual	Benefit-cost	Vision Zero	Maximum potential
Road safety audits (8)	-	-	14,000 km	14,000 km
Motor vehicle taxes (9)	-	-	0.14 SEK/km	0.14 SEK/km
Accident warning (14)	-	-	-	95% use in 2011
Bridge or tunnel for pedestrians (101)	700 new	1,225 new	1,750 new	1,750 new
Motorway class A (102)	750 km	-	-	1,720 km
Reconstructing motor traffic roads (102)	90 km	185 km	370 km	370 km
Bypasses (103)	150 km (30)	-	-	875 km (175)
Roundabouts in T-junctions (106)	400 junctions	-	-	1,200 junctions
Roundabouts in X-junctions (106)	400 junctions	600 junctions	600 junctions	800 junctions
Staggered junctions (108)	25 junctions	-	-	50 junctions
Interchanges (109)	10 junctions	25 junctions	-	25 junctions
Roadside safety treatment (112)	1,000 km	1,000 km	4,000 km	4,000 km
Reconstructing roads to new 13m profile (114)	110 km	-	-	280 km
General rehabilitation of roads (114)	70 km	-	-	1,400 km
New guard rails on side slopes (115)	1,000 km	-	18,300 km	18,300 km
Median guard rails (115)	150 km	150 km	3,500 km	3,500 km
Game fences (116)	100 km	2,000 km	100 km	2,000 km
Curve hazard warning signs (117)	2,000 curves	2,000 curves	3,000 curves	4,000 curves
Road lighting (118)	5,000 km	10,000 km	10,000 km	90,000 km
Winter maintenance (206)	-	1,480 km	136,500 km	136,500 km

Table 18. Use of road safety measures in each strategy, continued

Measure	Use of measure in each road safety strategy – refers to period 2002-2011			
	Business as usual	Benefit-cost	Vision Zero	Maximum potential
30 streets (301)	6,500 km	-	12,600 km	12,600 km
50/30 streets (302)	1,500 km	-	9,000 km	9,000 km
Walking speed streets (304)	750 km	-	8,000 km	8,000 km
Four way stop (308)	90 junctions	-	900 junctions	900 junctions
Traffic signals in T-junctions (309)	5 junctions	10 junctions	10 junctions	10 junctions
Traffic signals in X-junctions (309)	5 junctions	10 junctions	10 junctions	10 junctions
Traffic signals at pedestrian crossings (310)	25 crossings	-	-	50 crossings
Seasonal speed limits (311)	2,240 km	4,480 km	-	27,190 km
Optimal speed limits (311)	-	136,500 km (more enforcement)	-	
Vision Zero speed limits (311)	-	-	103,030 km (more enforcement)	103,030 km (more enforcement)
Improving pedestrian crossings (314)	3,200 crossings	13,750 crossings	-	-
Cycle lanes and advanced stop lines (314)	2,700 km	-	-	-
Feedback signs (320)	-	90 km	180 km	4,490 km
High mounted stop lamps (404)	95% use in 2011	95% use in 2011	95% use in 2011	95% use in 2011
Self levelling head lamps (407)	-	50% use in 2011 (law in 2002)	50% use in 2011 (law in 2002)	95% use in 2011 (theoretical max)
Pedestrian reflective devices (408)	-	75% use in 2011 (law in 2002)	75% use in 2011 (law in 2002)	90% use in 2011 (theoretical max)
Cyclist reflective devices (408)	-	-	85% use in 2011 (law in 2002)	90% use in 2011 (theoretical max)
Cycle helmets (410)	-	75% use in 2011 (law in 2002)	75% use in 2011 (law in 2002)	90% use in 2011 (theoretical max)
Seat belt reminder (412)	-	-	70% use in 2011 (law in 2002)	-
Seat belt ignition interlock (412)	-	50% use in 2011 (law in 2002)	-	95% use in 2011 (theoretical max)
Air bags (414)	95% use in 2011	95% use in 2011	95% use in 2011	95% use in 2011
Intelligent cruise control (418)	-	-	-	95% use in 2011 (theoretical max)
Intelligent speed adaptation system (420)	-	-	-	-

Table 18. Use of road safety measures in each strategy, continued

	Use of measure in each road safety strategy – refers to period 2002-2011			
Measure	Business as usual	Benefit-cost	Vision Zero	Maximum potential
Improved under run guard rails (422)	-	-	55% use in 2011 (law in 2002)	95% use in 2011 (theoretical max)
Energy absorbing truck fronts (423)	-	55% use in 2011 (law in 2002)	55% use in 2011 (law in 2002)	95% use in 2011 (theoretical max)
Crash data recorder (429)	-	50% use in 2011 (law in 2002)	50% use in 2011 (law in 2002)	95% use in 2011 (theoretical max)
New front and bumper design on cars (430)	-	50% use in 2011 (law in 2002)	50% use in 2011 (law in 2002)	95% use in 2011 (theoretical max)
Road side inspections of trucks (503)	-	357,500 inspections	357,500 inspections	650,000 inspections
Reforming driver training (604)	Reformed before 2011	Reformed before 2011-	Reformed before 2011	Reformed before 2011
Training problem drivers (605)	-	-	Introduced before 2011	Introduced before 2011
New training system for bus and truck (608)	-	-	Voluntary before 2011	Compulsory for all before 2011
Training school children (702)	-	-	Introduced before 2011	Introduced before 2011
Speed enforcement (801)	-	5 times current	10 times current	10 times current
Random breath testing (804)	2 times current	2 times current	10 times current	10 times current
Seat belt enforcement (805)	-	-	-	-
Speed cameras (806)	1,185 km	6,515 km	11,850 km	11,850 km
Red light cameras (807)	-	250 junctions	2,500 junctions	2,500 junctions
Demerit point system (810)	-	Introduced before 2011	Introduced before 2011	Introduced before 2011
Ignition interlock for alcohol (812)	-	Introduced before 2011	Introduced before 2011	Introduced before 2011
Vehicle impoundment for unlicensed (813)	-	Introduced before 2011	Introduced before 2011	Introduced before 2011

Some comments will be given with respect to the choice of measures included in each strategy. An attempt has been made to avoid double counting, by not including two or more measures that affect the same category of accidents.

The business as usual strategy consists of measures that are expected to be carried out according to current plans. In the benefit-cost strategy, it has been assumed that the introduction of optimal speed limits is combined with a five fold increase in enforcement. The costs of this enforcement have been included as part of the cost of introducing optimal speed limits. Moreover, introducing an ignition interlock for seat belts has been preferred to increasing seat belt enforcement, because it is a more cost effective measure.

In the Vision Zero strategy, improving pedestrian crossings and providing cycle lanes and advanced stop lines for cyclists have been assumed to be elements of reconstructing streets to 30 km/h design or 50/30 km/h design, and are therefore not included as measures in their own right. Moreover, it has been assumed that roads are reconstructed according to the design principles of Vision Zero before new speed limits are introduced. Vision Zero speed limits therefore apply to 103,000 km of road only (not the whole public road system of 136,500 km). It has been assumed that speed enforcement is increased by a factor of ten. The cost of this measure has been counted as part of the cost of introducing these speed limits.

In the maximum safety potentials strategy, the same assumption has been made as in Vision Zero to the effect that roads are reconstructed before lower speed limits are introduced. It has been assumed that speed enforcement is increased by a factor of ten. The costs of this have been allocated to speed limits.

This means that there are two measures that are not included in any of the road safety strategies: introducing an intelligent speed adaptation system for cars and increasing seat belt enforcement. Both of these measures have a large potential for improving road safety. The effects on fatalities of an intelligent speed adaptation system have been estimated to a reduction of 11 in the first year after the system has been introduced for new cars, a reduction of 95 fatalities when the system has been required for new cars during ten years, and a reduction of 181 fatalities if the system is retrofitted on all cars. However, introducing optimal speed limits, while at the same increasing enforcement, is more cost effective and can prevent 181 fatalities. In other words, it dominates the introduction of an intelligent speed adaptation system.

It was judged that once Vision Zero speed limits have been introduced and enforcement has been increased, the additional safety potential of an intelligent speed adaptation system is greatly reduced. To avoid double counting, this measure is therefore not included in any of the strategies. Besides, introducing this measure may not be within the jurisdiction of the Swedish government, as vehicle safety standards are to an increasing extent set at the international level.

Seat belt enforcement has been estimated to have a maximum potential of preventing 23 deaths, if it is increased by a factor of ten. However, effects of a similar magnitude can be obtained at a smaller cost by two other measures: a seat belt reminder in cars, and an ignition interlock device for seat belts. Seat belt enforcement is, in other words, dominated by two other more effective measures and was therefore not included in any strategy.

8 Effects of Road Safety Strategies

8.1 Effects of road safety measures on the current number of fatalities and injuries

The effects on the number of traffic accident fatalities and injuries of carrying out each of the four road safety strategies for a consecutive period of ten years (2002-2011) have been estimated. Figure 14 shows the best estimate of the expected annual number of fatalities if each strategy is fully implemented.

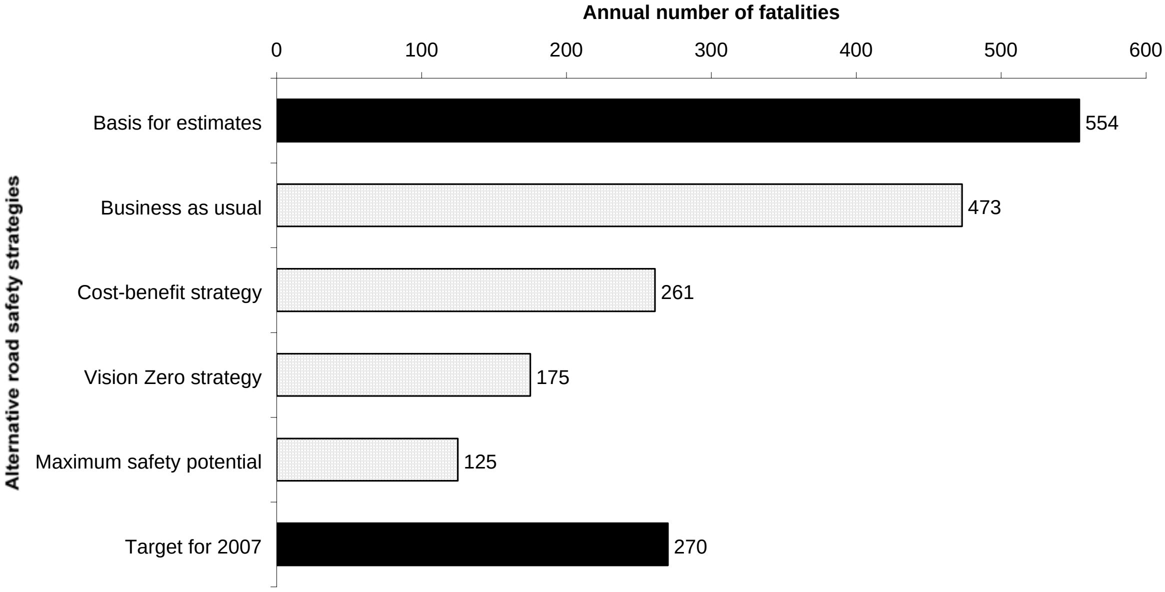

Figure 14: Estimated annual number of traffic accident fatalities if alternative road safety strategies are implemented

The mean annual number of fatalities for the years 1994-1998 was 554. It has been estimated that the business as usual strategy can reduce the number of fatalities by 81 over a period of ten years, resulting in 473 fatalities. This result applies *ceteris paribus*, that is assuming that everything else remains unchanged. The cost-benefit strategy can reduce the number of fatalities by 293, to an annual number of 261. The effects of the Vision Zero strategy are even greater, resulting in a reduction of the number of fatalities by 379 to 175, if a programme based on the principles of Vision Zero is carried out consistently for a period of ten years. The maximum safety potential has been estimated to a reduction of 429 in the current number of traffic accident fatalities, resulting in 125 fatalities. This corresponds to a reduction of nearly 80%. All these estimates are subject to numerous sources of uncertainty. Some of these are discussed in detail in the next chapter of the report.

Figure 15 shows the estimated effects of the four different road safety strategies on the number of killed or injured road users.

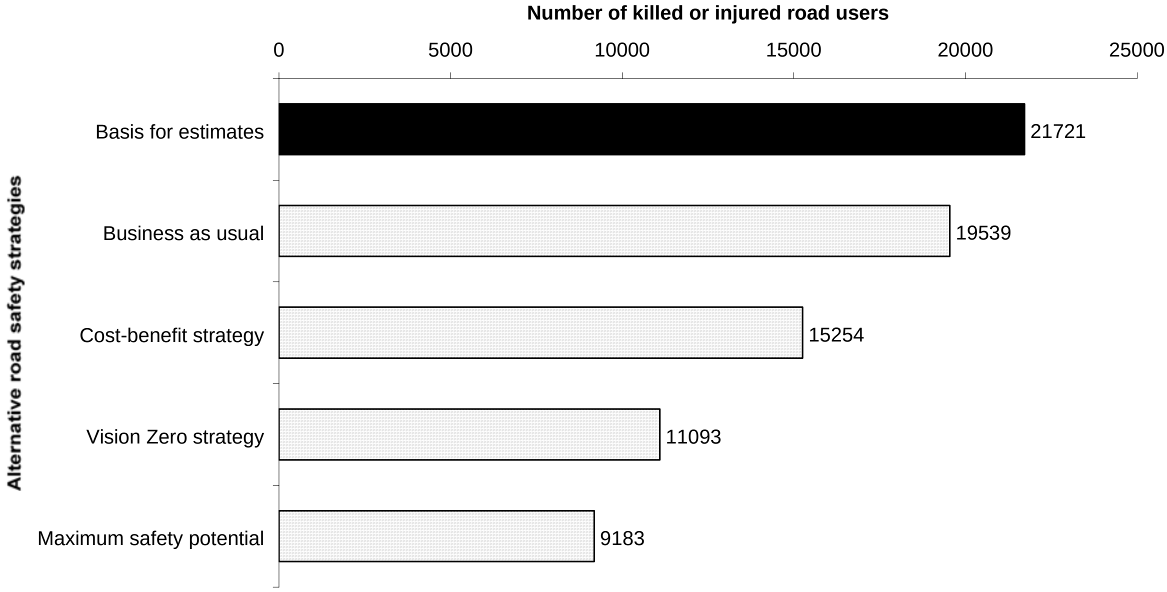

Figure 15: Estimated annual number of road users killed or injured if alternative road safety strategies are implemented

The mean annual number of road users killed or injured in police reported injury accidents during 1994-1998 was 21,721. If the business as usual strategy is continued for ten years, a reduction of 2,182 has been estimated, to 19,539 killed or injured road users per year. The cost-benefit strategy has been estimated to reduce the number of killed or injured road users by 6,467, to 15,254. An even greater reduction can be obtained by the Vision Zero strategy, from 21,721 to 11,093, which is a reduction of 10,628, or almost 50% of the current number of traffic accident casualties. The maximum potential for reducing traffic accident casualties has been estimated to 12,538, resulting in 9,183 casualties per year. This is a reduction of more than 55% from the current number of killed or injured road users.

There is, in other words, a large potential for improving road safety in Sweden. The current number of fatalities can – in theory – be reduced by about 75%, and the current number of killed or injured road users can be reduced by about 55%. These impressive numbers are, however, the maximum theoretical potentials, as known today. What are the opportunities for realising a substantial reduction in the number of killed or injured road users in the short run?

8.2 Forecasts of traffic volume, accidents and injuries

The estimates of the possible effects of road safety strategies presented in figures 14 and 15 are based on the following main assumptions:

- They refer to the effects of fully implementing all measures in a road safety strategy consistently for a period of ten years.

- They take the current number of killed or injured road users, that is the mean annual numbers for the years 1994-1998 as the basis for estimating the effects of the road safety strategies.
- They do account for the effects of traffic growth or other factors that may affect road safety.

In order to give somewhat more realistic predictions of the number of killed or injured road users that can be expected to occur in a specific year, the effects of traffic growth and other factors that influence road safety have to be estimated.

According to the National Road Plan 1998-2007 (Vägverket 1998), road traffic is expected to grow by about 1% per year from 1993 until 2010. In recent years, traffic has grown by more than 1% per year. The growth from 1998 to 1999 was 3%. A forecast based on an assumption of 1% annual growth in traffic volume has nevertheless been applied in this report.

The effects of a 1% annual growth in traffic volume on the number of accidents and road accident victims depends on a number of factors. Some of these factors, like the road safety measures introduced, can be controlled by government. Other factors are, for all practical purposes outside government control. Some of the factors that are outside government control can have a major effect on road safety.

An illustration of the importance for road safety of two factors that are mostly outside government control is given in a report by Brüde (1999A). In the report, the effects on the number of traffic accident fatalities of the reduction in the proportion of car kilometres driven by young drivers (age 18-24 years) after about 1990 and the reduction in the proportion of drinking drivers in Sweden has been estimated. It is concluded that these two factors are likely to have reduced the number of traffic accident fatalities in Sweden by 55 to 93 during the years 1994-1996. This amounts to an effect of 10-17%, which is very substantial.

The same report contains predictions for the number of traffic accident fatalities for the year 2007. The predictions are based on a model with the following structure:

Predicted number of traffic accident fatalities = $a \cdot b^{Year} \cdot Fuel^{c}$

This simple model fits the past changes in the number of traffic accident fatalities in Sweden very well. The fuel term captures the effects of changes in traffic volume on the number of traffic accident fatalities. The year term captures the total effects of all other factors on the number of fatalities. This includes the effects of road safety measures that are introduced, as well as effects of demographic changes, changes in road user behaviour and so on.

During the years from 1977 through 1997, the fatality rate per kilometre of travel declined by about 5% per year. Hence, it was only in periods of very strong traffic growth, combined with other unfavourable changes that the number of traffic accident fatalities increased. Based on the model fitted to data for the years 1977-1997, Brüde predicts 388 traffic accident fatalities in Sweden in the year 2007. Other predictions, based on the same model fitted to different years, range from 383 to 417 fatalities in the year 2007.

In a subsequent report (Brüde 1999B), predictions have been broken down by region and group of road user. However, this report gives predictions just for the year 2000, not for 2007.

Unfortunately, the prediction models developed by Brüde cannot be applied to the estimations presented in this report. The chief reason why these prediction models cannot be applied, is that they contain the effects of road safety measures. The decline in accident rate that has been observed in Sweden after 1977 is partly due to the road safety measures that have been introduced. The models developed by Brüde contains the effects of these measures, but lumps it together with whatever other factors have affected the accident rate as well, such as the recent decline in the proportion of young drivers and drinking drivers.

A main objective of this report is to estimate the potential effects of alternative road safety measures. Predictions of the future number of fatalities and injuries cannot then be based on a model which assumes that certain road safety measures have been implemented. An ideal prediction model for the purposes of this report would be a model that included all factors that influence road safety, *except road safety measures*. Such a model could then be applied to predict the number of fatalities and injuries expected to occur if no new road safety measures are introduced. It is, of course, assumed that no road safety measures already in place are removed. Briefly speaking this means that all elements of the road system are maintained at their current standard, and that turning over of the vehicle fleet is allowed to occur without government intervention or new vehicle safety standards.

The closest to such a model that has been found, is the model developed by Fridstrøm, Ifver, Ingebrigtsen, Kulmala and Krogsgård Thomsen (1993). Although this model does not perfectly fit the description above, it comes close to it. Moreover, the model has been shown to fit historical accident records quite well. The model accounts for the effects of:

- Traffic exposure (measured by means of fuel sales)
- Changes in the rules and routines for accident reporting
- Weather conditions (precipitation, temperature)
- Length of daylight
- Annual trend
- Pure random variation

As in the model developed by Brüde, the annual trend term is likely to contain effects of road safety measures. However, the model was fitted by means of state-of-the-art multivariate techniques, which means that the parameters estimated for each variable can be interpreted as the partial effect of that variable, controlling for all other variables in the model. This means that the model can be readily applied to estimate the effect on traffic injuries of traffic growth, controlling for all other factors that affect road safety.

For Sweden, elasticities have been estimated for the number of road users killed and the number of road users injured with respect to traffic volume. These elasticities were 0.64 for fatalities and 0.99 for injuries. This means that as traffic volume grows by 1%, one can expect a 0.64% growth in the number of fatalities and an 0.99% growth in the total number of police reported injuries. These results have been applied to predict the number of traffic accident fatalities and the number of people injured in traffic accidents in Sweden in the years from 1999 to 2012.

A traffic growth of 3% from 1998 to 1999 was assumed. For the subsequent years, an annual growth rate of 1% was assumed. The predicted number of traffic accident fatalities in 2012 came to 613. The predicted number of killed or injured road users in 2012 came to 25,422.

It should be noted that these predictions are likely to be quite pessimistic. These predictions assume that the only factor than contributes to improving road safety in the long run is the introduction of new road safety measures. This is unlikely to be true. As recent experience has shown, other factors may contribute to road safety as well. Predicting these factors is, however, very difficult.

8.3 Effects of road safety strategies in relation to road safety objectives

By relying on the predictions presented above, it is possible to estimate the effects of the alternative road safety strategies in relation to road safety objectives. Figure 16 presents the results of these estimates.

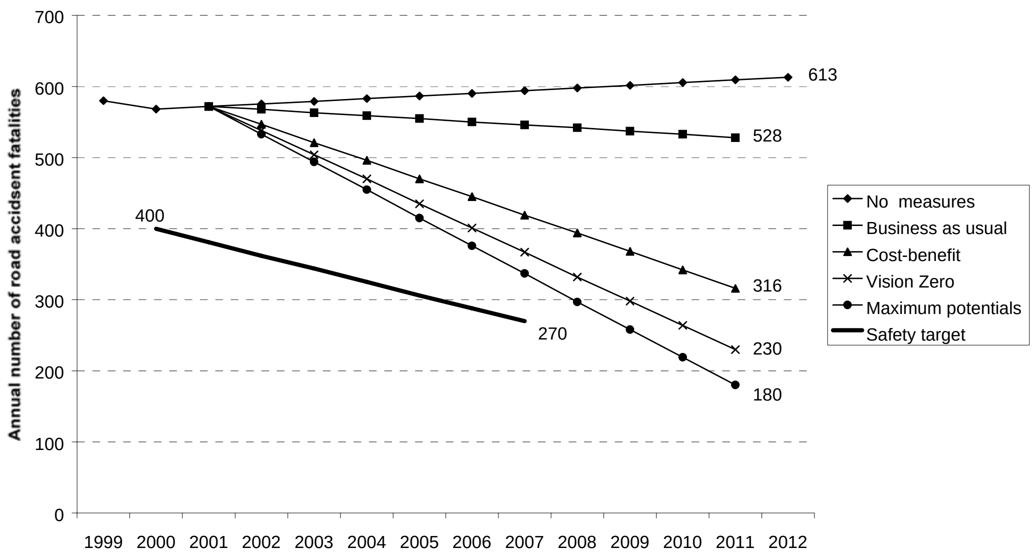

Figure 16: Predicted annual number of traffic accident fatalities in Sweden when alternative road safety strategies are implemented

The uppermost line in figure 16 shows the predicted number of traffic accident fatalities if no new road safety measures are introduced, reaching 609 in the year 2011. The business as usual strategy has been estimated to prevent 81 fatalities, resulting in a predicted number of 528 in 2011. If this strategy is implemented, no reduction of the number of fatalities compared to the current level can be expected.

The other strategies all result in a marked reduction in the number of fatalities. The assumption has been made for all strategies that the measures contribute 1/10 of their total effect each year of the 10 year period for which estimates were made. The cost-benefit strategy results in a predicted number of fatalities of 316 in 2011. The Vision Zero strategy results in a predicted number of 230 fatalities in 2011. The maximum safety potentials strategy results in a predicted number of 180 fatalities in 2011.

The target that has been set for 2007 of a maximum of 270 fatalities is not attained for any of the road safety strategies. This target can in principle only be attained by adopting the Vision Zero strategy or the maximum safety potentials strategy, and by implementing the most effective measures early in the period, in order to speed up the reduction in the number of fatalities. The curve showing the predicted number of fatalities would then drop most sharply in the first years after 2000 and then level out during later years. The endpoints shown in the year 2012 would, however, not be affected, as these show the total effects of the strategy at the end of the ten year period to which it applies.

Several questions can be posed on the basis of these results:

- Have important road safety measures been left out of the analysis?
- Would prolonging the period for which effects are estimated alter the results?
- Can the estimates be trusted, or are the results too uncertain to be of any practical value?

These questions will be discussed more extensively in chapter 11. Only brief remarks are therefore given here.

As shown earlier in this report, not all conceivable road safety measures were included in the formal assessment of costs and benefits. It is, however, very unlikely that any of the measures that were left out could have such a major effect before the year 2007 as to alter the finding that the target set for that year is unlikely to be realised. A measure like urban and regional planning, for example, typically affects road safety in the long term only. New safety features on motor vehicle also typically take 10-15 years to penetrate sufficiently into the vehicle fleet to make a major difference.

By prolonging the period to which the estimates refer, one could perhaps have included some long term measures, as well as allowing more time for the other measures to be fully implemented. But again, this would not alter the results. The fact that safety could be improved even more in, say, 2025 than in 2012 does not necessarily make it easier to realise a target set for 2007, at least not if the main reason for extending the time horizon would be to include long term measures.

The subject of uncertainty will be discussed in greater detail in the next chapter. There is considerable uncertainty in the estimates. It therefore cannot be ruled out that in very favourable circumstances, the road safety target set for 2007 can be realised. The uncertainty of the forecast made for traffic accident fatalities, as estimated on the basis of the standard error given by Fridstrøm et al (1993) is rather small. A 95% prediction interval for the year 2011 goes from 606 to 613 fatalities. There is far greater uncertainty with respect to the effects of the road safety strategies. The next chapter explains how this uncertainty has been estimated.

Table 19 shows the best estimate and the best and worst outcomes in 2011 based on the combined uncertainties of the accident forecast and the estimated effects of the road safety strategies.

Table 19: Sensitivity analysis for predicted number of traffic accident fatalities in Sweden in 2011 for each of four road safety strategies

	Predicted number of traffic accident fatalities in 2011		
Road safety strategy	Best estimate	Lower 95% limit	Upper 95% limit
Business as usual	528	473	587
Cost benefit	316	215	467
Vision Zero	230	135	396
Maximum potential	180	72	337

According to Table 19, it is in principle possible to realise a target of not more than 270 fatalities by means of all strategies, except business as usual, provided the highest estimate for the effects of all measures turns out to be correct. If, on the other hand, the lowest estimate for the effects of all measures turns out to be correct, a target of 270 fatalities is out of reach, no matter what road safety strategy is chosen.

8.4 Measures with a great potential for improving road safety

Which road safety measures have the greatest potential for improving road safety in Sweden? There is of course not a single correct answer to this question. The answer depends on the willingness to apply different measures. As far as traffic fatalities is concerned, the ten measures that have been estimated to have the greatest potentials are listed in table 20.

Measures that influence driving speed figure prominently on this list of measures. Adopting Vision Zero speed limits, while keeping current road design would lead to a reduction of the speed limit from 90 to 70 km/h on most roads that currently have a speed limit of 90 km/h. On urban main streets, the speed limit would be reduced to 30 km/h at all crossing locations for pedestrians and cyclists. It has been assumed that speed enforcement would have to be drastically increased in order to enforce these quite drastic changes in speed limits. When estimating the effect of the measure, it was assumed that speed enforcement would be increased to ten times the current level. It was further assumed that mean speed would be identical to the posted speed limit. If driving speeds are normally distributed, this assumption implies that a compliance with the new speed limits of about 50% has been assumed. This is virtually the same level of compliance as currently. In other words: It was assumed that Vision Zero speed limits, if enforced more effectively than current speed limits, would command about the same respect as current speed limits. It was estimated that this measure, or rather combination of measures, can reduce the number of fatalities by 307. This is more than 50% of the current number (assumed to be 554).

Table 20: The ten road safety measures that have the greatest potential for reducing the number of traffic accident fatalities in Sweden. First order effects. Effects cannot be added

Description of measure	Potential reduction in the number of traffic accident fatalities
Adopting Vision Zero speed limits on all roads, keeping current road design and increasing speed enforcement to ten times current level	307
Adopting Vision Zero speed limits, first reconstructing roads and increasing speed enforcement to ten times current level	216
Adopting optimal speed limits on all roads and increasing speed enforcement to five times current level	181
Requiring intelligent speed adaptation for all motor vehicles, without changing current speed limits (perfect compliance)	181
Increasing enforcement of current speed limits to ten times current level	133
Installing road lighting on all public roads	70
Reconstructing all main roads in urban areas according to the design principles of 50/30 streets in Vision Zero	49
Requiring ignition interlock for seat belts in all cars (perfect compliance)	37
Requiring a crash data recorder in all cars	35
Installing speed cameras (automatic enforcement) on about 12,000 km of road, speed limit 90 or 70 km/h	35

The price for safety in terms of reduced mobility if Vision Zero speed limits were to be introduced across the entire present road system would be substantial. The current strategy is to try to minimise the conflicts with other policy objective by reconstructing roads in order to allow a higher speed limit. If roads are first reconstructed according to the principles of Vision Zero, for example by providing median guard rails, by redesigning junctions or by providing raised pedestrian crossings, it would not be necessary to lower speed limits on all roads. However, on many roads, lowering the speed limit would remain the most cost-effective option for improving safety. If roads are reconstructed to the extent that can now be envisioned, adoption of Vision Zero speed limits, combined with increased enforcement on the remaining road system could reduce the number of fatalities by 216. Thus, a consistent introduction of Vision Zero speed limits remains a very potent road safety measure.

Third on the list of measures that have a great potential for reducing the number of fatalities is the introduction of optimal speed limits. These are speed limits that minimise the total costs to society of travel. The total costs include accident costs, costs of travel time, vehicle operating costs and environmental costs. Optimal speed limits were estimated for a total of twelve categories of road, as shown in Table 21. Table 21 compares the speed limits according to three different speed limit systems:

1 The current speed limits

2 Optimal speed limits

3 Vision Zero speed limits

The latter have been assumed to be introduced to the current road system, without first reconstructing roads.

Table 21: Three different speed limit systems for public roads in Sweden. Speed limits and driving speed in km/h

	Current driving speeds and three different speed limit systems for public roads in Sweden – kilometres per hour			
Category	Mean speed	Current limits	Optimal limits	Vision Zero limits
Motorway	109	110	110	100
Motorway	97	90	100	90
Motorway	82	70	80	70
Motor traffic road	108	110	90	70
Motor traffic road	96	90	80	70
Motor traffic road	82	70	80	70
Rural highway	106	110	90	70
Rural highway	95	90	80	70
Rural highway	82	70	70	70
Urban street	66	70	60	70/50
Urban street	50	50	60	50/30
Urban street	39	30	60	30/7

It is seen that Vision Zero speed limits are the lowest. Optimal speed limits are in most cases lower than or identical to current speed limits. In a few cases, optimal speed limits are higher than current speed limits. In particular, optimal speed limits in urban areas are estimated to 60 km/h both for main streets and access streets with a current speed limit of 30 km/h. If these results were to be taken at face value, a substantial increase of the number of killed or injured road users in urban areas would result. As noted in section 6.9, there are reasons to believe that the current framework for cost-benefit analysis of traffic control measures in urban areas is inadequate and leaves out important elements, such as travel times for pedestrians and cyclists and the sense of security felt by road users and residents along the road. The results for urban streets have therefore been rejected, and the current speed limit and current mean speed has been assumed to remain unchanged within a system of optimal speed limits.

When estimating the effects of optimal speed limits, it was assumed that enforcement would be increased by a factor of five, and that the new speed limits would command a compliance of 50%. Given these assumptions, a reduction of 181 in the annual number of killed road users was estimated.

Ensuring perfect compliance with current speed limits comes close to giving the same safety benefit. It was estimated that if all motor vehicles have systems for intelligent speed adaptation that ensure compliance with current speed limits, the number of fatalities would be reduced by 181.

It was judged that a similar effect cannot be attained by increasing conventional police enforcement. Based mainly on evidence from Swedish evaluation studies, it was estimated that the number of fatalities can be reduced by 133 by increasing the amount of speed enforcement by a factor of ten.

All these measures concern driving speed and the control of driving speed, which is clearly the most serious road safety problem in Sweden today. Sixth on the list of measures in Table 20 is providing road lighting on all public roads, which has the potential of reducing the number of fatalities by 70 per year. Reconstructing all urban main streets according to the design guidelines for 50/30 streets in Vision Zero can reduce the number of fatalities by 49 per year. The final three measures listed in Table 20 can each reduce the number of fatalities by about 35. These measures include an ignition interlock device for seat belt wearing, requiring a crash data recorder in all cars and installing speed cameras on selected roads. The estimate made for crash data recorders, in particular, is conservative, see the comments in section 11.1.

8.5 Measures that are cost-effective

To assess the cost-effectiveness of measures, the following ratio was estimated for each measure:

$$\text{Cost-effectiveness} = \frac{\text{Number of prevented fatal and serious injuries}}{\text{Annual cost of implementing measure}}$$

Costs were converted to an annual cost, employing the annuity method, in order to make all cost-effectiveness ratios comparable in terms of the duration of effects. Cost-effectiveness ratios were defined in terms of the number of prevented fatal and serious injuries, as attention is focused on these injuries in Vision Zero. Table 22 shows the ten most cost-effective measures according to the cost-effectiveness ratio as defined above.

Table 22: The ten most cost-effective road safety measures in Sweden. First order effects. Effects cannot be added

Description of measure	Number of prevented fatal and serious injuries per million SEK
Four way stop at hazardous junctions	5.39
Ignition interlocks for seat belts in all cars	3.46
Seat belt reminder system in all cars	1.38
Redesigning car fronts and bumpers to reduce injury to pedestrians	1.11
High mounted stop lamps on all cars	0.81
Requiring pedestrians to wear reflective devices	0.60
Vision Zero speed limits, current road system	0.58
Vision Zero speed limits, first reconstructing some roads	0.55
Optimal speed limits, all roads	0.55
Hazard warning signs in selected curves	0.40

The most cost-effective road safety measures include low-cost traffic engineering measures and minor modifications to cars. Some of these measures were also included on the list of the ten measures that can bring about the largest reduction in the number of fatalities. However, some the measures listed in Table 22 have a rather small effect on the total number of fatalities and injuries, although they are highly cost-effective. Two of the measures, ignition interlocks for seat belts and reminder systems for seat belts, essentially accomplish the same effect, but at a different cost.

8.6 Measures whose benefits are greater than the costs

For all measures, cost-benefit analyses have been performed. A measure will be designated as socially efficient, or optimal, if the marginal benefits are greater than or equal to the marginal costs of implementing the measure. It is important to remember that the benefits in this case includes not just safety benefits, but also benefits in terms of improved mobility, reduced vehicle operating costs, and an improved environment. Table 23 shows the ten most efficient road safety measures in Sweden, according to the cost-benefit analyses made for this report.

Table 23: The ten most efficient road safety measures in Sweden. Benefit-cost ratio. Based on first order effects. Figures cannot be added

Description of measure	Benefit-cost ratio
Ignition interlocks for seat belts in all cars	28.36
Seat belt reminder system in all cars	11.34
High mounted stop lamps on all cars	7.89
Redesigning car fronts and bumpers to reduce injury to pedestrians	6.80
Requiring pedestrians to wear reflective devices	5.09
Traffic signals at urban four leg junctions	3.74
Bicycle helmet, requirement	3.09
Ignition interlock device for drinking drivers (alcolock)	3.01
Increasing speed enforcement to ten times current level	2.89
Vehicle impoundment (confiscation) for unlicensed driving	2.86

There is some overlap between the list of the ten most efficient road safety measures in Table 23 and the list of the ten most cost-effective measures in Table 22. On top of the list in Table 23 are low-cost measures that mainly affect safety, and have small or negligible effects on mobility or the environment. Most of these measures are vehicle safety devices.

It may perhaps seem surprising that a new regulation aimed at pedestrians, requiring them to wear reflective devices when walking in the dark on unlit roads, comes out with a benefit-cost ratio of about 5. But the assumptions that lead to this result are fairly conservative. The current wearing rate for pedestrian reflective devices is about 30%. It has been assumed that if a law is introduced in 2011, the wearing rate in 2012 will have increased to 60%. If the law is introduced in 2002, the wearing rate in 2012 was assumed to be 75%. It was further assumed that a combination of enforcement and public information at the cost of 20 million SEK is introduced if the law is passed in 2011. The corresponding cost for enforcement and information if a law is introduced in 2002 was assumed to be 30 million SEK. The cost of producing a reflective tag was set at 5 SEK per piece. It was assumed that each person starting to wear reflective tags would need 10 of them. Finally, the effect of wearing reflective tags was assumed to be a reduction of 30% in the risk of accident during darkness. This effect is substantially lower than available evaluation studies suggest.

Similar comments can be made for a large number of measures. In general, the assumptions made are conservative. It is therefore likely that the benefit-cost ratio of many measures can be even more favourable than indicated by the calculations.

8.7 Socio-economic impacts of the road safety strategies

Each road safety strategy consists of a combination of road safety measures. The combined effects on safety have been estimated so as to avoid double counting. The socio-economic impacts of the strategies are expressed in monetary terms.

Table 24 shows the estimated socio-economic impacts of the road safety strategies.

Table 24: Socio-economic impacts of road safety strategies. Present values in million SEK

	Alternative road safety strategies (ten year period 2002-2011)			
Type of impact	Business as usual	Cost-benefit	Vision Zero	Maximum potential
Benefits				
Accidents	52,578	81,890	140,542	190,011
Travel time	-19,106	-2,925	-142,284	-109,237
Vehicle operation	-2,167	2,028	-2,493	-5,961
Environment	-2,888	4,137	4,129	1,182
Induced traffic	1,128	366	-7,854	-6,025
Total benefits	29,552	85,496	-7,960	69,970
Costs				
Investments	73,968	42,908	158,775	336,917
Running costs	27,183	11,998	107,543	150,856
Cost of taxes	35,455	13,531	118,196	180,218
Total costs	136,606	68,436	384,514	667,992
Benefit/cost ratio	*0.22*	*1.25*	*- 0,02*	*0.10*

Table 24 shows that, for all strategies, savings in accident costs constitute the by far greatest part of the total benefits of the strategy. This is hardly surprising, in view of the fact that the main objective of all strategies is to improve road safety.

In the business as usual strategy, there is an adverse net impacts for other policy objectives. This can be seen from the fact that the sum of benefits for travel time, vehicle operation, environment and induced traffic are negative. The most important reason for the adverse impact on mobility and the environment, is that it has been assumed – confer the Special Traffic Safety Programme (Särskild trafiksäkerhetsplan, Vägverket 1999) – that some main streets in urban areas will be reconstructed according to the design principles of 50/30 streets in Vision Zero. A reconstruction along these lines is assumed to lead to lower mean speed, which in turn leads to increased travel time and an increase in vehicle operation costs and pollution emissions. The assumptions made in the analysis of this measure were discussed in chapter 6.

The cost-benefit strategy by definition includes only those road safety measures for which the marginal benefits are greater than or equal to the marginal costs. In addition, vehicle safety features that are not mandatory will continue to spread (high mounted stop lamps and air bags). In this strategy, the net impacts with respect to other policy objectives are favourable, but of a quite marginal magnitude compared to the effects on road safety. A small reduction in mobility, associated with the introduction of optimal speed limits, is socially efficient. As one would expect, benefits exceed costs by a large margin.

The Vision Zero strategy has substantially greater impacts on safety than the business-as-usual strategy or the cost-benefit strategy. However, the impacts on other policy objectives of this strategy are quite adverse. Although it is an important consideration in Vision Zero to minimise conflicts with other policy objectives, a set of measures that do not lead to such conflicts has not been found in this study. Some reductions in speed are inevitable, and this does have an adverse effect on mobility. It would thus appear that the additional safety benefits gained by going further than in the benefit-cost strategy come at a disproportionate cost.

The maximum safety potentials strategy is mainly of theoretical interest. This strategy does have a positive total benefit, although the impacts for mobility and the environment are adverse even in this strategy. The costs of implementing the strategy are, however, prohibitively high.

As shown in the next chapter, there is considerable uncertainty in these results. Table 25 shows the 95% confidence limits for the benefit-cost ratio for each of the strategies.

Table 25: 95% confidence intervals for the benefit-cost ratio of the road safety strategies

	Benefit-cost ratio for alternative road safety strategies		
Road safety strategy	Best estimate	Lower 95% limit	Upper 95% limit
Business as usual	0.22	0.03	0.43
Cost-benefit	1.25	0.59	1.69
Vision Zero	-0.02	-0.17	0.07
Maximum potential	0.10	0.01	0.20

It can be seen that not even the cost-benefit strategy assures an outcome for which benefits are greater than costs. For the Vision Zero, there is uncertainty as to whether any positive total benefits will occur at all. Implications of this finding will be discussed in chapters 10 and 11.

8.8 Effects of road safety strategies for public and private expenditures

The costs of implementing the various road safety strategies given above are the costs to society. These costs are, however, not necessarily identical to the out-of-pocket expenses for the private and public sector. The annual direct expenditures arising as a consequence of the road safety strategies have been estimated. Expenditures for investments and running expenses have simply been added. This does not make sense in a cost-benefit analysis, but is consistent with the way private and public budgets are specified. It was assumed that costs for vehicle safety features, for basic driver training and for an ignition interlock to prevent drinking and driving are paid for by the private sector. All other costs were assumed to be paid for by the public sector. Table 26 presents the results.

Table 26: Annual direct expenditures for the public and private sector for implementing road safety strategies. Million SEK

	Annual direct outlays in million SEK		
Road safety strategy	Private expenses	Public expenses	Total expenses
Business as usual	1,560	5,717	7,277
Cost-benefit	3,647	3,357	7,004
Vision Zero	4,924	17,983	22,907
Maximum potential	11,466	32,218	43,684

The total annual expenditures are about the same for the business as usual strategy and for the cost-benefit strategy. The other two strategies involve substantial increases in expenditure. These increases comprise both the private and the public sector. In all strategies, the bulk of expenditures is paid by the public sector.

9 Uncertainty in the Estimated Effects of Alternative Road Safety Strategies

9.1 A Model of Compound Uncertainty

To estimate the costs and benefits of each road safety strategy, the following basic model has been applied:

Benefit = Exposure to measure x Effect of measure x Monetary valuation of effect x Net present value factor

For example, the road safety benefits of a certain measure, in terms of savings in accident costs, are the result of multiplying:

- The expected number of injured road users in the target group of the measure (exposure to measure)
- The percentage effect of the measure on target group injuries, specified according to severity (effect of measure)
- The official economic valuation of safety benefits, given as unit cost per injured person at each level of severity (monetary valuation of effect)
- The duration of the effects and the real growth rate expected in this period (the net present value factor)

Each of these four items can in turn be modelled as a function of several variables. The size of the group that is exposed to a measure depends on the definition of the target accidents or injuries, the proportion of travel exposure subject to the measure and the injury rate for this exposure:

Exposure to measure = Definition of target injuries x Travel exposure x Injury rate

In a similar manner, the present value factor, for example, is a function of three parameters:

Net present value factor = Duration of effect x Discount rate x Growth rate

It is therefore clear that there are many sources of uncertainty in the estimated benefits and costs of each road safety strategy. In order to estimate the contribution of these sources of uncertainty to the total uncertainty in estimated benefits and costs, the elementary model for the propagation of errors has been applied (Rasmussen 1964, Strand 1987, Elvik 1993):

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

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

$R = f(X, Y, \ldots W)$

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.

In this report, the basic model for the propagation of errors has been applied to estimate the uncertainty of the estimated effects of the road safety strategies on the number of killed or injured road users.

9.2 Sources of uncertainty in estimated safety benefits

There are several sources of uncertainty in the estimated safety benefits of each road safety strategy. The most important of these 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

A brief discussion of each point follows.

1 Definition of group of accidents or injuries affected by each road safety measure

It is sometimes not perfectly clear which group of road users, and in turn which category of accidents or injuries, a road safety measure affects. Introducing demerit point systems for traffic offences is a case in point. Does this measure affect all drivers, by raising the perceived risk of losing the driver’s license, thus providing a general deterrence from committing traffic offences? Or does the system just affect those who are caught for traffic offences? Or, even more restrictively, does it just affect those drivers who have already accumulated enough penalty points to be on the brink of losing their license (one more, and you are out)?

The choice between these three definitions of the group affected by the measure can make a major difference. If all drivers are affected, then nearly 100% of all accidents or injuries will be affected by the measure. If only drivers who are caught for traffic offences at least once during one year are assumed to be affected by the measure, it can be estimated on the basis of a report by Spolander (1997), that these drivers make up about 7.5% of all drivers and are involved in about 14% of all police reported injury accidents. The measure would then affect 14% of all accidents. Finally, assuming that only those who are on the brink of losing their license are affected, one can roughly estimated that they constitute about 1.5% of all drivers and are involved in 5% of all injury accidents each year. In this case, the choice of the definition of the group of drivers and accidents affected by the measure, ranging from close to 100% of all accidents to 5% of all accidents, can make a very big difference for the estimated effect of the measure.

A related, but more subtle point, concerns the possibility that a safety measure can have an effect, most of the time unintended, on other groups of road users in addition to those who are the primary target group for the measure. Consider, for example, ignition interlocks for recidivist drinking drivers. This measure is intended to help recidivists from repeating their offence. It is, however, not altogether implausible that this measure might affect even some first time offenders, who are attracted by the idea of having the possibility of continuing to drive legally even if they are caught for drinking and driving for a second time. For most drinking drivers, the loss of their driver’s license is the most severe sanction imposed on them. Many go on to drive unlicensed, but some refrain from doing so. For these drivers, having an ignition interlock means that they can go on driving. It cannot be ruled out that drivers belonging to this category are more likely to repeat their offence once the opportunity of ignition interlocks becomes available than they were before this opportunity existed. This, ignition interlocks may increase the likelihood of recidivism among some first time drinking drivers.

In most cases, there is little doubt about the definition of the target group of accidents or injuries affected by a certain measure. The choices that have been made in cases of doubt are generally conservative, which means that the smallest group of accidents or injuries has been assumed to be affected by the measure.

2 Random variation the number of accidents or injuries affected by each measure

In general, the number of injured road users affected by each measure has been estimated on the basis of the annual average for the year 1994-1998. Using a five year period will, at least for large groups, hopefully provide a sufficiently reliable basis for estimating the long-term expected number of injured road users, by eliminating the most extreme results of random fluctuation. However, even for a period of five years, the mean value can be affected by extreme data points. Moreover, there may be uncertainty as to whether there is a systematic long-term trend in the number of injured road users or not. Consider, as an example, the case of introducing new design standards for car fronts, intended to reduce the severity of injuries to pedestrians who are struck by cars. Table 27 shows that number of killed, seriously injured and slightly injured pedestrians struck by passenger cars in the years 1994-1998, and annual mean values for those years.

Table 27: Number of pedestrians killed or injured when struck by passenger cars 1994-1998. Sources: Statistics Sweden, official road accident statistics

	Number of pedestrians struck by passengers cars by injury severity		
Year	Killed	Seriously injured	Slightly injured
1994	58	337	783
1995	52	319	738
1996	45	319	778
1997	44	254	714
1998	45	313	729
Mean	48.8	308.4	748.4

Is there a long-term trend in these data or not? There does seem to be a tendency for the number of injured pedestrians to go down during the years from 1994 to 1998, but the tendency is not perfectly consistent. There was an increase in the number of injured pedestrians from 1997 to 1998. Are annual mean figures for the number of injured pedestrians unbiased estimates of the long-term expected values? It is impossible to know this for sure. As a rule of thumb, it is often suggested that a standard deviation encompassing pure random variation in counts of accidents corresponds to the square root of the count. This rule cannot be applied for the number of injured road users, because counts of injured road users are not independent events in the same sense as counts of accidents. This means that the traditional Poisson assumption will underestimate random fluctuations in counts of injured road users. Fridstrøm et al (1993, 1995) have estimated the likely size of random fluctuations in the number of killed road users and suggest that one should add at least 10% to the traditional Poisson approximation. This overdispersion parameter is a function of the expected number of killed or injured road users. The value of 10% has been used here as a conservative approximation. Applied to the mean number of killed pedestrians in table 27, this means that a 95% confidence interval comes to:

95% confidence interval for mean number of killed pedestrians =

$$48.8 \pm 1.1 \cdot 1.96 \cdot \sqrt{48.8} = 48.8 \pm 15.1 = (33.7; 63.9)$$

It is easily seen that the recorded number of killed pedestrians each year falls well within the 95% confidence interval for the mean, suggesting that the annual fluctuations are no greater than expected on the basis of randomness alone. Furthermore, it is seen that the uncertainty in the expected number of killed pedestrians assumed to be affected by the road safety measure, attributable to pure random variation is substantial. The 95% confidence interval amounts to 31% of the expected value, and the ratio of the upper 95% limit estimate to the lower 95% limit estimate is nearly 2:1 (63.9:33.7 = 1.9). This means that the number of killed pedestrians affected by the measure could vary by a factor of almost two on account of pure randomness.

The approximation suggested by Fridstrøm et al has been applied throughout to estimate the uncertainty attributable to random variation around the expected number of killed or injured road users assumed to be affected by each road safety measure. As noted, this is a conservative approach.

3 Incomplete and variable accident reporting in official accident statistics

The reporting of injury accidents in official statistics is known to be incomplete and unreliable. The true number of injured road users affected by the road safety measures is higher than official accident statistics indicate. Nearly all studies that have evaluated the effects of road safety measures on accidents or injuries are based on official accident statistics. Incomplete and unreliable accident reporting therefore affects the precision of estimates of both the number of injured road users affected by a measure and the number of injuries prevented by introducing the measure. In principle, it is possible to adjust for incomplete accident reporting by applying statistical techniques developed by Hauer and Hakkert (1988). Application of these techniques assumes that: (1) the mean reporting level is known and (2) the variance of the estimate of mean reporting level is known. Unfortunately, this knowledge is rarely likely to be available at the level of detail that is required for meaningful use of the corrections described by Hauer and Hakkert. The level of accident reporting varies, among other things, according to injury severity, group of road user, type of accident and age of victim. Moreover, it may change over time. It could therefore be misleading to correct for incomplete accident reporting by using an overall mean reporting level.

To illustrate the complexities involved, consider table 28, which shows the mean reporting level for injuries in official accident statistics for various groups of road users according to Statistics Sweden (Statistiska centralbyrån 1999).

Table 28. Mean level of accident reporting in official accident statistics for Sweden and uncertainty in the level of reporting

Group of road user	Mean reporting level (%)	95% confidence interval (%)
Car drivers	51	(37; 63)
Car passengers	46	(30; 62)
All car occupants	49	(20; 78)
Motor cycle riders	49	(20; 78)
Moped riders	32	(7; 57)
Cyclists	15	(11; 19)
Pedestrians	54	(15; 93)

The mean level of reporting varies substantially between different groups of road users. The size of the confidence intervals are also highly variable, and are in some cases very wide. Moreover, the level of reporting varies according to injury severity. Statistics Sweden states that the mean level of reporting is 59% for serious injuries and 32% for slight injuries. In order to adjust adequately for incomplete accident reporting, one would need to know both the mean level of reporting and the variance of the level of reporting for each category of road users and each level of injury severity. Table 28 provides only part of this information. A cross tabulation by injury severity, resulting in a table with 14 cells (7 groups of road users times 2 levels of injury severity; assuming fatal injuries are completely reported), would be needed to provide the necessary information. Even then, however, adjusting for incomplete accident reporting would be rather crude, as the level of reporting might be expected to vary over the year, across different types of road and between different types of accident.

No attempt has been made in this report to adjust for incomplete accident reporting. However, an illustration is given below of the potential contribution of incomplete accident reporting to the uncertainty in the estimated effect of a road safety measure.

4 Random variation in estimated effects of road safety measures

The estimates used for the effects of road safety measures have mostly been taken from the latest edition of the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997). This book provides information on the uncertainty in the estimated effects of each measure, attributable to random variation in the number of accidents or injuries on which the estimates of effect are based. For most of the measures included in the analysis, the 95% confidence intervals given in the Traffic Safety Handbook have been applied to indicate uncertainty in the estimated effects on accidents or injuries.

However, not all measures included in the analysis were included in the Traffic Safety Handbook. For new measures, the uncertainty of the estimated effects cannot be quantified on the basis of previous evaluation studies. For these measures, it has been assumed that the uncertainty of the mean effect is at least plus or minus 50%. Only future evaluation studies can tell whether or not this estimate is a good approximation.

5 Unknown sources of systematic variation in effects of road safety measures

For most of the measures whose potential contributions to improving road safety have been assessed in this report, the estimate of their percentage effect on accidents or injuries is based on meta-analyses performed as part of the Traffic Safety Handbook. The approach taken in these analyses has generally been to stratify available studies according to:

- Accident or injury severity, specifying effects for fatal accidents (or injuries), personal injury accidents, and property-damage-only accidents (PDO-accidents),
- Design of the evaluation studies, specifying effects for study designs that differ with respect to their control of confounding variables,
- Characteristics of the measure that were thought to be associated with the size of its effect on accidents or injuries.

Thus, for roundabouts, for example, a distinction was made between injury accidents and PDO-accidents, six different study designs employed in evaluation studies, and three leg and four leg junctions. This stratification resulted in a table of 24 (2 x 6 x 2) cells, some of which were empty, because that particular combination of accident severity, study design and type of junction was not represented in the set of evaluation studies retrieved for the meta-analysis.

It was believed that this approach would account for most sources of systematic variation in the effects of the measures. A fixed effects model of meta-analysis, which accounts for random variation in study results only, was therefore applied (see Elvik 1999D for a more extensive discussion). Subsequent analyses relying on a random effects model of meta-analysis have, however, shown that this assumption is not always correct.

A meta-analysis of area-wide urban traffic calming schemes is a case in point (Elvik 2000C). In this analysis, 33 evaluation studies containing a total of 76 results were retrieved. These results were stratified into nine groups, on the basis of accident severity and type of road affected. The homogeneity of effects within each of these nine strata was tested. The homogeneity test statistic was statistically significant in each group, indicating the presence of systematic variation in the effects of traffic calming within each group. A random effects model of meta-analysis was then applied. The weighted mean effects estimated according to the random effects model were virtually identical to those estimated according to the fixed effects model. But the confidence intervals surrounding the weighted mean effects increased substantially.

This analysis shows that even if available studies are stratified extensively prior to analysis, an element of systematic variation in study results may still remain. A fixed effects model – which accounts for random variation in study findings only – will then underestimate the uncertainty of the mean effects of a measure. In order to illustrate the effects of this, the confidence interval of the weighted mean effect on accidents or area-wide urban traffic calming schemes was estimated for three cases (Elvik 1999E):

1 The case in which a fixed effects model of meta-analysis is applied. The confidence interval includes random variation in effects only.

2 The case in which a random effects model of meta-analysis is applied. The confidence interval includes both random and systematic variation in effects.

3 The case in which an adjustment is made for incomplete and variable accident reporting, employing the method of Hauer and Hakkert (1988). The confidence interval includes random and systematic variation in effects, and adjustment for incomplete accident reporting.

Figure 17 gives the results of this calculation. It is seen that the size of the confidence interval for the weighted mean effect of area-wide urban traffic calming schemes increases as more sources of uncertainty are taken into account in estimating it. This is of course hardly surprising. The important point to note in the present context, is that the estimate of uncertainty applied for most measures assessed includes random variation in effects only. This is the most conservative estimate of uncertainty. The most correct one is the one to the right in figure 17, which accounts for more sources of uncertainty. In particular, accounting for incomplete and variable accident reporting is seen to increase the size of the confidence interval substantially.

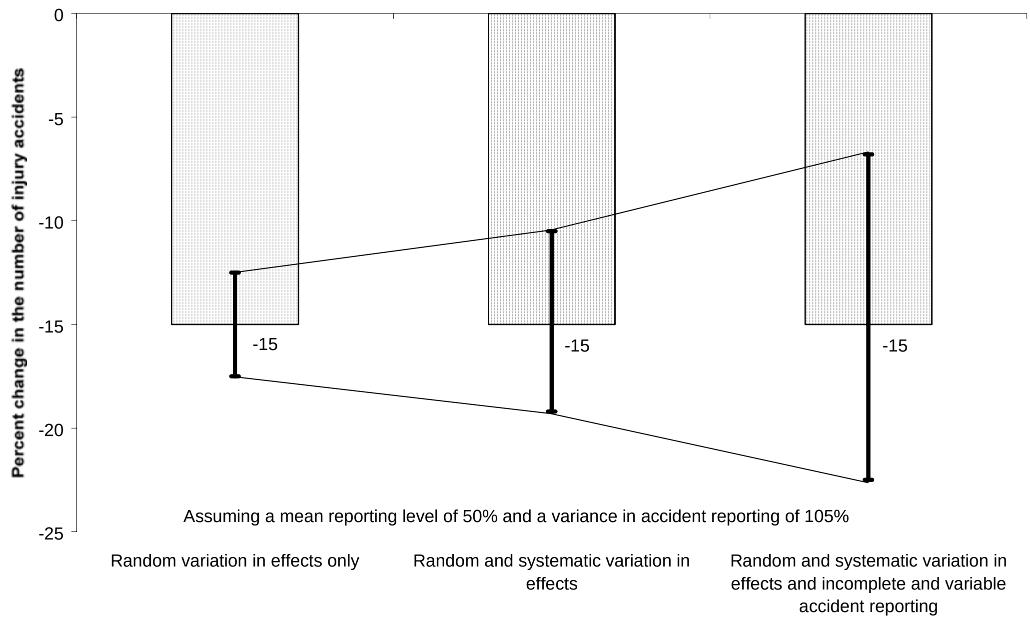

Figure 17: Size of confidence interval for mean effects of area-wide urban traffic calming schemes, depending on which sources of uncertainty are included when estimating the confidence interval

The contribution of unknown sources of systematic variation in the effects of each road safety measure to the uncertainty of the estimated effects cannot be assessed precisely without redoing all the meta-analyses reported in the Traffic Safety Handbook according to a random effects model. This is a major effort, which it has not been possible to undertake in this project.

6 Possible modifications of the effects of measures when they are combined

As noted above, the combined effects of two or more measures that are implemented together have been estimated by applying the method of joint residuals. This method assumes that the percentage effect of each measure is independent of whether the measure is introduced as a stand-alone measure, or combined with one or several other measures.

Very little is known about the accuracy of this assumption. It is, however, not difficult to think of cases in which it is likely to be wrong. Consider the case of road lighting and reflective devices for pedestrians, for example. Providing road lighting reduces the number of pedestrian accidents in the dark by about 50%. Reflective devices worn by pedestrians are also known to reduce the number of accidents substantially (Elvik, Mysen and Vaa 1997), even if the very great reduction estimated on the basis of the few studies that have been made is likely to be exaggerated. Are reflective devices equally effective once good road lighting is provided? It does not seem likely that they are, but no study has been found that has evaluated this. In the analysis, the assumption was therefore made that the effect of reflective devices is the same irrespective of whether or not road lighting is provided. This assumption is unlikely to be correct, but evidence to support an alternative assumption has not been found.

One of the very few studies that gives data that permit the assumption of constant and independent effects to be tested, is a study of junction improvements by Brüde and Larsson (1985). This study states explicitly if one or several measures were introduced in each of the junctions that were studied. Elvik (1988) reanalysed the study in order to test the validity of the assumption of constant effects made in the method of joint residuals. The number of accidents was reduced by 16% on the average in junctions in which just one measure was carried out. In junctions where more than one measure was carried out, the number of accidents was, on the average, reduced by 28%. The mean number of measures carried out in junctions where more than one measure was introduced, was 2.83. Hence, according to the method of joint residuals one would expect an accident reduction of:

$$1 - (0.84^{2.83}) = 1 - 0.61 = 0.39 = 39\%$$

in these junctions. The observed reduction was 28%. This suggests that when several measures are introduced at the same time, their combined effects are smaller than what one would expect on the basis of their first order effects. This finding is reasonable, since many measures are likely to influence more or less the same set of risk factors contributing to accidents. If this is correct, estimates of the combined effects of several measures may not just be uncertain, but biased as well.

Unfortunately, it was impossible in this project to determine if the method of joint residuals applied to estimate the joint effects of several measures gives results that are systematically biased or not. This source of uncertainty can only be removed, or estimated numerically, by conducting further empirical studies along the lines of the study reported by Brüde and Larsson (1985).

7 Uncertainty in road accident costs

Current official road accident costs for Sweden, as reported by SIKA (1999) have been applied in this report. Neither the report issued by SIKA, nor a similar report on cost-benefit analysis issued by the Swedish National Road Administration a couple of years earlier (Vägverket 1997), discusses uncertainty in the road accident costs. It is, however, obvious that these costs are highly uncertain.

In the report that lead to the adoption of a willingness-to-pay based estimate of road accident costs in Sweden, Persson and Cedervall (1991) state (page 78):

"What can be said about the appropriate interpretation and the relevant use of available estimates? According to figure 3.22, there will be at least 15 different estimates of the value of statistical lives, ranging from SEK 5.3 million to SEK 41.3 million, each of them relevant for allocative and regulatory decisions."

The choice of a recommended value to be used in cost-benefit analyses of road projects was ultimately based not just on the statistical precision of the available estimates, but on their presumed relevance with respect to characteristics such as:

- The initial level of risk from which a reduction was to be valued
- The size of the risk reduction from this initial level
- Characteristics of the distribution of responses in the sample asked to state their willingness to pay for a certain risk reduction. Due to skewness in the answers, the median value was preferred to the mean value.

This means that the recommended value of a statistical life used by the Swedish National Roads Administration is the result of a choice made on the basis of several considerations, whose nature do not easily lend themselves to meaningful statistical treatment. Although it is in principle possible to obtain a confidence interval for the recommended value of a statistical life, this confidence interval does not adequately reflect the contributions of the most important sources of uncertainty in value of life estimates.

In view of this, no account has been taken of the uncertainty inherent in road accident costs in this report. A similar point of view applies to the monetary valuation of other non-market goods as well.

8 The duration of the effects of a measure

In order to estimate the present value of the accident savings obtained by introducing a certain road safety measure, one has to make assumptions about the duration of those effects. To a large extent, the assumptions made are based on the recommendations given by SIKA with respect to the time horizon and service life for various types of road related measures. These recommendations do not include vehicle-related measures and road user related measures. For these measures, assumptions have been made on a discretionary basis.

It is not known if assuming an effect lasting for as long as 15 or even 40 years is correct. In most before-and-after studies that have evaluated the effects of road safety measures, the after-period is shorter than five years. What happens after this period is essentially unknown and perhaps impossible to know. In the long run, everything changes and it becomes very difficult to keep track of the effects of a certain road safety measure in the middle of an increasingly complex web of influencing factors.

At the present state of knowledge, the assumptions made in a cost-benefit analysis about the duration of the effects of a measure have to be treated as part of the framework for analysis, and not as an empirical parameter whose value is to be determined as part of the analysis. Hence, no meaningful numerical assessment of uncertainty is possible.

Summary of discussion

In this report, the contribution has been assessed of two of a total of eight sources of uncertainty in the estimates of the safety benefits of the road safety measures that have been included in the analysis. Table 29 summarises the current state of knowledge with respect to quantification of uncertainty. It can be seen that it is in principle possible to estimate statistically the contributions of a further three sources of uncertainty. The remaining three sources of uncertainty are, however, impossible to give a satisfactory statistical treatment at the current state of knowledge. This means that the uncertainty estimated in this report is a minimum estimate of the true amount of uncertainty present in the results. The actual amount of uncertainty is greater than the estimated uncertainty and is partly of a nature that does not permit numerical estimation at all. The implications of this for the interpretation of the results, and their application to policy making, are discussed below.

Table 29: Current state-of-the-art with respect to quantification of uncertainty in estimated safety benefits of measures

Source of uncertainty	Treatment of the source in this report
1 Definition of target accidents or injuries	Not estimated; in principle possible to estimate
2 Random variation in accident counts	Included
3 Incomplete accident reporting	Not estimated; in principle possible to estimate
4 Random variation in effects of measures	Included
5 Unknown systematic variation in effects of measures	Not estimated, in principle possible to estimate
6 Modifications of effects when measures are combined	Not estimated; not possible to estimate at the current state of knowledge
7 Uncertain road accident costs	Not estimated; principal sources of uncertainty are not of a statistical nature
8 Uncertain duration of effects of measure	Not estimated; must be treated as part of the framework for analysis

It should be noted that the entire discussion presented above is equally valid for all other effects that have been estimated. The effects of the measures on travel time, for example, are subject to uncertainties attributable to random fluctuations, inaccurate speed measurements, uncertain values of travel time, and so on. It is, however, beyond the scope of this report to treat sources of uncertainty with respect to other effects with the same level of details as sources of uncertainty in the estimated safety benefits of the measures.

9.3 Estimated uncertainty in the effects of the road safety measures

Table 30 presents the estimated lower and upper 95% prediction interval limits of the estimated effects of the measures included in each road safety strategy on the number of killed road users and on the total number of killed or injured road users.

Table 30. Estimated uncertainty in the effects of the road safety strategies. 95% prediction interval

	Reduction in number of road users killed			Reduction in number of road users killed or injured		
Road safety strategy	Best estimate	Lower 95% limit	Upper 95% limit	Best estimate	Lower 95% limit	Upper 95% limit
Business as usual	81	26	133	2182	1554	2888
Cost-benefit	293	146	391	6467	2805	9303
Vision zero	379	217	471	10628	6715	13564
Maximum potential	429	276	534	12538	8834	17597

In most cases, the ratio of the upper to the lower 95% limit values are between 2:1 and 3:1. This shows that there is a considerable element of uncertainty in estimated effects, despite the fact that a very conservative approach to the estimation of uncertainty has been adopted in this report. The greatest amount of uncertainty, as indicated by the ratio of upper to lower 95% values, attaches to the effects of the cost-benefit strategy.

In what way can or should the presence of a large element of uncertainty in estimated effects affect the choice of strategy?

9.4 The implications of uncertainty for the choice of road safety strategy

A number of decision rules have been proposed for choices made under uncertainty. A lucid discussion of these rules, as topical today as when it was written nearly forty years ago, is presented by Robert Dorfman (1972; originally published 1962). Before going into this discussion, it is useful to restate the distinctions made in normative decision theory between three, or possibly four, levels of uncertainty in decision making:

1 Certainty

A decision is made under certainty when all possible outcomes of the decision are known for sure. Such a state of perfect knowledge is probably found only for utterly trivial decisions and their outcomes. A decision to walk from one room to another in your home can be made with the perfect knowledge that these rooms exist and that the floor will not collapse when you step into the room.

2 Risk

A decision is made under risk when all possible outcomes of the decision and their probabilities of occurrence are known. When we buy a bottle of milk, for example, we know that there is a very small chance that it may be sour. We do not usually estimate this probability, but in principle, this can be done.

3 Uncertainty

A decision is made under uncertainty when all possible outcomes of the decision are known, but their probabilities are unknown.

4 Ignorance

A decision is made under ignorance when at least some possible outcomes of the decision are not known in advance.

Although analytically clear, the trouble with this taxonomy is that it is difficult to apply in practice. When decisions are made about road safety measures, some of the possible outcomes are known with certainty, some have a certain probability of occurring, some can be specified, but their probability is unknown, and some are unknown. Is the decision then made under conditions of certainty, risk, uncertainty or ignorance? In a sense, it is made under all these conditions at the same time. How to apply a normative theory of choice in this situation is far from clear.

If, despite this, one were to give a general description of the conditions that characterise decision making concerning road safety measures, it would have to be that these decisions are made under uncertainty, and partly under ignorance. Although a lot is known about the effects of road safety measures, the situation in which this knowledge is to be applied is so complex that confident predictions about the probabilities of various outcomes cannot be made. There are simply too many sources of uncertainty present at the same time.

Unfortunately, satisfactory decision rules for decisions under uncertainty have not been developed. Dorfman (1972) reviews different rules that have been proposed, but is critical of all of them, because they can be shown to lead to inconsistent choices. This occurs because nearly all rules that have been proposed for making decisions under uncertainty violate the axiom of independence of irrelevant alternatives. This axiom was first proposed by Von Neumann and Morgenstern (1953), as one of the axioms of rational choice under uncertainty. In fact, the only rule that does not violate this axiom, is the rule of maximising expected utility. Applied to the present context, this simply means that decisions should be made on the basis of the best estimate of the expected effects of the road safety strategies.

Would it matter at all if a different decision rule were adopted? One rule that has been proposed is the minimax rule, according to which decisions should be made so as to maximise the worst possible outcome. Let us treat the lower 95% confidence limit for the estimated effects of the road safety strategies as the worst possible outcome in this case. As one can ascertain by looking at table 30, it makes no difference at all if the choice of strategy is based on the expected outcome or on the lower 95% limit for the outcome. The rank ordering of the alternative strategies is the same for both these decision rules. The same applies to a third possible decision rule, the maximax rule, according to which one should maximise the best possible outcome (upper 95% confidence limit). In short, the expected utility rule, the minimax rule and the maximax rule all result in the same choice.

In short, the presence of uncertainty in the results does not have a major effect on the choice of strategy. The chief implication of the presence of a large element of uncertainty is that is impossible to confidently predict the number of traffic accident fatalities or injuries in 2007 or 2012.

10 Considerations Relevant to the Choice of Strategy

10.1 Specification of some relevant considerations

Ideally speaking, cost-benefit analyses summarise all considerations that are relevant to the choice of road safety strategy. But this is true only in case a maximally efficient use of road safety measures, with due consideration being taken to other policy objective affected by these measures, is regarded as an overriding principle of road safety policy making. In practice, this is unlikely to be the case. The preference structures that are the basis for policy objectives are likely to be too complex to be adequately summarised in the form of a single figure of merit, the benefit-cost ratio. It is therefore instructive to list explicitly some of the considerations that are likely to be regarded as relevant to the choice of strategy, and discuss the extent to which tradeoffs between these considerations have to be made. Some considerations likely to be regarded as relevant include:

- Effects on safety
- Effects on other transport policy objectives
- Costs to the public sector and possibilities for financing
- Public acceptance
- Practical feasibility – jurisdiction to introduce measures
- Uncertainty about effects

Each of these considerations will be explained more in detail.

Effects on safety. Given the fact that Vision Zero is the official basis for transport policy in Sweden, it is reasonable to assume that a programme with a large effect on safety is, ceteris paribus, preferred to one with a smaller effect on safety.

Effects on other policy objectives. It is stated explicitly in official policy documents that conflicts between policy objectives should be minimised. It is therefore assumed that a programme that favours several policy objectives is preferred to a programme that favours just one policy objective or promotes one objective while counteracting other policy objectives.

Costs to the public sector. It is difficult to finance large increases in public expenditures in Sweden, just as it is in many other countries. Ceteris paribus, a programme that does not involve additional public expenditures is therefore likely to be preferred to one that does involves additional public expenditures.

Public acceptance. An important criterion for introducing new road safety measures, is that there should be widespread public acceptance of these measures. Although the possibility of passing legislation in the face of public opposition is not ruled out, this is regarded as a less desirable option than voluntary introduction of measures, or passing laws that are supported by a clear majority of the public.

Practical feasibility. Some measures included in the formal assessment of costs and benefits are still more or less at an experimental stage. This is particularly true of some ITS applications for cars. Moreover, vehicle safety regulations are increasingly made at an international level, that no longer leaves national governments with the power to pass any regulations they might wish. Ceteris paribus, it is assumed that the Swedish government prefers a safety programme consisting of measures within its jurisdiction to a safety programme consisting of measures largely outside its jurisdiction. In the latter case, a strategy for implementation at the international level is required before the measures can be introduced domestically.

Uncertainty about effects. It is assumed that the government is risk averse, meaning that it prefers the programme for which the worst possible outcome is best (that is gives the lowest number of fatalities and injuries) to any other programme.

The objective of this chapter is to discuss the extent to which these considerations coincide or point in different directions, creating a need for tradeoffs.

10.2 Comparison of road safety strategies in terms of the considerations relevant for choice

Table 31 provides a ranking of the four different road safety strategies in terms of the considerations listed above. A rank of 1 indicates that the strategy is best according to a certain criterion, a rank of 4 indicates that it is worst according to the same criterion.

Table 31: Ranking of alternative road safety strategies according to considerations relevant for choice between them

	Ranking of alternative road safety strategies (1 = best; 4 = worst)			
Considerations	Business as usual	Cost-benefit	Vision Zero	Maximum potential
Safety effects	4	3	2	1
Effects on other policy objectives	2	1	4	3
Costs to the public sector	2	1	3	4
Public acceptance	1	2	3	4
Practical feasibility	1	2	3	4
Uncertainty about effects (worst outcome)	4	3	2	1
Mean rank	2.3	2.0	2.8	2.8

It is seen that the considerations to a large extent point in different directions. The differences between the four strategies in mean rank scores are therefore quite small. The ranking of the strategies with respect to public acceptance is based on the annual survey of attitudes to road safety commissioned by the Swedish National Roads Administration (Boynton 1999). This survey shows that there support for some, but not all of the new measures that have been discussed since Vision Zero was officially launched as the basis for road safety policy in Sweden. Some new measures that are supported by a majority of the public include:

- Ignition interlock to prevent drinking and driving (supported by 61%)
- Lower speed limits in general (supported by 54%)
- Speed limit of 30 km/h in areas with many pedestrians and cyclists (supported by 70%)

Some measures that do not get the support of a majority include:

- Paying higher fuel taxes to raise revenue for road safety measures (supported by 15%)
- Introducing a law requiring the wearing of cycle helmets (supported by 49%)
- Requiring a top speed of not more than 130 km/h for all cars (supported by 33%)

The ranking of the strategies in terms of practical feasibility was based, roughly speaking, on the number of measures included in it. The more measures that are to be implemented, and the more diverse these are, the more practical obstacles are likely to be encountered.

If one wants to be sure that the number of fatalities and injuries is reduced, one should adopt a highly ambitious road safety programme. That would, however, involve a number of other problems.

It is beyond the scope of this report to recommend a certain road safety strategy. The analyses presented in this report are limited to identifying potential road safety strategies and some considerations that are relevant in choosing between these strategies.

11 Discussion and Conclusions

This chapter presents a discussion of the results and the main conclusions that can be drawn on the basis of the results. The following issues are discussed:

- Are the estimates of the effects of the road safety strategies on the number of killed or injured road users likely to be biased?
- Do cost-benefit analyses provide an adequate basis for setting priorities between road safety measures, or are important relevant considerations likely to be left out of these analyses?

11.1 Potential sources of bias in estimates of the safety effects of the alternative strategies

There is a fundamental difference between error and bias. Errors are basically random and make an estimate uncertain. An estimate subject to error is uncertain in the sense that the true value could be *both higher and lower* than the estimate. Bias, on the other hand, means that an estimate is systematically wrong. Bias creates a systematic difference between the true value of a variable and the estimated value.

Some sources of uncertainty in the estimated effects on the number of killed or injured road users of the road safety strategies were discussed in chapter 9. In this chapter, some potential sources of bias are discussed. These are:

- Omission of potentially effective road safety measures from the analyses
- Inclusion of ineffective measures in the analyses, erroneously treated as effective
- Biased estimates of the first order effects of some of the measures that are included in the analyses
- Biased estimates of the combined effects of the measures within a given road safety strategy

These points will be discussed in turn.

Omission of potentially effective road safety measures. Some potentially effective road safety measures have been omitted from the analysis. There is, therefore, a theoretical possibility that the true potential for improving road safety in Sweden has been underestimated. However, it can be argued that, for the time horizon considered in this report, the underestimate is likely to be very small.

There are two categories of potentially effective measures that have been omitted from the analysis. These are:

1 Measures that were classified as analytically intractable

2 Measures that were classified as ineffective on the basis of conflicting evidence from evaluation research

The first group of measures includes urban and regional planning, changing the modal split of travel, vehicle crashworthiness and safety equipment on motorcycles.

As far as urban and regional planning (land use planning) is concerned, there is little doubt that road safety can be improved by designing new residential and commercial areas according to known safety principles. In existing residential and commercial areas, the potential for improving safety is, in general, related to the use of the measures included in the analyses in this report, and not to land use planning as such. Current trends in new developments of land use in Sweden, as in most other rich countries, are somewhat conflicting as far as road safety effects are concerned. On the one hand, there is an increasing use of speed reducing measures in residential areas, which is likely to make these areas safer. On the other hand, urban sprawl is increasing, generating more travel by car in urban areas, which is likely to increase the number of accidents. Which of these effects is the stronger one, is not known. At any rate, defining suitable units to describe the use of this measure for the purpose of estimating effects on safety is very difficult and was not attempted.

Changing the modal split of travel, in particular by transferring journeys from individual modes of transport to public transport, can improve safety. This has been shown both in evaluation studies and in more theoretical model based calculations (Elvik, Mysen and Vaa 1997). There are, however, a multitude of problems involved in estimating the effects on safety of changing the modal split of travel. Effects on safety depend on, among other things:

- Which mode of transport journeys are transferred from (large effect if motorcycle trips are transferred, comparatively small effect if car trips are transferred)
- Which type of public transport journeys are transferred to (large effect if trips are transferred to trains, small effects if trips are transferred to trams – the latter are found only in the cities of Gothenburg, Norrköping and Stockholm)
- The size of the transfer (larger effect the larger the transfer)
- The total length of the trips (larger effect the longer the trips are)
- The proportion of total trip length spent walking, or cycling, to and from a public transport terminal or street stop (the higher the proportion of the total trip length spent walking or cycling, the smaller the effect on safety)
- The severity of the accidents for which effects are assessed (large effect on fatal accidents, smaller effect on less serious accident, and a potentially adverse effect on single accidents while walking or cycling)

To estimate the effects on safety of changing the modal split of travel, assumptions would have to be made regarding all these items. Moreover, in order to estimate the costs of changing the modal split of travel, one would have to make additional assumptions regarding the measures to be used to induce the change. Potential measures include lowering fares, increasing the number of departures, establishing new services, and so on. These measures do not have the same effects, nor do they cost the same. Assumptions would therefore have to be made about the measures to be used to effectuate a change in the modal split of travel.

On top of this, experience (Stangeby and Norheim 1995) shows that it is not easy to change travel habits. The market for personal travel is highly segmented, and the real amount of competition between different modes of travel is quite limited. In fact, the strongest competition is between cycling and bus riding. Although cyclists would probably be safer if they rode a bus, cycling is promoted in many cities because it is good for environment and for public health.

Although it is possible to cut through this maze of complexities and define a set of assumptions needed to estimate the safety effects of changing the modal split of travel, it was decided not to do so, because the element of arbitrariness in defining the necessary assumptions was judged to be too great.

Changes in vehicle crashworthiness are also likely to affect road safety in the years to come. Vehicle crashworthiness is a generic term, which includes a number of design changes to motor vehicles. Some of these are included in the analyses:

- Continuing diffusion of cars with air bags in the vehicle fleet
- Introduction of a seat belt reminder in cars
- Introduction of an ignition interlock system for seat belts in cars
- Modification of bumpers and car fronts to reduce the severity of injuries to pedestrians

In addition to these measures, a number of measures related to active safety have been included. There are, on the other hand, a couple of crashworthiness measures that have not been included:

- Introduction of an anti-lacerative windshield
- Introduction of the WHIPS seat, developed by Volvo to prevent whiplash injuries

With respect to the WHIPS seat, the results of technical tests are very promising (Jakobsson et al 2000), but it is not possible to use these results as a basis for predicting the effects of the seat on the number of whiplash injuries. Moreover, the cost of a WHIPS seat are difficult to specify. Although this measure clearly has a potential for improving safety, it is not possible to quantify this potential on the basis of current knowledge.

A number of modifications can be made to motorcycles to make them safer (Elvik, Mysen and Vaa 1997). However, the cost of these modifications is largely unknown. This is the main reason why the measure was classified as analytically intractable.

Some measures were classified as ineffective, although there exist evaluation studies indicating that the measures are effective. There are four measures belonging to this group:

- Road markings designed as rumble strips
- Periodic motor vehicle inspections
- Children's Traffic Club
- Increasing traffic tickets

According to most evaluation studies, marking edge lines and centre lines with broken lines designed to make a rumbling noise when the lines are crossed improves road safety. But a recent Norwegian study (Giæver et al 1999) did not find any effect on safety of this kind of road marking. Nor did an Australian study (Corben et al 1997) reported a couple of years earlier. Some of the studies that claim an effect of road markings designed as rumble strips are simple before-and-after studies, subject to serious biases such as no control for regression-to-the-mean. In a case like this, a conservative interpretation of evaluation studies has consistently been chosen. This means that the measure has been assumed to be ineffective.

Similar comments apply to periodic motor vehicle inspection. The best study ever made of this measure is an experiment carried out in Norway (Fosser 1992). This experiment did not find an effect on safety of periodic motor vehicle inspections. Although other studies (see Elvik, Mysen and Vaa 1997 for a review) have come to other conclusions, less confidence can be placed in the results of those studies, because they employed less rigorous research designs. An additional consideration in this case, is that Sweden already has an extensive programme of motor vehicle inspections, which means that stepping these further up is not a very realistic option.

With respect to Traffic Clubs for Children aged 3-6, conflicting results have been reported from evaluation studies in Norway and Sweden. A Norwegian study (Schioldborg 1974) concluded that the Traffic Club reduces the incidence of traffic injury. A Swedish study (Gregersen and Nolén 1994) came to the opposite conclusion. The Swedish study is more recent and methodologically stronger than the Norwegian study. Hence, the measure has been assumed to be ineffective.

Finally, there are conflicting results with respect to traffic tickets. Fridstrøm (1999) found that increasing the ticket given for not wearing seat belts in Norway lead to increased use of seat belts. Swedish studies (Nilsson and Åberg 1986; Andersson 1989) have, on the other hand, found no effects on speeding of increased tickets for speeding in Sweden. The results of the Swedish studies have been applied, and the measure has therefore been classified as ineffective.

In summary, a conservative interpretation of the results of evaluation studies has been adopted. Measures have not been regarded as effective if reasonably well controlled evaluation studies, reported in recent years in Norway or Sweden, have not found the measures to be effective in reducing accidents or injuries.

Erroneous inclusion of ineffective measures. Some measures that are still not widely used have been included in the analyses, although one cannot be perfectly sure that these measures are indeed effective. Three of these measures deserve discussion:

- Self levelling headlamps
- Intelligent cruise control
- Crash data recorder

Self levelling headlamps for passenger cars have existed for nearly thirty years, but are still not standard equipment. These lamps eliminate the problem of headlamps aiming either too high, causing glare for oncoming drivers, or too low, reducing one's own sight distance. According to tests, in which wrongly aimed headlamps have been compared to correctly aimed headlamps, self levelling headlamps have a potential to increase the sight distance in darkness by about 15% (Elvik, Mysen and Vaa 1997). It is, however, unlikely that an effect on accidents of a similar magnitude can be attained by requiring self levelling headlamps on all cars.

In the first place, not all cars have wrongly aimed headlamps today. In the second place, the possibility of behavioural adaptation to the measure cannot be ruled out. It has been assumed that cars equipped with self levelling headlamps have a 4% lower accident rate in darkness than cars without self levelling headlamps. A 95% confidence interval for this effect of ± 50% has been assumed.

An intelligent cruise control (ICC) is a device that continuously monitors the headway to the vehicle in front and gives the driver a warning when the headway is below a certain threshold or closes rapidly. In principle, the system can even override driver control by braking the car when the headway gets too small. According to studies that have been reviewed in the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997), intelligent cruise control has been estimated to potentially reduce the number of rear-end collisions by about 50%. Experiments made at VTI, however, suggest that the possibility of unintended behavioural adaptation to this measure cannot be ruled out. One experiment (Nilsson 1996) found that drivers of cars equipped with automatic cruise control (ACC) more often crashed when approaching a stationary queue than drivers of cars without ACC, possibly because they trusted the system too much and reacted too late. Another experiment found that drivers of cars with ICC slightly reduced their speed and increased their headway, while reaction time did not change much (Nilsson and Nåbo 1996). While later reactions may be detrimental to safety, reduced speed and larger headways are likely to benefit safety. On balance, it is assumed that these potential behavioural adaptations will not eliminate the potential safety effects of intelligent cruise control.

Crash data recorders have been tested in an experiment in Belgium (Wouters and Bos 1997). According to the authors, cars equipped with crash data recorders were involved in about 20% fewer crashes than cars without crash data recorders. However, the data indicated that effects varied substantially between the different groups of car fleets that were tested. A re-analysis of the data indicate an accident reduction of 7%. This reduction was not statistically significant, with a 95% confidence interval going from 24% accident reduction to 14% accident increase.

The best estimate of the effect, 7% accident reduction, has nevertheless been used in the analysis. Despite the fact that this reduction was not statistically significant, there are reasons to believe that it is a real effect. When a car has a crash data recorder, this may affect driver behaviour, because drivers know that it will be more difficult to lie about accidents, for example by stating that speed was lower than it actually was. Besides, there may be an indirect safety benefit of crash data recorders in the longer term, as the data these recorders provide are utilised by car manufacturers to design more crashworthy cars.

Biased estimates of first order effects of measures. For most of the measures, estimates of the first order effects on safety have been taken from the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997). Unfortunately, the effects stated in the Traffic Safety Handbook cannot always be taken at face value. In some cases, there is reason to believe that available evaluation studies overstate the effects of the measures. For some measures, estimates of effects have therefore been adjusted. Table 32 lists the measures for which such adjustments have been made.

Table 32: Adjustments of estimates of effect for some road safety measures included in analysis

	Percent reduction of accidents or injuries in the target group affected by the measure	
Measure	Stated in the Traffic Safety Handbook	Assumed in this project
Interchanges (to replace at grade four leg junctions)	50	20
Guard rails along embankments	52	33
Signing of hazardous curves	39	20
Reconstructing streets to 50/30 design	38	30
Feedback signs	45	5
Use of pedestrian reflective devices	85	30
Vehicle impoundment for unlicensed driving	38	30

In the case of interchanges, the effect has been set equal to the difference in accident rate (number of injury accidents per million entering vehicles) between a four leg at grade junction and an interchange. It is assumed that the true long term differences in safety are shown by differences in accident rate.

The adjustment made for guard rails is based on the assumption that the most hazardous sites have already been treated by means of guard rails, which means that the effect of putting up new guard rails will become gradually smaller. The effects of signing of hazardous curves, reconstructing streets according to the 50/30 design (assumed to be equivalent to constructing an environmentally adapted through road), and putting up feedback signs have all been estimated by relying on the relationship between changes in mean speed and changes in fatal, serious and slight injuries (the power functions discussed in chapter 6). For all these measures, there is reason to believe that the before-and-after studies that have been reported have overestimated effects, because these studies did not control for regression-to-the-mean.

It has – admittedly somewhat arbitrarily – been assumed that using pedestrian reflective devices cuts in half the increase in accident rate at night for pedestrians. According to Andersson et al (1998) the relative risk at night for pedestrians, if the risk during daytime is set to 1.0, is 3.6 for fatal injuries, 3.0 for serious injuries and 2.7 for slight injuries. Cutting these relative risks in half gives new relative risks of 1.8 for fatal injuries, 1.5 for serious injuries and 1.35 for slight injuries (all corresponding to a 50% reduction in relative risks). These effects on relative risk translate into an average injury reduction at night of 30% for all levels of injury severity combined. It is unlikely that the true effects are as great as stated in the Traffic Safety Handbook. It is more likely that the estimates of effect given in the Traffic Safety Handbook are influenced by a selective recruitment of wearers of reflective devices among the safest pedestrians.

Finally, the effects of vehicle impoundment have been adjusted slightly to account for a possible bias in the original data set.

No measure has been assumed to have a greater effect on accidents or injuries than stated in the Traffic Safety Handbook. The adjustments that have been made are intended to remove bias, not introduce it. To the extent that results of evaluation studies are biased, they are more likely to overstate effects than underestimate them (Elvik 1999D).

Biased estimates of combined effects of measures. As noted in chapter 9, very little is known about the joint effects of several road safety measures introduced at the same time. Different models can be imagined concerning these effects. Table 33 illustrates some different models and their implications for the joint effects of two road safety measures affecting the same group of accidents.

Table 33: Implications of different models for the joint effects of two measures affecting the same group of accidents

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 33, is most correct. Model 2, assuming independent effects, has been chosen 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 33. As an illustration, three different models for estimating the combined effects of the measures are shown in Table 34 for the cost-benefit strategy. Only best estimates are shown.

Table 34: Implications of choice of model for the estimated total effects of measures. Case illustration based on the cost-benefit strategy

	Estimated number of prevented fatalities and injuries	
Model employed	Prevented fatalities	Prevented injuries
Simple additive model	378	7,402
Joint residuals model within groups, additive model between groups	367	7,289
Joint residuals models both within and between groups	293	6,467

In the simple additive model, first order effects have been added for all measures that are included in the cost-benefit strategy. According to this model, fatalities can be reduced by 378 (68%) and injuries by 7,402 (34%). At least for fatalities, this estimate is implausibly large.

Effects have been estimated within each of the following groups of measures:

- General purpose measures
- Road design
- Road maintenance
- Traffic control
- Vehicle design and inspection
- Driver training and public information
- Enforcement

If the joint residuals model is employed to estimate combined effects within each of these groups, and an additive model used to estimate combined effects between groups, it is estimated that 367 fatalities and 7,289 injuries can be prevented. If the joint residuals model is applied both within and between groups, total estimated effects come 293 prevented fatalities and 6,467 prevented injuries. It is this latter model which has been applied in this project. This is the most conservative of the three models listed in Table 34.

The reason this model was chosen, was that it is was judged to be better to err by making a conservative estimate than to err by giving a too rosy impression of the possibilities of reducing traffic injury. Whether the estimates are biased or not, cannot be known with certainty.

11.2 Comparison of the estimates made in this report and other estimates of the effects of road safety programmes

Another way of assessing the possible presence of bias in the estimates made in this report, is to compare it to other estimates of the effects of road safety programmes. A comparison will be made with two such estimates.

The Swedish National Road Administration has presented a special traffic safety programme (Vägverket 1999). The programme contains estimates of the effects of a number of measures that can be implemented before 2007. Table 35 compares the estimates presented in this programme to the estimates made in this report.

In general, there is a very high agreement between the two sets of estimates. There is tendency for the estimates made in this report to be more conservative. On the other hand, it is not known if the assumptions made are strictly comparable. The overall impression is that there is a reassuring agreement between the two sets of estimates.

Table 35: Comparison of effects on fatalities estimated in special traffic safety programme and effects estimated for the same measures in this report. First order effects

Measure	Estimated annual number of fatalities prevented (best estimate only)	
	Traffic Safety Programme	This report
Construction of new roads	25	11
Other road investments	22	25
Winter maintenance of roads	6	0
Traffic safety measures in towns	15	18
Seasonal speed limits	10	1
Other reductions of speed limits	5	See note 1
Law requiring the use of winter tires	5	Not included
Law requiring the use of bicycle helmets	15	14
New system of driver training	7	6
Reduced safety margin in speed enforcement	7	Not included
Speed cameras	10	8
Increased enforcement of drinking and driving	27	8 (see note 2)
Ambulance helicopters	7	Not included

Notes:

1: Many alternatives for reducing speed limits have been assessed, but none of them identical to the one in the Traffic Safety Programme

2: Refers to a doubling of the enforcement of drinking and driving. If enforcement is increased by a factor of 10, a reduction of 27 fatalities has been estimated (identical to the Traffic Safety Programme)

Another estimate of the effects of traffic safety measures, is the estimate made by VTI (Andersson et al 1998) of the effects of implementing the traffic safety reforms proposed in the National Road Safety Programme in 1994. Table 36 compares the estimate of the effects of realising these policy reforms made by VTI to the estimates made in this report. The same set of measures has been selected for the comparison (although this set of measures does not correspond exactly to any of the four road safety strategies defined in this report).

Table 36: Comparison of effects on fatalities estimated by VTI of realising traffic safety policy reforms and effects estimated in this report. Marginal effects estimated by the method of joint residuals

Measures (main categories)	Estimated number of fatalities prevented (best estimate only)	
	VTI estimate	This report
Road improvements etc	72	66
Vehicle improvements etc	52	47
Better compliance	204	136
Total effects of measures	328	249

The two estimates are very close as far as road improvements and vehicle improvements are concerned. There is a greater difference with respect to the effects of better compliance. VTI has made a more optimistic estimate of the effects of improving compliance with “other regulations” than the estimate made in this report. Other regulations are all regulations except speed limits, regulation of drinking and driving and seat belt wearing.

11.3 The Applicability of Cost-Benefit Analysis to Road safety Policy Making

Cost-benefit analysis has been applied in this report to assess the benefits and costs of road safety measures and road safety strategies. It is important, however, to keep in mind that the application of cost-benefit analysis to analyse policy options relies on a number of assumptions.

Cost-benefit analysis has been used for at least twenty five years to help in setting priorities for road safety measures. The use of cost-benefit analysis in road safety policy making has, however, remained controversial. Not everybody accepts the idea that putting a monetary value on life and limb is ethically defensible, or in any way helpful in the task of developing an effective road safety programme. Others, while accepting that there is a legitimate role for cost-benefit analysis, are sceptical because they think that the estimates of accident costs, in particular the valuation of quality of life, are too uncertain to give reliable guidance.

It would go beyond the scope of this report to discuss all the objections to cost-benefit analysis in detail. However, the basic principles of cost-benefit analysis will be stated, to give readers the opportunity to make up their own minds about whether they accept these principles or not.

Applied welfare economics supplies the basic principles of cost-benefit analysis. There are four main principles: Consumer sovereignty, welfare maximisation, valuation of goods according to willingness-to-pay, and neutrality with respect to distributive outcomes. The principle of consumer sovereignty, briefly stated, means that welfare is defined in terms of how consumers choose to spend their income between commodity bundles. The right of consumers to choose how to spend their income is respected. The strength of consumer preferences for the provision of various public goods is measured by the amount of money that consumers are willing to pay for these goods. Various techniques have been developed to assess willingness to pay for non-marketed goods. It is beyond the scope of this report to discuss these techniques in detail.

The objective of cost-benefit analysis is welfare maximisation. To determine whether a project increases welfare or not, cost-benefit analysis relies on the Pareto-criterion. This criterion states that welfare is increased when a change makes at least one person better off and nobody worse off. In practice, many public projects will make some people better off and others worse off. Hence, the Pareto criterion is not very practical. Most economists therefore subscribe to a less demanding criterion of welfare maximisation, stating that welfare is increased when *a potential* Pareto improvement occurs. A project satisfies this criterion when those who benefit from it can compensate those who lose from it (in utility terms) and still retain a net benefit (in utility terms). In practice, a project is regarded as satisfying this criterion when benefits are greater than costs. There is, however, no requirement that actual compensation of those who lose takes place. Cost-benefit analysis is neutral with respect to distributive outcomes. What counts is the aggregate size of benefits and costs, not how these impacts are distributed between various groups of the population.

The monetary valuation of a non-marketed good in cost-benefit analysis should be based on the willingness-to-pay of the potential purchasers of the good. There are many ways of estimating the monetary value of a good not provided by the market. One way of doing it, is to set up a hypothetical market, in which people are asked to state their willingness-to-pay for a certain amount of the good, or choose between various options that provide different amounts of the good. Another way of estimating the value of a non-marketed good is to study the choices people make when the probability of sustaining a fatal injury has to be traded off against other values, at least one of which is denominated in monetary terms. Workers, for example, face a choice between occupations that differ with respect to wages and fatality risk (as well as numerous other attributes). There is a host of methodological pitfalls in such studies. It would go beyond the scope of this report to discuss all these difficulties in detail. An essential assumption made in all techniques designed to estimate the monetary value of non-marketed goods, is that the choices made by individuals can be adequately modelled by relying on the principle of utility maximisation. If individuals are not rational utility maximisers, the values estimated for non-marketed goods may be wrong, or at least highly uncertain.

Cost-benefit analysis is designed to help decision makers set the priorities that will maximise overall goal achievement in situations where there are several policy objectives that have to be traded off against each other. Relevant policy objectives typically include improving road safety, improving mobility, reducing transport costs and improving the environment. Each policy objective may consist of several sub-targets, like those of reducing noise, reducing air pollution and improving visual amenity, all subsumed under the objective of improving the environment.

Although the hierarchy of policy objectives may consist of many levels, it is assumed that, at the most basic level, each objective is *unitary* in the sense that the value of realising it can be adequately expressed in monetary terms. Is this assumption reasonable? There is evidence to suggest that “improving road safety” is not a unitary policy objective in this sense, but has many dimensions, not all of which can be adequately represented by assigning a monetary value to life and limb. Consider the following possible interpretations of a target of improving road safety:

1 Reducing the absolute number of accidents and injuries.

2 Reducing the average risk of road accident injury per kilometre travelled or per inhabitant.

3 Reducing the severity of injuries, by reducing the probability of death or serious injury when involved in an accident.

4 Reducing the difference in accident risk between different groups of road users, in particular reducing the high risk of injury for pedestrians and cyclists.

5 Reducing the probability of accidents in which a large number of people can be killed or injured, such as bus accidents or accidents involving hazardous goods.

6 Reducing the insecurity (anxiety) some groups of road users feel, particularly to the extent that insecurity prevents people from travelling where and when they want to.

It is obvious that some of these targets can be mutually conflicting. Costing accidents in the conventional manner can accommodate targets 1 and 3, and perhaps target 2. Targets 4 and 5 require a different approach to accident costing. For target 4, costs that are proportional to the accident rate per kilometre of travel might be used. For target 5, functions are needed that take account of the fact that 20 fatalities in one accident count for more than 20 fatalities occurring one by one in 20 different accidents.

Whether target 6 is accommodated by standard accident costs or not, is a matter of interpretation. If the desire to avoid insecurity is part of the reason why people are willing to pay something to prevent accidents, it can be argued that this aspect of road safety is included in cost estimates based on the willingness-to-pay principle. In general, one would expect the fear of having an accident to be one of the factors that influences willingness to pay for reduced risk. If this interpretation is accepted, it would constitute double counting to add an extra value of reduced insecurity to accident costs in evaluating projects that are believed to reduce insecurity. On the other hand, insecurity is not simply a function of statistical risk, but is likely to contain additional elements. It would therefore probably be wrong to simply assume that the entire benefit of feeling more secure is included in accident costs. One would need to obtain a separate value of security in order to be certain that this item is given sufficient weight in a cost-benefit analysis.

Some policy objectives are by their very nature unsuitable for cost-benefit analysis. This is particularly true of distributive objectives. An important distributive objective for transport policy in Sweden and many other countries has been to provide a certain minimum standard for transport facilities in all parts of the country, regardless of traffic volume. This means that the regional distribution of road investments and the standard of roads is an important policy objective. This often means that a disproportionate amount of investments are carried out in areas with little traffic, compared to the share of investments that would benefit these areas if funds were allocated on the basis of the returns earned on investments. In short, road investments in sparsely populated areas are not performed because they earn a good return, but despite the fact that the return on these investments is often very low.

To summarise, the current state of the art with respect to the use of cost-benefit analysis to set priorities for road safety measures can be characterised as follows:

- Cost-benefit analysis comprises many of the policy objectives that are relevant for road safety policy, but is unlikely to comprise all relevant policy objectives. In particular the objectives of balancing regional development and reducing the differences in accident rate between protected and unprotected road users are unlikely to be given due weight within the current framework for cost-benefit analysis.
- It is not clear to what extent the objective of reducing road user insecurity, as well as insecurity among residents along a road is part of the accident costs and thus included in current cost-benefit analyses.
- According to the cost-benefit analyses made in this report, measures that have a potential of reducing the number of fatalities by nearly 25% are not efficient, in the sense that benefits are smaller than costs. Abstaining from introducing these measures by referring to cost-benefit analyses is inconsistent with the ethical principles underlying Vision Zero.

11.4 Constraints on Road Safety Policy Making – the Power of Government to influence the Number of Accidents and Injuries

To what extent is it possible for governments to influence road accident counts and the outcomes of road accidents in terms of fatalities and injuries? In principle, there is little doubt that governments could exercise a major influence on the level of road safety. In practice, however, there are many constraints on policy making that limit the power of governments to control the level of road safety. Fridstrøm (1999) has made a distinction between six main categories of factors that influence road safety. His remarks are very instructive, and are therefore quoted at length (1999, page 11):

> "Road accidents occur as a result of a potentially very large number of (causal) factors exerting their influence at the same location and time. It might be fruitful to distinguish between six broad categories of factors influencing accident counts."
>
> First, accident numbers depend on a number of truly *autonomous factors, determined outside the (national) social system*, such as the weather, the natural resources, the state of technology, the international price of oil, the population size and structure, etc – in short, factors that can hardly be influenced (except perhaps in the very long term) by any (single) government, no matter how strong the political commitment.
>
> Second, they depend on a number of *general socio-economic conditions*, some of which are, in practice or in principle, subject to political intervention, although rarely with the primary purpose of promoting road safety, nor – more generally – as an intended part of transportation policy (industrial development, (un)employment, disposable income, consumption, taxation, inflation, public education, etc).
>
> At a third level, however, the size and structure of the *transportation sector*, and the policy directed towards it, obviously have a bearing on accident counts, although usually not intended as an element of road safety policy (transport

infrastructure, public transportation level-of-service and fares, overall travel demand, modal choice, fuel and vehicle tax rates, size and structure of vehicle pool, driver's license penetration rates, etc). Most importantly, many of these factors are strongly associated with aggregate *exposure*, i e with the total volume of activities exposing the members of society to road accident risk.

Fourth, the accident statistics depend, of course, on the system of *data collection*. Accident underreporting is the rule rather than the exception. Changes in the reporting routines are liable to produce fictitious changes in the accident counts.

Fifth, accidents counts, much like the throws of a die, are strongly influenced by sheer *randomness*, producing literally unexplainable variation. This source of variation is particularly prominent in small accident counts. For larger accident counts, the law of large numbers prevails, producing an astonishing degree of long-run stability, again in striking analogy with the dice game.

Finally, accident counts are susceptible to influence – and, indeed, influenced – by *accident countermeasures*, i e measures intended to reduce the risk of being involved or injured in a road accident, as reckoned per unit of exposure.

Although generally at the centre of attention among policy-makers and practitioners in the field of accident prevention, this last source of influence is far from being the only one, and may not even be the most important. To effectively combat road casualties at the societal level, it appears necessary to broaden the perspective on accident prevention, so as to – at the very least – incorporate *exposure* as an important intermediate variable for policy analysis and intervention."

In the analyses presented in this report, exposure has generally been taken as an exogenous factor, with the exception of increasing taxes on the use of motor vehicles in order to match the level of external costs caused by the use of motor vehicles. Figure 18 is an attempt to sort out the relative contributions of some major factors affecting the number of road accident fatalities in Sweden, inspired by the taxonomy proposed by Fridstrøm.

The first factor which is outside the control of any agent, is random variation in the count of fatalities. The contribution of this factor has been assessed as 1.96 times the square root of the mean count of fatalities during 1994-1998. This comes to 46, which is 8.3% of the count of 554 fatalities. This represents the upper limit of the explanatory power of any model designed to explain the variations in fatality counts (in time or space). Any multivariate model with a multiple squared correlation coefficient exceeding the value of 0.917 (1 – 0.083) would be over fitted and would include a spurious explanation of random variation as well as systematic variation.

In chapter 2, the population attributable risks of 20 risk factors was estimated. Although incompleteness in the data set precluded the use of a multivariate technique, the combined estimated attributable risk came to 0.885. This means that, in theory, if all the risk factors could be eliminated, the number of fatalities could be reduced by 88.5%.

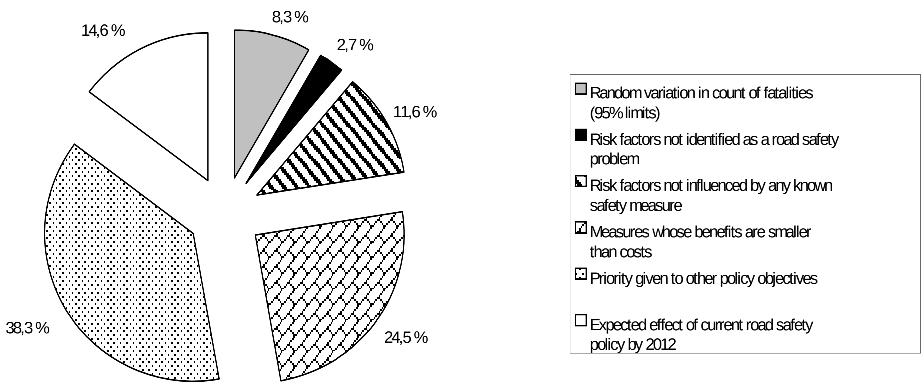

Figure 18: A taxonomy of factors affecting the power of government to reduce traffic fatalities. Percentage contribution of each factor

The difference between the proportion of systematic variation in fatality counts, and the combined attributable risk of the risk factors included in the analysis (0.917 – 0.89 = 0.027) can be interpreted as an estimate of the proportion of fatalities attributable to risk factors that have not been identified as road safety problems. This may include a large number of risk factors, each of which has a very small effect on the number of fatalities.

The remaining proportion of fatalities, 0.89, is attributable to risk factors that may be partly subject to control by means of safety measures. It has been estimated that the maximum potential for reducing the number of fatalities is 77.4% (or 0.774 as a proportion). This means that a complete removal of all risk factors is impossible. In fact, 11.6% of fatalities (0.89 – 0.774) can be attributed to risk factors not amenable to control by means of any of the road safety measures considered in this report.

If one were to rely only on measures whose benefits are greater than the costs, the number of fatalities could be reduced by 293, or 52.9%. By refraining from using more expensive measures, that is measures whose benefits are smaller than the costs, the prevention of 24,5% (0.774 – 0.529 = 0.245) of fatalities is given up as being too expensive. This can be interpreted as the limit imposed on accident prevention by relying on cost-benefit analysis.

Many people may find it unacceptable to abstain from preventing nearly 25% of fatalities on account of a rather abstract economic line of reasoning, if it is in principle possible to prevent these fatalities. No claim is made in this report that relying on cost-benefit analysis is the only sensible approach to policy making. Indeed, a number of serious objections can be raised to cost-benefit analysis. However, the biggest problem in current road safety policy is not that an excessive reliance on cost-benefit analysis is used as an argument for not applying effective road safety measures. A far bigger problem is that current priorities are ineffective, which means that a greater reduction in fatalities could be attained if priorities were set according to the results of cost-benefit analyses.

Figure 18 shows that the expected effect of current road safety policy is a reduction in the number of fatalities of 14,6% by 2012 (not allowing for the adverse effect of traffic growth). By using all measures whose benefits are greater than the costs, this could be increased to 52,9%. Hence, the priority currently given to other policy objectives – other than those that are formally included in cost-benefit analyses – implies that the Swedish government is refraining from using measures that would reduce the number of fatalities by close to 40%, at no additional net cost to society. By definition, all these measures provide benefits that are greater than costs.

It is surprising indeed that road safety policy is so inefficient in a country that has officially adopted a long term vision of zero fatalities and zero serious injuries as the only morally defensible ideal that can be set for road safety. By launching Vision Zero on the moral high ground, justifying it by means of set of ethical principles claimed to be self evident, the Swedish government has implicitly branded those who take exception to this point of as immoral cynics, who are prepared to sacrifice human life for the sake of an abstract economic principle. But the Swedish government itself fails to live up to the moral standards it has set for road safety policy. There seems to be a growing distance between the lofty ideals of Vision Zero and the realities of a road safety policy that is not delivering any reduction at all in the number of road accident fatalities.

11.5 Conclusions

The main conclusions of the analyses presented in this report can be summarised as follows:

1 The objectives of this report were to estimate the maximum theoretical potential for improving road safety in Sweden, to identify the most cost-effective measures for improving safety, and to identify road safety measures that do not conflict with other policy objectives. Other policy objectives include improving mobility, reducing transport costs and improving the environment.

2 The contributions of various risk factors to the current number of traffic accident fatalities and injuries in Sweden was assessed. The contribution of a risk factor to accidents and injuries was measured in terms of the population attributable risk, which means the size of the reduction in accidents and injuries that can be obtained by removing the risk factor. The single most important risk factor in Sweden today is violations of speed limits. About 50% of all driving is above the speed limit. It was estimated that perfect compliance with speed limits can reduce the number of fatalities by 38% and the total number of injured road users by 21%. A total of 20 risk factors was assessed.

3 Vision Zero, which states that the long term ideal for road safety is that nobody shall be killed or seriously injured in road traffic, has been adopted as the official basis for road safety policy in Sweden. Quantified road safety targets have been set of not more than 400 fatalities in 2000 and not more than 270 fatalities in 2007. In addition to these targets, transport policy in Sweden has set targets for more efficient transport, a better environment, a more accessible transport system, and regional development.

4 Guidelines for priority setting for road safety measures can be derived from Vision Zero and from official policy documents. The most important guidelines include:

- Prevention of fatal and serious injury is more important than prevention of slight injury.
- Prevention of injury to unprotected road users is more important than prevention of injury to protected road users.
- Possible conflicts between improving road safety and other policy objectives should be minimised.
- It is desirable that there is a widespread support for, or at least acceptance of, new road safety measures before they are introduced.

5 A survey of potentially effective road safety measures was conducted. The survey included all 124 road safety measures described in the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997), and 15 additional measures. Measures were not included in a formal assessment of their potential, cost-effectiveness and cost-benefit value if:

- The effects of the measure on accidents or injuries was not known,
- The measure does not, according to evaluation studies, reduce the number of accidents or the severity of injuries,
- The measure has already been fully implemented,
- The measure overlaps another measure in the set of measures considered,
- The measure is analytically intractable, meaning that it is difficult to define meaningful levels of use of the measure.

77 measures were omitted from further study according to these criteria, 62 measures were retained for analysis.

6 For each measure, the maximum safety potential of the measure, its cost-effectiveness and its benefit-cost ratio was estimated. In order to do these estimates, the maximum conceivable use of each measure was defined. Defining the maximum conceivable use of a measure obviously contains an element of arbitrariness. However, the maximum use conceived of, was in all cases substantially greater than the current use of a measure. In addition to the maximum conceivable use of a measure, other levels of use were defined, including no use, continuing current use, or increased use (but less than maximum use).

7 Four different road safety strategies were developed, each consisting of a set of measures put together as a programme. Each strategy applied to the period 2002-2011. The road safety strategies developed were:

- Business as usual, which means to continue current road safety policy in Sweden,
- Cost-benefit strategy, which consists of measures whose marginal benefits (for all policy objectives) are greater than their marginal costs,

- Vision Zero strategy, which consists of the measures that have so far been developed or proposed as most consistent with the ambitions and principles embodied in Vision Zero,
- Maximum safety potentials strategy, in which all measures are applied to the maximum conceivable extent. This strategy is mainly of theoretical interest, but can serve as a benchmark when assessing the other strategies.

8 The effects of each road safety strategy was assessed in terms of it maximum safety potential, cost-effectiveness and cost-benefit ratio. Cost-benefit analyses were based on current official Swedish valuations of non-marketed goods (1999 prices). It was found that:

- The maximum potential for improving road safety in Sweden is a reduction of the current number of fatalities of about 75%, and a reduction of the current number of injured road users of about 55%. These reductions refer to the effects of a ten year programme in which all measures are used to the maximum conceivable extent.
- The business as usual strategy has the smallest effect on road safety. The cost-benefit strategy has a greater effect, and the Vision Zero strategy a still greater effect.
- When the effects on fatalities and injuries of the expected growth in road traffic from 1999 to 2012 is taken into account, it is clear that the quantified road safety targets set for 2000 (400 fatalities) and 2007 (270 fatalities) are unlikely to be realised, no matter which road safety strategy is adopted. In principle, the target set for 2007 can be realised if measures that are effective in the short term – in particular a *very substantial increase* in police enforcement – are introduced before that year.

9 According to the cost-benefit analyses, it is possible to develop a road safety strategy that will reduce the number of fatalities by nearly 300 per year, without any adverse net effect on other policy objectives and without requiring any increase in public expenditures. The analyses show that a programme which is faithful to the basic principles of Vision Zero, as far as their practical implications can be assessed today, entail fairly sharp conflicts with other policy objectives. The analyses made in this report, have not been able to device a way of trying to implement Vision Zero without getting into conflict with other policy objectives. These conflicts cannot be resolved by applying cost-benefit analyses. Cost-benefit analyses merely identifies conflicting policy objectives, it does not tell how to resolve these conflicts. If one wishes to avoid the conflicts with other policy objectives uncovered in this report, there seems to be only two options:

- To adopt the cost-benefit strategy, which consists of measures that do not have adverse effects for other policy objectives when seen as a whole. Adopting this strategy would, however, imply giving up the long term ambition of Vision Zero, since cost-benefit analysis explicitly recognises the fact that some road safety measures are too expensive. Vision Zero explicitly rejects this, by stating that human life cannot be traded off against other goods.

- To markedly increase the official valuation of road safety, thereby making it clear that improving road safety is an overriding target, more important than all the other policy objectives taken together. To make benefits greater than costs in the Vision Zero strategy, the valuation of road safety would have to be increased, on the average, by a factor of about 3.8.

10 There is considerable uncertainty in the estimated effects of the road safety measures and road safety strategies. A total of eight sources of uncertainty were identified. Only two of these were quantified and their contributions estimated. A further three sources of uncertainty can in principle be quantified, but was not quantified in this study, because available data were insufficient to do so. Finally, three sources of uncertainty were judged to be difficult to quantify in a meaningful way. It is important to sensitise policy makers to the substantial element of uncertainty present in road safety policy making. An insufficient recognition of this uncertainty may be one of the reasons why policy makers tend to be taken by surprise every time apparently stable long term trends are upset. To be able to maintain stable progress in improving road safety, even in periods of rapid traffic growth, it is necessary to rely on a mixture of measures that give immediate effects and measures of a more long term nature.

11 Current priorities in road safety policy in Sweden are not as efficient as they could be. A growing gap seems to be emerging between the lofty rhetoric of Vision Zero on the one hand, and the dismal road safety record of recent years on the other. The most important reason for inefficient priorities cannot be conflicts with other transport policy objectives, since cost-benefit analyses show that more effective measures than those that are currently used can be implemented without getting into conflict with these objectives. Hence, the obstacles to a more efficient use of road safety measures have to be found outside the framework of cost-benefit analyses.

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Appendix 1: The Contribution of various Risk Factors to Road Safety Problems in Sweden

This appendix presents the data used to estimate the risks attributable to various risk factors in Sweden. The list of road safety problems is presented in chapter 2 of the main text of the report. The contributing risk factors have been sorted into the following five main categories:

- Inadequate system design
- Environmental risk factors
- Vulnerability of road users
- Road user behaviour
- Provision of emergency medical services

The tables below present estimates of the first order attributable risks of risk factors subsumed under each of these main categories. The estimation proceeded in the following stages:

1 The first order attributable risk of each risk factor in the target group was estimated.

2 Target group attributable risk was converted to population attributable risk.

3 Estimates were adjusted for correlations and overlapping accident categories.

4 The marginal contribution to injury prevention of removing each risk factor was estimated by applying the method of joint residuals.

Table 1 gives the data used in stage 1 of the analysis. Following table 1, the text explains how attributable risk was estimated in stages 1 and 2 for each risk factor.

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
			Category A: Inadequate or bad system design						
Traffic environment	Urban/rural	Mv 70	3	388	950	0,35	1,64	-0,009	0,009
		Mv 90	5	299	2000	0,27	0,60	-0,022	-0,012
		Mv 110	21	680	7400	0,31	0,37	-0,080	-0,073
		Mtl 70	1	65	160	0,69	1,63	-0,001	0,001
		Mtl 90	7	118	450	1,71	1,06	0,005	0,000
		Mtl 110	9	120	520	1,90	0,93	0,007	-0,001
		Av 50	39	2195	3950	1,08	2,24	0,005	0,066
		Av 70	111	3956	9920	1,23	1,60	0,032	0,080
		Av 90	198	4227	18215	1,19	0,93	0,048	-0,018
		Av 110	34	493	2555	1,46	0,78	0,017	-0,008
		Ag 30	2	201	920	0,24	0,88	-0,010	-0,002
		Ag 50	80	7006	15860	0,55	1,78	-0,115	0,152
		Ag 70	20	829	1830	1,20	1,82	0,005	0,021
		Ev 50	2	67	700	0,31	0,39	-0,007	-0,006
		Ev 70	20	796	2670	0,82	1,20	-0,007	0,008
		Div 30	0	47	200	0,00	0,95	-0,003	0,000
		Div 50	2	234	400	0,55	2,35	-0,003	0,008
	Reference	Rural	409	11142	44840	1,00	1,00	0,000	0,000
	Risk factor	Towns	145	10579	23860	0,67	1,78	-0,131	0,214

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
Road standard	Motorway/other	Mv 90	5	299	2261	1,00	1,00		
		Av >8000	31	504	3100	4,52	1,23	0,671	0,117
Roadside obstacles	None/objects	None	273	7362	20925	1,00	1,00		
		Objects	338	3714	5770	4,49	1,83	0,430	0,152
Highway signs	Correct/erroneous							0,010	0,015
Junctions	High risk/low risk		20	470				0,036	0,022
Crashworthiness	Car mass	650--899	35	1284	4496	1,01	1,00	0,001	0,000
		900--999	44	1840	6430	0,89	1,00	-0,011	0,000
		1000--1099	68	2400	8990	0,99	0,94	-0,002	-0,009
		1100--1199	78	2400	8350	1,22	1,01	0,027	0,001
		1200--1299	73	2600	8990	1,06	1,01	0,008	0,002
		1300--1399	78	3500	12845	0,79	0,96	-0,044	-0,009
		1400--1499	73	2800	9630	0,99	1,02	-0,002	0,003
		1500--	44	1480	4498	1,27	1,15	0,019	0,011
		Total	493	18304	64229	1,00	1,00	0,341	0,066
Heavy vehicles	Heavy/light	Small	455	18640	102650	1,00	1,00		
		Heavy	134	3032	16150	1,87	1,03	0,106	0,005

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
			Category B: Environmental risk factors						
Darkness	Night/day	Daylight	341	11000	93572	1,00	1,00		
		Dark – no lighting	107	1544	7950	3,69	1,65	0,150	0,041
		Dark - yes	53	2266	12000	1,21	1,61	0,021	0,056
		Dawn – no lighting	25	763	5500	1,25	1,18	0,011	0,008
		Dawn - yes	2	312	2500	0,22	1,06	-0,016	0,001
		Total	528	15885	121522	1,19	1,11	0,165	0,107
Winter time	Winter/summer	Dry	295	9319	84022	1,00	1,00		
		Wet	117	3754	28195	1,18	1,20	0,040	0,044
		Snow	111	2556	9305	3,40	2,48	0,155	0,102
		Total	523	15629	121522	1,23	1,16	0,196	0,146
Animal crashes	Animals involved	No animal	580	20845	NA	PAR = proportion of			
		Involved	9	827	NA	accidents involving animals		0,015	0,038

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
			Category C: Vulnerability of road users						
Road users	Pedestrians	1 to 3	2	33	35	2,24	2,51	0,554	0,602
		4 to 6	2	64	65	1,21	2,63	0,171	0,619
		7 to 14	7	208	273	1,01	2,03	0,005	0,508
		15 to 19	4	155	255	0,61	1,62	-0,626	0,383
		20 to 24	8	138	302	1,04	1,22	0,037	0,179
		25 to 34	8	180	393	0,80	1,22	-0,253	0,181
		35 to 44	10	147	392	1,00	1,00		
		45 to 54	10	160	381	1,03	1,12	0,028	0,107
		55 to 64	16	150	265	2,37	1,51	0,577	0,338
		65 to 74	20	203	242	3,24	2,24	0,691	0,553
		75 to 84	33	230	88	14,70	6,97	0,932	0,857
		Total	120	1668	2691	1,75	1,65	0,428	0,395

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
Road users	Cyclists	1 to 3	0	5	12	0,00	0,63	0,000	-0,579
		4 to 6	1	30	51	3,27	0,89	0,694	-0,119
		7 to 14	4	429	462	1,44	1,41	0,307	0,291
		15 to 19	5	340	392	2,13	1,32	0,530	0,241
		20 to 24	0	302	368	0,00	1,25	0,000	0,198
		25 to 34	4	361	478	1,39	1,15	0,283	0,129
		35 to 44	3	329	500	1,00	1,00		
		45 to 54	6	327	496	2,02	1,00	0,504	0,002
		55 to 64	8	266	222	6,01	1,82	0,834	0,451
		65 to 74	19	247	202	15,68	1,86	0,936	0,462
		75 to 84	18	176	87	34,48	3,07	0,971	0,675
		Total	68	2812	3270	3,47	1,31	0,711	0,235

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
Road users	Car drivers	18 to 19	30	861	1815	6,77	6,22	0,852	0,839
		20 to 24	47	1722	4025	4,78	5,61	0,791	0,822
		25 to 34	66	2235	12149	2,22	2,41	0,550	0,586
		35 to 44	42	1661	13765	1,25	1,58	0,199	0,368
		45 to 54	41	1279	16782	1,00	1,00		
		55 to 64	38	802	8929	1,74	1,18	0,426	0,151
		65 to 74	30	595	5824	2,11	1,34	0,526	0,254
		75 to 84	24	303	940	10,45	4,23	0,904	0,764
		Total	318	9458	64229	2,03	1,93	0,507	0,482

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
Road users	Car passengers	1 to 3	5	134	2382	3,83	1,32	0,739	0,240
		4 to 6	2	156	3647	1,00	1,00		
		7 to 14	7	419	6521	1,96	1,50	0,489	0,334
		15 to 19	23	890	2559	16,39	8,13	0,939	0,877
		20 to 24	20	704	2409	15,14	6,83	0,934	0,854
		25 to 34	21	733	4708	8,13	3,64	0,877	0,725
		35 to 44	13	458	5669	4,18	1,89	0,761	0,471
		45 to 54	10	384	5844	3,12	1,54	0,680	0,349
		55 to 64	9	328	1947	8,43	3,94	0,881	0,746
		65 to 74	15	367	1781	15,36	4,82	0,935	0,792
		75 to 84	12	196	254	86,15	18,04	0,988	0,945
		Total	137	4769	37721	6,62	2,96	0,849	0,662

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
	Bus passengers	1 to 6	1	3	245	2,71	1,81	0,631	0,447
		7 to 12	2	10	851	1,56	1,73	0,359	0,423
		13 to 17	4	18	2657	1,00	1,00		
		18 to 24	5	20	1368	2,43	2,16	0,588	0,537
		25 to 44	9	41	3564	1,68	1,70	0,404	0,411
		45 to 64	10	40	1672	3,97	3,53	0,748	0,717
		65 to 84	9	42	1756	3,40	3,53	0,706	0,717
		Total	40	174	12113	2,19	2,12	0,544	0,528
Road users	Protected/unprotected	Pedestrians	132	1737	2691	12,09	5,07		
		Cyclists	71	2843	3270	5,35	6,82		
		Moped rds	17	870	200	20,95	34,15		
		Mc rds	39	1004	500	19,23	15,76		
		Car drivers	323	9500	64229	1,24	1,16		
		Car pass	141	4905	37720	0,92	1,02		
		Bus drivers	1	47	800	0,31	0,46		
		Bus pass	1	181	12112	0,02	0,12		
		Protected	466	14633	114861	1,00	1,00		
		Unprotected	259	6454	6661	9,58	7,61	0,320	0,266

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
			Category D: Road user behaviour						
Speeding	Violation rate	Mv 70	1	260					
		Mv 90	2	309					
		Mv 110	28	589					
		Mtl 70	0	81					
		Mtl 90	4	130					
		Mtl 110	10	177					
		Av 50	50	2068					
		Av 70	102	3762					
		Av 90	233	4247					
		Av 110	30	390					
		Ag 30	1	197					
		Ag 50	94	7867					
		Ag 70	21	845					
		Ev 50	0	100					
		Ev 70	10	450					
		Div 30	0	100					
		Div 50	3	100					
		Total	589	21672					

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
Drinking and driving	Drivers	Sober	497	20283		1,00	1,00		
		Drunk	40	1064		25,00	25,00	0,072	0,048
		Total	537	21347					
Seat belt wearing	Drivers	Yes (87)	197	7375	55879	1,00	1,00		
		No (13)	82	2045	8350	2,78	1,85	0,146	0,054
		Total	279	9420	64229				
	Passengers	Yes (91,5)	96	3871	34515	1,00	1,00		
		No (8,5)	16	662	3206	1,84	1,84	0,036	0,036
		Total	112	4533	37721				
		Total	391					0,084	0,032

Appendix 1, Table 1: Data used to estimate the risks attributable to various risk factors in Sweden, continued

			Road safety statistics			Relative rates		Attributable risks	
Risk factor	Variable	Categories	Fatal	Injured	Exposure	Fatalities	Injuries	Fatalities	Injuries
Other violations	Male car driver	No violations	50539	55032			1,00		
		Violations	10486	5990			1,91		0,082
		Total	61025	61022					
	Female car driver	No violations	23957	24618			1,00		
		Violations	1213	552			2,26		0,027
		Total	25170	25170					
	Male bus drivers	No violations	1374	1409			1,00		
		Violations	184	149			1,27		0,025
		Total	1558	1558					
	Female bus drivers	No violations	282	287			1,00		
		Violations	11	6			1,87		0,017
		Total	293	293					
	Male truck drivers	No violations	3590	3822			1,00		
		Violations	631	399			1,68		0,061
		Total	4221	4221					
	Male motorcyclists	No violations	2932	3503			1,00		
		Violations	1060	465			2,72		0,168
		Total	3992	3968					
Excessive driving	3% of town driving							0,005	0,015
			Category E: Emergency medical services						
Rescue services			100	5000				0,167	0,071

Category A: Inadequate or bad system design

This category comprises the following risk factors:

A1: Traffic environment. This variable was defined in terms of a rural or urban environment.

A2: Substandard roads. This variable was defined as lack of motorway standard on roads with an AADT of more than 8,000.

A3: Roadside obstacles: This variable was defined as accidents in which a roadside obstacle was hit.

A4: Highway signs: This variable was defined as erroneous highway signing.

A5: Junctions: This variable was defined as high risk junctions.

A6: Car crashworthiness: This variable was defined in terms of the difference in crashworthiness performance between the best cars and the average car in a certain weight category.

A7: Heavy vehicles: This variable was defined as the additional fatality or injury risk posed by heavy vehicles compared to light vehicles.

The risk attributable to each of these variables was estimated as follows:

A1: Traffic environment

Roads were divided into the categories listed in the table. The data were taken from the road data bank, and are identical to Table 6 in the main text of the report. Roads with a speed limit of 50 km/h or less were classified as belonging to an urban traffic environment. Some roads with a speed limit of 70 km/h were also classified as urban. Roads in rural areas was defined as the reference category. Relative risk was estimated to 0.67 for fatalities and 1.78 for injuries in total. This results in an attributable risk of –0.131 for fatalities and 0.214 for injuries in total. The risk of a fatality is, in other words, higher in rural areas than in urban areas. For injuries in total, the reverse holds.

A2: Substandard roads

The concept of “substandard roads” is somewhat flexible. In this report, a rather narrow interpretation was chosen. All roads in rural areas with an AADT of more than 8,000 were regarded as substandard if they did not have motorway standard. According to Andersson et al (1998), there are 750 km of such road. This appears to be a conservative estimate, but has been used. The annual mean number of fatalities during 1994-1996 was 31. The total number of injured road users was 504. The relative injury rate on these roads, compared to motorways is 4.52 for fatalities and 1.23 for the total number of injured road users, using injury rates on motorways as reference. Target attributable risk is 0.671 for fatalities and 0.117 for injured road users in total. This translates to a population attributable risk of 0.034 and 0.010, respectively.

A3: Roadside obstacles

Accidents were classified into those in which a fixed object is struck, and those that do not involve striking a fixed object. The number of accidents in each category was taken from a report by Schandersson (1979, Appendix 3, Table C5). These data refer to the years 1972-1976. Accidents involving property damage only were taken as a measure of exposure. The relative risks associated with fixed objects were estimated to 4.49 for fatalities and 1.83 for injuries in total. Attributable risk in the target group of accidents is 0.430 for fatalities and 0.152 for injured road users in total. These estimates were then applied to official accident statistics for 1994, in which 229 of 589 fatalities involved hitting a fixed object, and 5,621 of 21,672 injured road users in total were injured in accidents in which a fixed object was struck. Population attributable risks were estimated to (229 × 0.43)/589 = 0.167 for fatalities, and (5,621 × 0.152)/21,672 = 0.039 for injured road users in total.

A4: Erroneous highway signs

No precise information exists concerning the current prevalence of erroneous highway signing in Sweden. In a Nordic survey in 1990 (Vaa et al 1990), 14% of 703 highway signs were classified as erroneous in Sweden. A sign was classified as erroneous if it did not comply with the current guidelines for highway signing. A study quoted in the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997) shows that correcting traffic control devices to make them conform to the US Manual on Uniform Traffic Control Devices, can reduce the number of injury accidents by 15% and the number of property-damage-only accidents by 7%. Based on this study, it was assumed that the risk attributable to erroneous or substandard highway signs in Sweden is 0.010 for fatalities and 0.015 for injuries in total. These estimates are highly uncertain.

A5: High risk junctions

Andersson et al (1998) estimate that treatment of high risk four leg junctions in Sweden, of which they estimate that there is 875, can reduce the number of fatalities by 20 and the number of injured road users by 470. These estimates are taken to indicate the risk attributable to high risk junctions in Sweden, which then becomes 20/554 = 0.036 for fatalities, and 470/21721 = 0.022 for injuries.

A6: Car crashworthiness

The contribution of this risk factor was assessed by putting together information from two different sources. The Folksam car model safety rating 1991-1992 (Hägg et al 1992) provides information on the performance in crashes of many car models. The official accident statistics for Sweden shows the number of registered cars by mass (weight). This was taken as a measure of exposure. Official accident statistics also shows the rates of involvement of cars of different masses in fatal accidents and injury accidents. Cars were divided into the following groups with respect to mass in kilograms:

- Below 900
- 900-999
- 1,000-1,099
- 1,100-1,199
- 1,200-1,299
- 1,300-1,399
- 1,400-1,499

- 1,500-

In each of these groups, the number of cars involved in fatal accidents, the number of cars involved in injury accidents, and the number of registered cars was noted. There were 493 fatalities in 1994 in accidents in which passenger cars were involved. 391 of these were car occupants, the other 102 were other groups of road users, mainly pedestrians, cyclists and moped riders. It was assumed that injuries to other road users are independent of car crashworthiness. Only injuries to car occupants are affected.

The Folksam study presents a safety performance indicator called Z for cars in four groups by mass. These groups are somewhat broader than those used by Statistics Sweden, but were applied in the following manner:

- Folksam group 751-950 kg, comprises SCB groups –899 and 900-999 kg
- Folksam group 950-1,050 kg, comprises SCB group 1,000-1,099 kg
- Folksam group 1,050-1,250 kg, comprises SCB groups 1,100-1,199 and 1,200-1,299 kg
- Folksam group 1,250-1,550 kg, comprises SCB groups 1,300-1,399, 1,400-1,499 and 1,500- kg

For each group, the contribution of inferior crashworthiness to fatalities and injuries was assessed by applying the ratio of the best Z value in each class to the average value for that class:

Class –899: 0.074/0.138 = 0.536

The Z value for the best performing car in this class was 0.074. The mean Z value for the class was 0.138. If all cars in the class had performed as the best car, the number of fatalities could have been reduced to 0.074/0.138 = 0.536 = 54% of the actual number. Similar estimates were made for each of the four Folksam classes. Estimates were summed. For injuries in total, the effect of differences in crashworthiness were assumed to be 20% of those found for fatalities. It was found that 201 fatalities could be prevented, and 1,434 injuries in total. This give a population attributable risk for 1994 of 201/589 = 0.344 for fatalities and 1,434/21,672 = 0.066 for the total number of injured road users.

A7: Heavy vehicles

VTI report 387, part 3 (Nilsson 1994A) was used as the source for estimating the risks attributable to heavy vehicles. Relative risks were estimated to 1.87 for fatalities and 1.03 for injured road users in total. This resulted in an attributable risk of 0.106 for fatalities and 0.005 for injured road users in total.

Category B: Environmental risk factors

This category comprises the following risk factors:

B1: Darkness. This variable takes on five values: daylight, darkness with no road lighting, darkness with road lighting, dusk or dawn with no road lighting, and dusk or dawn with road lighting.

B2: Road surface condition: This variable takes on the values dry, wet and covered by snow or ice.

B3: Animals: This variable takes on two values: animal involved and animal not involved.

The risks attributable to these factors was assessed as follows:

B1: Darkness

Accidents were categorised by light conditions according to the official accident statistics for 1994. The risk attributable to darkness was estimated by assuming that 77% of all traffic is during daylight. This estimate is admittedly judgmental, but is in the right order of magnitude. The distribution of traffic between darkness, on the one hand, and dusk and dawn, on the other was also determined informally, by assuming that: (1) The relative risks during darkness (using daylight as reference) are higher than during dusk and dawn, (2) The relative risks are higher on unlit roads than on lit roads. Applying these assumptions resulted in an attributable risk of 0.165 for fatalities and 0.107 for injured road users in total.

B2: Weather/road surface condition

This variable takes on the value dry, wet, and covered by snow. As for daylight conditions, the exact proportion of exposure subject to wet or snow covered roads is not known. It was, judgementally, assumed that the relative risk of injury is about 1.2 on wet road surfaces, and about 2.5 on snow covered road surfaces. The risk attributable to road surface condition then came to 0.196 for fatal injury and 0.146 for any injury.

B3: Animals

The official accident statistics for 1994 recorded 9 fatalities in accidents in which animals were involved, out of a total of 589. A total of 827 people were injured in accidents involving animals, out of a total of 21,672. Since the exposure to animals is unknown, and likely to be a very momentary nature, the risk attributable to animals was set equal to the portion of accidents involving animals. This comes to 9/589 = 0.015 for fatalities, and 827/21,672 = 0.038 for the total number of injured road users. It is evident that the accidents involving animals are less severe than injury accidents in general.

Category C: Vulnerability of road users

This category includes the following characteristics of road users that put them at a disproportionate risk of injury:

C1: Being an unprotected road user

C2: Being a child

C3: Being a young driver

C4: Being an older citizen

This risks attributable to these characteristics overlap to a considerable extent. The first order risks attributable to each risk factor were estimated by relying on a detailed breakdown of injuries and exposure by age and group of road user. The most recent statistics giving such a breakdown are given in a report by Thulin and

Kronberg (1998). Additional reports giving this kind of information include Thulin and Nilsson (1994) and Thulin (1997).

C1: Unprotected road users

Unprotected road users include pedestrians, cyclists, riders of mopeds and riders of motor cycles. All other road users are protected. Based on statistics applying to 1992 (Thulin and Nilsson 1992), the risk attributable to being an unprotected road users was estimated to 0.320 for fatalities and 0.266 for the total number of injured road users. Truck drivers were not included in this estimate.

C2: Children

Road users aged less than 15 years were counted as children, all others as adults. The risk attributable to being a child was estimated by group of road users, and the estimates added. The risk attributable to being a child came to 0.016 for fatal injury and 0.022 for the total number of injuries. Apparently, accidents involving children lead to less severe injuries than injury accidents in general.

C3: Young drivers

This risk factor applies to car drivers only. Young drivers were defined as those of the age 18 to 24 years. The risk attributable to young drivers was estimated to 0.086 for fatalities and 0.101 for the total number of injuries.

C4: Older road users

This category was defined as all road users of the age of 65 years or older. The risk attributable to being an older road user was estimated to 0.206 for fatalities and 0.068 for injured road users in total. Older road users are apparently at greater risk of being killed than road users in general, perhaps because older people have a reduced tolerance for biomechanical impacts.

Category D: Road user behaviour

This category includes the following risk factors:

D1: Speed limit violations

D2: Drinking and driving

D3: Not wearing seat belts

D4: Other violations of road traffic law

D5: Excessive driving in towns

The risks attributable to these factors have been estimated as follows.

D1: Speed limit violations

Based on a report issued by VTI (Andersson et al 1998), fatalities and injuries were tabulated by category of road and speed limit. Data on the current mean speed of driving was mostly taken from the same source, but in a few cases from a report issued by the Swedish National Roads Administration (Isaksson 1997). Speed was assumed to be normally distributed around the mean. It was further assumed that the entire distribution of speeds is contained within plus or minus 3 standard deviations from the mean (covering a range of six standard deviations in total). Perfect compliance with current speed limits was defined as a distribution in which 93% of all speeds (corresponding to the mean plus 1.5 standard deviation above it) are at or below the speed limit. The effect of perfect compliance on the number of road users killed or injured was estimated by applying functions relating the number of fatal accidents and injury accidents to the mean speed of traffic. Hence, it was necessary to estimate how perfect compliance would affect the mean speed of travel. To give an example of such a calculation, information is reproduced below for the case of rural roads with a posted speed limit of 90 km/h.

Percent of traffic (cumulative)	Mean speed today (km/h)	Mean speed in case of perfect compliance (km/h)
0	60,0	60,0
1	66,0	66,0
2	72,0	72,0
7	78,0	78,0
16	84,0	80,0
31	90,0	82,0
50	96,0	84,0
69	102,0	86,0
84	108,0	88,0
93	114,0	90,0
98	120,0	96,0
99	126,0	102,0
100	132,0	108,0

In the initial distribution, speeds range from 60 to 132 km/h. Mean speed (the 50 percentile speed) is 96 km/h. Perfect compliance is assumed not to affect the speeds of those driving at a speed of up to about 10 km/h below the speed limit. All speeds higher than this are, however, reduced. The largest reductions occur for the highest speeds. The new mean speed is 84 km/h. 93% of all vehicles are assumed to stay at or below the speed limit. The effect of perfect compliance on accidents was estimated by applying power functions developed by VTI. For fatalities, for example, the effect of perfect compliance is estimated according to the following function:

Effect on fatalities $(84/96)^4 = 0.586 = 41.4\%$ reduction in the number of fatalities.

For serious and slight injuries, the exponent is 3 and 2, respectively. The risk attributable to speeding was estimated by applying these functions to all types of road, and summing the results. An attributable risk of 0.376 for fatalities and 0.210 for the total number of injured road users was estimated.

D2: Drinking and driving

The proportion of accidents in 1996 involving drinking drivers was taken from a report published by VTI (Andersson et al 1998). It was assumed that drinking drivers have an accident rate which is 25 times higher than the rate for sober drivers. The risk attributable to drinking and driving then becomes 0.072 for fatalities and 0.048 for the total number of injured road users.

D3: Seat belt wearing

VTI has estimated the potential for reducing traffic injury in Sweden by increasing the wearing of seat belts (Andersson et al 1998). However, these estimates were based on a more optimistic assumption about the protective effect of seat belt than available evaluation studies seem to support. A further problem is the fact that the proportion of accident victims not wearing seat belts is not recorded in official accident statistics for Sweden. It was therefore necessary to estimate this proportion on the basis of counts made of the use of seat belts in traffic. The estimate was based on the assumption that the safest drivers are selectively recruited among seat belt wearer, which implies that wearing rates will be lower among drivers involved in accidents than in the general population of drivers. Functions describing the selective recruitment process have been fitted to data reviewed in the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997), but it should be noted that these functions rely on few data points, most of which are located outside the range of wearing rates applying to Sweden. The assumptions made about the percentage of seat belt wearers by seating position are shown below.

		Percent seat belt wearing in traffic and among accident victims			
Seating position	Seat belt	Traffic	Involved in accidents	Killed	Injured
Driver	Yes	87.0	82.8	70.6	78.3
	No	13.0	17.2	29.4	21.7
	Total	100.0	100.0	100.0	100.0
Passenger	Yes	91.5	88.6	85.4	85.4
	No	8.5	11.4	14.6	14.6
	Total	100	100.0	100.0	100.0

It was estimated that about 70% of killed driver will wear a seat belt. This assumption agrees well with the results of in-depth studies of fatal accidents made by road authorities in region South-East in Sweden. The fatality risk for drivers attributable to not wearing a seat belt, is equal to the reduction in the number of killed drivers not wearing a seat belt that could be attained if they wore one. For 1996, the population risk attributable to not wearing seat belts came to 0.084 for fatalities and 0.032 for the total number of injured road users.

D4: Other violations of road traffic law

The risk attributable to other traffic violations (than speeding, drinking and driving, and not wearing seat belts) was estimated by using a report by Spolander (1997). This report contains a case control study, in which a sample of accident involved drivers have been compared to a representative sample of drivers, matched by age, sex and type of driver's license. According to this report, the injury risk attributable to traffic law violations can be estimated to 0.061. There is no information on fatality risk, but is seems reasonable to assume that many traffic violations have a greater effect on fatalities than on injuries in general. Hence, an attributable risk of 0.092 was judgementally assumed for fatalities.

D5: Excessive driving in towns

The concept of ”excessive driving” is somewhat elusive. It has been assumed, arbitrarily, that 3% of the current amount of driving in towns is "excessive", in the sense that it does not have a specific purpose and can easily be replaced by other modes of transport. Based on a report by Fridstrøm et al (1993), the elasticity of fatalities with respect to traffic volume is set to 0.64, and the elasticity of the total number of injured road users with respect to traffic volume set to 0.99. A 3% reduction in urban traffic then results in a population attributable risk of 0.005 for fatalities and 0.015 for injuries in total.

Category E: Insufficient rescue services

There are no subcategories for this factor. A discussion of the potential contribution of medical services to traffic accident fatalities and injuries is given in the report "Mot det trafiksäkra samhället" (Kommunikationsdepartementet 1997). Based on the discussion in this report, the risks attributable to rescue services have been estimated to 0.167 for fatalities and 0.071 for the total number of injured road users.

Summary of first order attributable risks

The estimated first order attributable risks are summarised in the table below.

It can be seen that three groups of risk factors each contribute to about 60% of fatalities. These are inadequate or bad system design, vulnerability of road users, and road user behaviour. The single most important risk factors in terms of its contribution to fatalities is speeding. Eliminating it would reduce the number of fatalities by almost 40%.

The same three groups of risk factors also make significant contributions to the total number of injuries, each contributing around 40%. With respect to the total number of injuries, the vulnerability of unprotected road users is the single most important risk factor, contributing to about 27% of all injuries. Speeding is a close second, responsible for 21% of all injured road users.

When all risk factors are added, their contributions come to more than 100%. This is not surprising. In the first place, all accidents are the result of a combination of several risk factors, not just one. In the second place, risk factors are correlated. Drinking and driving, for example, is hazardous partly because drinking drivers tend to wear seat belts less often than sober drivers, partly because there are roadside obstacles, and partly because drinking drivers tend to drive in hours of darkness. The risks attributed to drinking and driving, and to each of the other risk factors mentioned, reflects the total contribution of both drinking and driving and the other risk factors with which it is correlated.

Appendix 1, Table 2. Summary of first order attributable risks

Risk factor	First order attributable risk: Fatal injuries	First order attributable risk: All injuries
A1: Traffic environment	-0.131	0.214
A2: Substandard roads	0.034	0.010
A3: Roadside obstacles	0.167	0.039
A4: Erroneous highway signs	0.010	0.015
A5: High risk junctions	0.036	0.022
A6: Car crashworthiness	0.341	0.066
A7: Heavy vehicles	0.106	0.005
A. System design	*0.563*	*0.371*
B1: Darkness	0.165	0.107
B2: Winter and wet roads	0.196	0.146
B3: Animals	0.015	0.038
B. Environmental factors	*0.376*	*0.291*
C1: Unprotected road users	0.320	0.266
C2: Children	0.016	0.022
C3: Young drivers	0.086	0.101
C4: Older road users	0.206	0.068
C. Vulnerability of road users	*0.628*	*0.457*
D1: Speeding	0.376	0.210
D2: Drinking and driving	0.072	0.048
D3: Not wearing seat belts	0.084	0.032
D4: Other violations	0.092	0.061
D5: Excessive driving in towns	0.005	0.015
D. Behaviour	*0.629*	*0.366*
E1: Rescue service	0.167	0.071
E. Rescue services	*0.167*	*0.071*
F: All risk factors	2.363	1.556

In view of this, one cannot use the results presented in table 2 to estimate what the effects on safety would be of eliminating all the risk factors listed. It is logically impossible to reduce the number of fatalities or injuries by more than one hundred percent. In order to get a better impression of the likely marginal contributions to safety of trying to control each risk factor, adjustments have been made for presumed correlations between the risk factors. Since these correlations are not very well known, the adjustments made are somewhat informal.

Adjusting first order attributable risks for overlapping problem categories and correlations between risk factors

The adjustments that have been made to the first order estimates of attributable risk are shown in table 3. The adjustments are all subtractions from first order attributable risks.

Appendix 1; Table 3: Adjustments to first order attributable risks

	First order attributable risk		Adjustment for overlap with other risk factors		Adjustment for correlation with other risk factors	
Risk factor	Fatal	Injury	Fatal	Injury	Fatal	Injury
A1: Traffic environment	-0.131	0.214				
A2: Substandard roads	0.034	0.010				
A3: Roadside obstacles	0.167	0.039	0.014	0.003		
A4: Erroneous highway signs	0.010	0.015				
A5: High risk junctions	0.036	0.022	0.014	0.015		
A6: Car crashworthiness	0.341	0.066				
A7: Heavy vehicles	0.106	0.005				
A. System design	*0.563*	*0.371*	*0.535*	*0.353*	*0.535*	*0.353*
B1: Darkness	0.165	0.107			0.049	0.032
B2: Winter and wet roads	0.196	0.146			0.058	0.044
B3: Animals	0.015	0.038				
B. Environmental factors	*0.376*	*0.291*	*0.376*	*0.291*	*0.269*	*0.215*
C1: Unprotected road users	0.320	0.266	0.144	0.178		
C2: Children	0.016	0.022	0.005	0.014		
C3: Young drivers	0.086	0.101				
C4: Older road users	0.206	0.068	0.110	0.026		
C. Vulnerability of road users	*0.628*	*0.457*	*0.369*	*0.239*	*0.369*	*0.239*
D1: Speeding	0.376	0.210				
D2: Drinking and driving	0.072	0.048			0.007	0.005
D3: Not wearing seat belts	0.084	0.032			0.008	0.003
D4: Other violations	0.092	0.061			0.009	0.006
D5: Excessive driving in towns	0.005	0.015				
D. Behaviour	*0.629*	*0.366*	*0.629*	*0.366*	*0.605*	*0.352*
E1: Rescue service	0.167	0.071				
E. Rescue services	*0.167*	*0.071*	*0.167*	*0.071*	*0.167*	*0.071*
F: All risk factors	2.363	1.556	2.076	1.320	1.945	1.230

The adjustments made reduce the total attributable risks for fatalities from 2.36 to 1.95. The corresponding reduction for injured road users in total is from 1.56 to 1.23.

The potential for improving road safety by eliminating risk factors

The potential for improving road safety by eliminating the risk factors was estimated by using the method of joint residuals. For each risk factor, the residual of that factor was estimated. For speeding, for example, the residual with respect to fatal injury is 1 – 0.376 = 0.624. This is the proportion of fatal injuries that would remain if speeding was eliminated. All the residual were multiplied. 1 minus the product of the residuals gives the potential gain in safety by eliminating all risk factors. This was estimated to 0.891 for fatalities and 0.731 for the total number of injured road users. Table 4 lists the marginal safety potential associated with the elimination of each risk factor.

Appendix 1, Table 4: Marginal safety potentials associated with eliminating each risk factor

	Marginal safety potential by eliminating risk factor	
Risk factor	Fatal injuries	All injuries
A1: Traffic environment	-0.060	0.127
A2: Substandard roads	0.016	0.006
A3: Roadside obstacles	0.070	0.021
A4: Erroneous highway signs	0.005	0.009
A5: High risk junctions	0.010	0.004
A6: Car crashworthiness	0.156	0.039
A7: Heavy vehicles	0.049	0.003
A. System design	*0.245*	*0.210*
B1: Darkness	0.053	0.045
B2: Winter and wet roads	0.063	0.061
B3: Animals	0.007	0.023
B. Environmental factors	*0.123*	*0.128*
C1: Unprotected road users	0.081	0.052
C2: Children	0.005	0.005
C3: Young drivers	0.039	0.060
C4: Older road users	0.044	0.025
C. Vulnerability of road users	*0.169*	*0.142*
D1: Speeding	0.172	0.125
D2: Drinking and driving	0.030	0.026
D3: Not wearing seat belts	0.035	0.017
D4: Other violations	0.038	0.033
D5: Excessive driving in towns	0.002	0.009
D. Behaviour	*0.277*	*0.209*
E1: Rescue service	0.076	0.042
E. Rescue services	*0.076*	*0.042*
F: All risk factors	*0.890*	*0.730*

Uncertainty in estimated attributable risks

The approach taken in textbooks in epidemiology to estimating uncertainty for an attributable risk is to estimate the uncertainty of the relative risk used in estimating attributable risk. This approach is not applicable to the estimates presented here. Attributable risk has in some cases been estimated informally, in other cases by using methods that do not utilise information about relative risks. Hence, another approach has been taken.

The risks attributable to each risk factor can be interpreted as a potential safety effect, that is an effect of removing the risk factor entirely. An attributable risk of 0.034, for example, corresponds to a potential safety improvement of 3.4%. Interpreted this way, uncertainties can be estimated by relying on the log odds method applied in meta-analysis. Each estimate of attributable risk is related to the mean annual number of traffic injuries in Sweden for 1994-1998. This was 554 for fatalities and 21,721 for injured road users in total. The value of the statistical weights is determined by estimating the prevented number of injuries corresponding to each estimate of attributable risk. Thus, an estimate of 0.034 for fatalities, for example, corresponds to 0.034 × 554 = 18.8 prevented fatalities. The statistical weight assigned to this estimate then becomes:

Weight (w) = 1/(1/554 + 1/18.8)

These weights are inversely proportional to sample size, which will in turn minimise the variance of the weighted estimate. The log odds estimate of attributable risk is:

$$\text{Attributable risk} = \exp\left(\frac{\sum_{i=1}^{g} w_i\, y_i}{\sum_{i=1}^{g} w_i}\right)$$

in which y_i is the natural logarithm of the first order estimate of attributable risk. the 95% confidence interval for attributable risk is estimated according to:

$$\text{95\% confidence interval} = \exp\left[\left(\sum_{i=1}^{g} w_i\, y_i \Big/ \sum_{i=1}^{g} w_i\right) \pm 1.96 \cdot 1\Big/\sqrt{\sum_{i=1}^{g} w_i}\right]$$

This method of estimation is strictly analogous to the one used in meta-analysis employing the log odds method. Table 5 gives the estimated 95% confidence intervals for first order attributable risks. Two main tendencies are apparent in the table:

3 There is greater uncertainty about attributable risks for fatal injury than for injured road users in total.

4 There is greater relative uncertainty about the risks attributed to risk factors that make a comparatively small contribution than to the risks attributed to factors that make a greater contribution to fatalities and injuries.

Appendix 1, Table 5: 95% confidence intervals for estimates of first order attributable risks

Risk factor	Fatalities			Total injuries		
	Best estimate	Lower 95% limit	Upper 95% limit	Best estimate	Lower 95% limit	Upper 95% limit
A1: Traffic environment	-0.131	-0.009	-0.268	0.214	0.207	0.221
A2: Substandard roads	0.034	0.021	0.054	0.010	0.009	0.011
A3: Roadside obstacles	0.167	0.134	0.208	0.039	0.036	0.042
A4: Erroneous highway signs	0.010	0.004	0.023	0.015	0.013	0.017
A5: High risk junctions	0.036	0.023	0.056	0.022	0.020	0.024
A6: Car crashworthiness	0.341	0.289	0.402	0.066	0.063	0.070
A7: Heavy vehicles	0.106	0.081	0.139	0.005	0.004	0.006
A. System design	*0.563*	0.490	0.647	*0.371*	0.362	0.381
B1: Darkness	0.165	0.132	0.206	0.107	0.103	0.112
B2: Winter and wet roads	0.196	0.160	0.241	0.146	0.141	0.152
B3: Animals	0.015	0.008	0.030	0.038	0.035	0.041
B. Environmental factors	*0.376*	0.321	0.441	*0.291*	0.283	0.299
C1: Unprotected road users	0.320	0.270	0.379	0.266	0.258	0.274
C2: Children	0.016	0.008	0.031	0.022	0.020	0.024
C3: Young drivers	0.086	0.064	0.116	0.101	0.097	0.106
C4: Older road users	0.206	0.168	0.252	0.068	0.065	0.072
C. Vulnerability of road users	*0.628*	0.549	0.718	*0.457*	0.446	0.468
D1: Speeding	0.376	0.321	0.441	0.210	0.203	0.217
D2: Drinking and driving	0.072	0.052	0.099	0.048	0.045	0.051
D3: Not wearing seat belts	0.084	0.062	0.113	0.032	0.030	0.035
D4: Other violations	0.092	0.069	0.123	0.061	0.058	0.064
D5: Excessive driving in towns	0.005	0.002	0.016	0.015	0.013	0.017
D. Behaviour	*0.629*	0.550	0.719	*0.366*	0.357	0.376
E1: Rescue service	0.167	0.134	0.208	0.071	0.067	0.075
E. Rescue services	*0.167*	0.134	0.208	*0.071*	0.067	0.075
F: All risk factors	2.363	2.140	2.610	1.556	1.530	1.583

Appendix 2: Estimation of the Effects of Each Road Safety Measure

The following appendix describes the estimation of the safety effect of each measure. It has been copied from an Excel spreadsheet. The appendix is divided into three parts. The meaning of the columns listed is briefly explained below.

Column 1 (No) lists the code number used to identify each road safety measure. Whenever possible, the code number is identical to the chapter number dealing with the measure in the Traffic Safety Handbook.

Column 2 (Measure) gives the name of the measure. Sometimes, additional information is provided concerning the application of the measure (eligible units etc).

Column 3 (Status) classifies each measure as used or new. New measures are measures that have so far not been used extensively, or are not used on a regular basis.

Column 4 (Unit) denotes the unit of implementation used to assess the effects of a measure. For road related measures, this is usually the number of kilometres of road or the number of junctions (or curves). For vehicle related measures, it is the number of vehicles. For road user related measures, it is the number of road users affected. For some measure, units are measures as the percentage use of the measure. This scale is used for protective devices like helmets or reflective devices. In a few cases, no unit is given, and the measure is assumed to apply to the entire road system (enforcement).

Column 5 (Target group) briefly identifies the target group of injuries for the measure, that is the subset of all injured road users that have been assumed to benefit from the measure.

Column 6 (Current use) describes the current level of use of the measure, as well as the assumed maximum potential use (abbreviation max pot in the table). The difference between the maximum potential use and the current use shows the potential for increased use of a measure.

Column 7 (Levels of use 2002-2011) shows the alternative levels of use defined for each measure for the ten year period 2002-2011 (both years included). These levels refer to the entire period.

Column 8 (Unit costs – Investment) shows the assumed investment cost per unit (kilometre of road, for example) applied of the measure. The cost is given in SEK 1999 prices.

Column 9(Unit costs – Operating) shows the assumed annual costs of operation or maintenance of each measure. per unit applied of the measure. These are annual costs per unit, recurring every year of the ten year planning term.

Column 10 (Exposure) provides information on the exposure to the measure. Exposure is denoted in terms of million vehicle kilometres of travel for road related measures and traffic control. For vehicle related measures, exposure is generally denoted as the percentage of vehicles that have been assumed to be equipped with the safety measure. For road user related measures, exposure denotes the number of road users exposed to the measure.

Column 11(Risk of injury) denotes the number of injured road users per million units of exposure. For vehicle related measures, risk of injury has in most cases not been estimated, but the number of vehicles involved in injury accidents has been taken directly from official accident statistics.

Columns 12 through 15 (Number of injured affected) shows the estimated annual number of injured road users affected by each measure. These numbers are in most cases estimated either as the product of exposure and injury risk, or as the product of the number of units affected and the percentage of units affected. The number of injured road users are given for three levels of injury severity, in addition to the total number. The three levels of injury severity are fatal injury (Killed), serious injury, and slight injury. The number of injured road users represents the annual average for the years 1994-1998 (both years included).

These fifteen columns form part 1 of the Appendix. Part 2 consists of an additional 13 columns, plus columns 1 and 2, which are repeated to ease reading. Hence, in part 2 of the Appendix, columns 1 and 2 denote the code number and name of each measure. Columns 3 through 5 presents information on the assumed effect of the measure on the number of injured road users. The effect is stated as a proportionate reduction of the number of injured road users. Thus, 0.80 means an 80% reduction. Effects are stated separately for fatal injury (Killed), serious injury and slight injury. In some cases, the same proportionate effect has been assumed for all levels of severity, in other cases, the effect has been assumed to vary according to injury severity.

Columns 6 through 9 in part 2 state the estimated annual reduction of the number of injured road users by injury severity. Numbers have been rounded, and decimals are not shown, although the calculations did use decimals.

Columns 10 through 15 presents the present values of benefits in million SEK. Column 10 gives savings in accident costs. Column 11 gives changes in the costs of travel time. Negative amounts represent increases in travel time. Column 12, labelled Vehicle, refers to changes in vehicle operating costs. Column 13, labelled Environment, refers to changes in environmental costs. These costs are the sum of the valuations of traffic noise and air pollution. Column 14, labelled Traffic, concerns the change in consumer's surplus attributable to changes in the volume of travel. Negative amounts refer to reductions in the volume of travel, positive amounts refer to increases. Column 15 presents the sum of these benefits (Sum benefit).

Part 3 of the Appendix consists of six columns, in addition to columns 1 and 2, which are repeated. Column 1 gives the code number of reach measure, column 2 gives the name. Columns 3 through 6 provide information on the costs of the measure. Column 3 refers to investment costs, column 4 to annual costs (operating costs), column 5 to the opportunity costs of taxation, and column 6 to total costs. Finally, columns 7 and 8 presents to measures of efficiency. Column 7 gives the (marginal) benefit-cost ratio of each measure for each level of use. The benefit cost ratio was estimated simply as total benefits divided by total costs. Values greater than 1.0 indicate that benefits are greater than costs. Column 8 presents the (marginal) cost-effectiveness, defined in terms of the number of fatal and serious injuries prevented per million SEK it costs to implement the measure.

In addition to the information given in this Appendix, the spreadsheet used for the calculations contains additional columns used to estimate the uncertainty of the results. The details of these estimates are not shown here, but are available upon request.

Documentation of assumptions and calculations, Part 1

							Unit costs				Number of injured affected			
No	Measure	Status	Unit	Target group	Current use	Levels of use 2002-2011	Investment	Operating	Exposure	Risk of injury	Killed	Serious injury	Slight injury	All injured
	GENERAL PURPOSE MEASURES													
8	Road safety audits	New	Km road	All injuries	0	1400	500000		3000	0,279	28	165	644	837
		New	Km road	All injuries	Max pot 14000	2800	500000		5600	0,279	52	308	1202	1562
		New	Km road	All injuries	Max km 14000	14000	500000		23670	0,279	221	1303	5080	6604
9	Motor vehicle taxes	Used	Kr/veh km	All injuries	10% traffic red	0,14		0,13	68700		554	3968	17199	21721
14	Automatic accident warning system	New	New cars	Injuries in cars		200000	2500		5,5		250	2000	6230	8480
		New	New cars	Injuries in cars		1850000	2500		50		250	2000	6230	8480
		New	New cars	Injuries in cars	Max pot 95	3610000	2500		95		250	2000	6230	8480
	ROAD DESIGN													
101	Grade separated pedestrian crossing	Used	Number	Pedestrians	3500	700	2000000	10000	1500	0,050	1	16	58	75
		Used	Number	Pedestrians	Max pot 5250	1225	2000000	10000	2400	0,050	2	26	92	120
		Used	Number	Pedestrians	Max ant 1750	1750	2000000	10000	3100	0,050	3	33	119	155
102	Motorway class A (New)	Used	Km road	All injuries	1480	750	40000000	350000	3340	0,156	22	99	400	521
	(ÅADT >8000, 70-110 km/h)	Used	Km road	All injuries	Max pot 3200	1235	40000000	350000	4920	0,156	33	146	589	768
		Used	Km road	All injuries	Max km 1720	1720	40000000	350000	6500	0,156	43	193	778	1014
102	Motorway class A (upgrading)	Used	Km road	All injuries	370	90	20000000	175000	350	0,267	5	18	70	93
		Used	Km road	All injuries	Max pot 370	185	20000000	175000	650	0,267	10	34	130	174
		Used	Km road	All injuries	Max km 370	370	20000000	175000	1130	0,267	17	59	226	302
103	Bypasses	Used	Km road	All injuries	1385	150	20000000	150000	250	0,523	3	23	104	130
		Used	Km road	All injuries	Max pot 2260	510	20000000	150000	625	0,523	7	57	263	327
	(ca 5 km per road)	Used	Km road	All injuries	Max km 875	875	20000000	150000	850	0,523	9	77	359	445
106	Roundabouts T-crossings	Used	Number	Junction injuries	1000	400	1000000		1300	0,070	2	15	74	91
	(all junctions, AADT > 5000)	Used	Number	Junction injuries	Pot 1200	800	1000000		2200	0,070	3	26	126	154
		Used	Number	Junction injuries	No 1600	1200	1000000		2800	0,070	3	33	160	196

No	Measure	Status	Unit	Target group	Current use	Levels of use 2002-2011	Unit costs		Exposure	Risk of injury	Number of injured affected			
							Investment	Operating			Killed	Serious injured	Slight injury	All injured
106	Roundabouts X-crossings	Used	Number	Junction injuries	500	400	2000000		1500	0,100	2	23	124	150
	(all junctions, AADT > 5000)	Used	Number	Junction injuries	Pot 1300	600	2000000		2050	0,100	3	32	170	205
		Used	Number	Junction injuries	No 800	800	2000000		2400	0,100	3	38	199	240
108	Staggered junctions	Used	Number	Junction injuries	50	25	4500000		70	0,150	0	2	9	11
		Used	Number	Junction injuries	Max pot 100	37	4500000		95	0,150	0	2	12	14
		Used	Number	Junction injuries	Max ant 50	50	4500000		115	0,150	0	3	14	17
109	Interchanges	Used	Number	Junction injuries	800	10	20000000	50000	100	0,150	0	1	14	15
		Used	Number	Junction injuries	Max pot 825	17	20000000	50000	155	0,150	0	2	21	23
		Used	Number	Junction injuries	Max ant 25	25	20000000	50000	200	0,150	0	2	27	30
112	Roadside safety treatment	Used	Km road	Off the road	100	1000	1000000		2000	0,084	6	41	121	168
	(all rural roads, AADT >2000)	Used	Km road	Off the road	Pot 4000	2500	1000000		4200	0,084	13	86	254	353
		Used	Km road	Off the road	Max km 4000	4000	1000000		5900	0,084	18	121	357	496
114	Widening road to 13 m	Used	Km road	All injuries	100	110	10000000	50000	380	0,225	4	20	62	86
	(AADT > 8000, 90-110 km/h)	Used	Km road	All injuries	Max pot 280	195	10000000	50000	665	0,225	7	35	108	150
		Used	Km road	All injuries	Max km 280	280	10000000	50000	950	0,225	10	49	155	214
114	General rehabilitation of roads	Used	Km road	Distance in car	1400	70	3500000		70	0,299	1	4	16	21
	(AADT >2000, 70-110 km/h)	Used	Km road	Distance in car	Pot 2870	735	3500000		670	0,299	6	40	154	200
		Used	Km road	Distance in car	Max 1400	1400	3500000		1200	0,299	10	71	278	359
115	New guard rails on embankments	Used	Km road	Off the road	4600	1000	275000	6000	400	0,085	1	8	25	34
		Used	Km road	Off the road	Pot 22900	9650	275000	6000	3300	0,085	11	68	201	280
		Used	Km road	Off the road	No 18300	18300	275000	6000	6000	0,085	20	124	366	510

							Unit costs				Number of injured affected			
No	Measure	Status	Unit	Target group	Current use	Levels of use 2002-2011	Investments	Operating	Exposure	Injury risk	Killed	Serious injury	Slight injury	All injured
115	Median guard rails (wire) on wide roads	Used	Km road	Head on crash	30	150	1000000	25000	600	0,038	3	7	13	23
		Used	Km road	Head on crash	3530	1825	1000000	25000	5000	0,038	25	55	108	188
		Used	Km road	Head on crash	Max 3500	3500	1000000	25000	8000	0,038	40	88	172	300
116	Game fences (animal accidents)	Used	Km road	Elk accident	2000	100	150000	2700	50	0,227	0	1	10	11
	(rural roads, AADT >2000)	Used	Km road	Elk accident	4000	550	150000	2700	230	0,227	1	6	45	52
		Used	Km road	Elk accident	Max 2000	2000	150000	2700	660	0,227	3	18	129	150
117	Curve treatments	Used	Number	Curve accident	4000	2000	25000		1000	0,058	2	12	45	58
		Used	Number	Curve accident	pot 4000	3000	25000		1300	0,057	2	15	57	74
		Used	Number	Curve accident	ant 8000	4000	25000		1450	0,055	2	16	62	80
118	New road lighting	Used	Km road	Accs at night	46500	5000	400000	20000	6000	0,125	23	157	568	748
	(all unlit roads)	Used	Km road	Accs at night	pot 136500	10000	400000	20000	10000	0,125	38	258	937	1233
		Used	Km road	Accs at night	No 90000	90000	400000	20000	30000	0,125	116	783	2840	3739
	ROAD MAINTENANCE													
206	Improving winter maintenance of roads	Used	Km road	Accs in winter		1480		6000	10350		11	67	427	505
	(AADT >10000)	Used	Km road	Accs in winter	pot 136500	91120		5500	42170		144	782	2904	3830
		Used	Km road	Accs in winter	km 136500	136500		5500	64730		216	1403	6431	8050
	TRAFFIC CONTROL													
301	30 km/h streets (Vision Zero)	Used	Km road	All injuries	650	6500	1000000	80000	1190	0,442	6	80	440	526
	(about 25 % of urban roads)	Used	Km road	All injuries	pot 13600	9550	1000000	80000	1745	0,442	9	118	645	772
		Used	Km road	All injuries	ant 12600	12600	1000000	80000	2300	0,442	12	155	850	1017
302	30 km/h streets (Vision Zero)	New	Km road	All injuries	0	1500	8000000	500000	4000	0,464	24	292	1540	1856
		New	Km road	All injuries	pot 9000	4500	8000000	500000	10000	0,464	60	730	3850	4640
		New	Km road	All injuries	ant 9000	9000	8000000	500000	16400	0,464	98	1197	6315	7610
304	Walking speed streets (woonerfs)	Used	Km road	All injuries	1000	750	750000	50000	45	0,218	0	2	8	10
	(about 20 % of urban roads)	Used	Km road	All injuries	pot 9000	4375	750000	50000	250	0,218	1	8	46	55
		Used	Km road	All injuries	km 8000	8000	750000	50000	435	0,218	1	15	79	95

No	Measure	Status	Unit	Target group	Current use	Levels of use 2002-2011	Unit costs: Investment	Unit costs: Operating	Exposure	Risk of injury	Number of injured affected: Killed	Serious injury	Slight injury	All injured
308	Four way stop at urban junctions	New	Junctions	Junction injuries	0	90	25000		165	0,150	0	4	21	25
		New	Junctions	Junction injuries	Max pot 900	495	25000		750	0,150	2	18	93	112
		New	Junctions	Junction injuries	Max ant 900	900	25000		1165	0,150	2	27	145	175
309	Traffic signal control at junctions	Used	Number	Junction injuries	1600	5	800000	50000	20	0,070	0	0	1	1
	(T- junctions)	Used	Number	Junction injuries	Max pot 10	8	800000	50000	32	0,070	0	0	2	2
		Used	Number	Junction injuries	Max ant 410	10	800000	50000	40	0,070	0	0	2	3
309	Traffic signal control at junctions	Used	Number	Junction injuries	900	5	1000000	75000	25	0,100	0	0	2	3
	(X-junctions)	Used	Number	Junction injuries	Max pot 10	8	1000000	75000	40	0,100	0	1	3	4
		Used	Number	Junction injuries	Max ant 410	10	1000000	75000	50	0,100	0	1	4	5
310	Traffic signal control at pedestrian crossings	Used	Number	Pedestrians	200	25	200000	30000	100	0,050	0	1	4	5
		Used	Number	Pedestrians	Max pot 50	38	200000	30000	145	0,050	0	2	5	7
		Used	Number	Pedestrians	Max ant 200	50	200000	30000	180	0,050	0	2	7	9
311	Seasonal speed limits	Used	Km road	All injuries	2240	2240	10000		1500	0,068	5	23	74	102
	(110 km/h → 90, 90 km/h → 70)	Used	Km road	All injuries	pot 27190	4480	10000		2700	0,068	9	42	133	184
		Used	Km road	All injuries	ant 27190	27190	10000		13165	0,068	44	206	645	895
311	Optimal speed limits	New	Km road	All injuries	Mv 110	1050	0		7400		21	112	547	680
		New	Km road	All injuries	Mv 90	290	3000		2000		5	33	261	299
		New	Km road	All injuries	Mv 70	140	3000		950		3	36	349	388
		New	Km road	All injuries	Mtl 110	100	3000		520		9	27	83	120
		New	Km road	All injuries	Mtl 90	200	3000		450		7	23	88	118
		New	Km road	All injuries	Mtl 70	70	3000		160		1	9	55	65
		New	Km road	All injuries	Lv 110	4180	6000		2555		34	130	329	493
		New	Km road	All injuries	Lv 90	26410	6000		18215		198	956	3073	4227
		New	Km road	All injuries	Lv 70	58680	0		9920		111	786	3059	3956
		New	Km road	All injuries	Bygt 70	1700	12000		1830		20	148	661	829
		New	Km road	All injuries	Bygt 50	28680	0		19810		119	1447	7635	9202
		New	Km road	All injuries	Bygt 30	15000	0		920		2	31	168	201
		New	Km road	All injuries	Alle veger	136500			64730		530	3738	16308	20578

No	Measure	Status	Unity	Target group	Current use	Levels of use 2002-2011	Unit costs		Exposure	Risk of injury	Number of injured affected			
							Investment	Operating			Killed	Serious injury	Slight injury	All injured
311	Vision Zero speed limits	New	Km road	All injuries	Mv 110	1050	0		7400		21	112	547	680
		New	Km road	All injuries	Mv 90	290	0		2000		5	33	261	299
		New	Km road	All injuries	Mv 70	140	0		950		3	36	349	388
		New	Km road	All injuries	Mtl 110	100	3000		520		9	27	83	120
		New	Km road	All injuries	Mtl 90	200	3000		450		7	23	88	118
		New	Km road	All injuries	Mtl 70	70	0		160		1	9	55	65
		New	Km road	All injuries	Lv 110	4180	6000		2555		34	130	329	493
		New	Km road	All injuries	Lv 90	26410	6000		18215		198	956	3073	4227
		New	Km road	All injuries	Lv 70	58680	0		9920		111	786	3059	3956
		New	Km road	All injuries	Bygt 70	1700	6000		1830		20	148	661	829
		New	Km road	All injuries	Bygt 50	28680	6000		19810		119	1447	7635	9202
		New	Km road	All injuries	Bygt 30	15000	6000		920		2	31	168	201
	(10 times present control)	New	Km road	All injuries	All	136500			64730		530	3738	16308	20578
	(except MTL)	New	Km road	All injuries	All	136130			63600		513	3679	16082	20275
	(except MTL and reconstructed roads)	New	Km road	All injuries	All	103030			36465		362	2224	8666	11253
314	Upgrading pedestrian crossings	Used	Number	Pedestrians	1000	3200	100000	1000	1500	0,050	1	17	57	75
		Used	Number	Pedestrians	pot 55000	13750	100000	1000	5000	0,050	4	57	189	250
		Used	Number	Pedestrians	ant 54000	54000	100000	1000	13460	0,050	12	154	507	673
314	Cycle lanes, and stop line in junctions	Used	Km road	Cyclists	2870	2700	700000		4000	0,077	6	62	242	310
		Used	Km road	Cyclists	pot 28680	14250	700000		14000	0,077	21	217	842	1080
		Used	Km road	Cyclists	ant 25810	25800	700000		19810	0,077	30	310	1200	1540
320	Feedback signs	Used	Km road	All injuries	0	90	200000	20000	450	0,232	5	24	76	104
	(AADT > 5000)	Used	Km road	All injuries	pot 4490	180	200000	20000	750	0,232	8	39	127	174
		Used	Km road	All injuries	Max 4490	4490	200000	20000	7540	0,232	82	396	1272	1749

No	Measure	Status	Unit	Target group	Current use	Levels of use 2002-2011	Unit costs		Exposure	Injury risk	Number of injured affected			
							Investments	Operating			Killed	Serious injury	Slight injury	All injured
	VEHICLE DESIGN													
404	High mounted stop lamps	Used	% use	Behind	50	600000	150		16		12	327	3223	3562
		Used	% use	Behind		1940000	150		45		12	327	3223	3562
		Used	% use	Behind		1940000	150		45		12	327	3223	3562
407	Self levelling head lamp requirement	New	New car	Accidents in dark	0	200000	1000		5,5		150	1140	4565	5855
		New	New car	Accidents in dark		1850000	1000		50		150	1140	4565	5855
		New	New car	Accidents in dark		3610000	1000		95		150	1140	4565	5855
408	Pedestrian reflective devices (law)	New	% use	Pedestrians	30	26550000	5		30		34	167	397	598
		New	% use	Pedestrians		39825000	5		45		34	167	397	598
		New	% use	Pedestrians	Max use 90	53100000	5		60		34	167	397	598
408	Reflective devices on bicycles (law)	New	% use	Cyclists	63	1050000	230		12		13	173	576	762
		New	% use	Cyclists		1925000	230		22		13	173	576	762
		New	% use	Cyclists	Max use 90	2363000	230		27		13	173	576	762
410	Bicycle helmets, campaign and law	New	% use	Cyclists	15	3000000	300		45		60	706	2301	3067
		New	% use	Cyclists		4000000	300		60		60	706	2301	3067
		New	% use	Cyclists	Max use 90	5000000	300		75		60	706	2301	3067
412	Seal belt reminder in light cars	Used	New cars	Drivers	35	140000	500		3,85		77	385	1665	2050
		Used	New cars	Drivers		1295000	500		35		77	385	1665	2050
		Used	New cars	Drivers	Max use 95	2350000	500		61,8		77	385	1665	2050
412	Ignition interlock device for seat belts	New	New cars	Drivers	0	200000	200		5,5		77	385	1665	2050
		New	New cars	Drivers		1850000	200		50		77	385	1665	2050
		New	New cars	Drivers	Max use 95	3610000	200		95		77	385	1665	2050
414	Air bags	Used	% use	Car, front	44	600000	5000		16		90	355	900	1345
		Used	% use	Car, front		1940000	5000		51		90	355	900	1345
		Used	% use	Car, front	Max use 95	1940000	5000		51		90	355	900	1345
418	Intelligent cruise control (headway control)	New	New cars	Behind	0	220000	6000		5,5		6	165	2209	2380
		New	New cars	Behind		2075000	6000		50		6	165	2209	2380
		New	New cars	Behind	Max 95	3940000	6000		95		6	165	2209	2380

							Unit costs				Number of injured affected			
No	Measure	Status	Unit	Target group	Current uses	Levels of use 2002-2011	Investments	Operating	Exposure	Injury risk	Killed	Serious injury	Slight injury	All injured
420	Intelligent speed adaptation for cars	New	Km road	All injuries	Mv 110	1050	0		7400		21	112	547	680
		New	Km road	All injuries	Mv 90	290	0		2000		5	33	261	299
		New	Km road	All injuries	Mv 70	140	0		950		3	36	349	388
		New	Km road	All injuries	Mtl 110	100	0		520		9	27	83	120
		New	Km road	All injuries	Mtl 90	200	0		450		7	23	88	118
		New	Km road	All injuries	Mtl 70	70	0		160		1	9	55	65
		New	Km road	All injuries	Lv 110	4180	0		2555		34	130	329	493
		New	Km road	All injuries	Lv 90	26410	0		18215		198	956	3073	4227
		New	Km road	All injuries	Lv 70	58680	0		9920		111	786	3059	3956
		New	Km road	All injuries	Bygt 70	1700	0		1830		20	148	661	829
		New	Km road	All injuries	Bygt 50	28680	0		19810		119	1447	7635	9202
		New	Km road	All injuries	Bygt 30	15000	0		920		2	31	168	201
		New	Km road	All injuries	All road	136500	0		64730		530	3738	16308	20578
		New	All cars	All injuries	New cars from 2011	220000	10000	500	5,5		530	3738	16308	20578
		New	All cars	All injuries	New cars from 2002	2075000	10000	500	50		530	3738	16308	20578
		New	All cars	All injuries	All cars (95%)	3940000	14000	500	95		530	3738	16308	20578
422	Improving under guard rails on trucks	Used	All cars	Accs inv trucks	0	20000	15000		2,5		143	505	2432	3080
		Used	All cars	Accs inv trucks		180000	15000		22,5		143	505	2432	3080
		Used	All cars	Accs inv trucks	Max use 95	304000	15000		38		143	505	2432	3080
423	Front impact protections on truck	New	New cars	Accs inv trucks	0	20000	15000		3,75		143	505	2432	3080
		New	New cars	Accs inv trucks		180000	15000		33,75		143	505	2432	3080
		New	New cars	Accs inv trucks	Max use 95	304000	15000		57		143	505	2432	3080
429	Crash data recorder	New	New cars	All injuries	0	220000	5000		5,5		530	3700	16750	20980
		New	New cars	All injuries		2075000	5000		50		530	3700	16750	20980
		New	New cars	All injuries	Max use 95	3940000	5000		95		530	3700	16750	20980

No	Measure	Status	Unit	Target group	Current use	Levels of use 2002-2011	Unit costs		Exposure	Injury risk	Number of injured affected			
							Investments	Operating			Killed	Serious injured	Slight injury	All injured
430	New safety standards for front and bumpers on light cars	New	New cars	Pedestrians		200000	200		5,5		49	308	748	1105
		New	New cars	Pedestrians		1850000	200		50		49	308	748	1105
		New	New cars	Pedestrians		3610000	200		95		49	308	748	1105
503	Roadside motor vehicle inspections	Used	% controlled	Accs inv trucks		65000	0	360			143	505	2432	3080
		Used	% controlled	Accs inv trucks		357500	0	360			143	505	2432	3080
		Used	% controlled	Accs inv trucks		650000	0	360			143	505	2432	3080
	TRAINING AND EDUCATION													
604	Reforming basic driver training	New	Number	New drivers	Max ant	80000		6625			60	380	1960	2400
605	Training of problem drivers	New	Number	All injuries	ant 400000	400000		2000			80	465	1675	2220
608	Training of bus and truck drivers	New	Number	Accs inv trucks		17000		5000	5,5		59	271	944	1274
		New	Number	Accs inv trucks		385000		5000	50		59	271	944	1274
		New	Number	Accs inv trucks	ant 770000	770000		5000	95		59	271	944	1274
702	Training of school age children (7-12 year)	Used	Number	Children (7-12)	ant 725000	725000		100			3	40	106	149
	ENFORCEMENT AND SANCTIONS													
801	Stationary speed enforcement	Used	Factor 2	All injuries		136500		1465,2	66000		530	3738	16308	20576
		Used	Factor 3	All injuries		136500		2930,4	66000		530	3738	16308	20576
		Used	Factor 6	All injuries		136500		7326,0	66000		530	3738	16308	20576
		Used	Factor 10	All injuries	Max pot 10	136500		13186,8	66000		530	3738	16308	20576
804	Random breath testing	Used	Factor 2	All injuries		136500		1465,2			530	3738	16308	20576
		Used	Factor 3	All injuries		136500		2930,4			530	3738	16308	20576
		Used	Factor 6	All injuries		136500		7326,0			530	3738	16308	20576
		Used	Factor 10	All injuries	Max pot 10	136500		13186,8			530	3738	16308	20576

							Unit costs				Number of injured affected			
No	Measure	Status	Unit	Target group	Current use	Levels of use 2002-2011	Investments	Operating	Exposure	Injury risk	Killed	Serious injured	Slight injury	All injured
805	Seat belt enforcement	Used	Factor 2	Injuries in car		136500		366,3			325	2350	12300	14975
		Used	Factor 3	Injuries in car		136500		732,6			325	2350	12300	14975
		Used	Factor 6	Injuries in car		136500		1831,5			325	2350	12300	14975
		Used	Factor 10	Injuries in car	Max pot 10	136500		3296,7			325	2350	12300	14975
806	Automatic speed enforcement	Used	Km road	All injuries	0	1185	100000	100000	2500	0,291	27	155	546	728
	(increased enforcement)	Used	Km road	All injuries	inc 11850	6515	100000	100000	10800	0,291	119	669	2355	3143
		Used	Km road	All injuries	km 11850	11850	100000	100000	19000	0,291	209	1177	4143	5529
807	Automatic red light enforcement	Used	Junctions	Accidents in junctions with traffic signals		125	100000	100000			2	36	247	285
		Used	Junctions	Accidents in junctions with traffic signals		250	100000	100000			3	54	370	427
		Used	Junctions	Accidents in junctions with traffic signals		2500	100000	100000			15	270	1540	1825
810	Demerit point system	New	Number	All injuries	5465000	5465000	5	10	7,5	2,000	80	580	2350	3010
812	Ignition interlock system for alcohol	New	Number	All injuries	ant 5000	5000	5000	15000	35		49	335	698	1082
813	Vehicle impoundment to prevent unlicensed driving	New	Number	All injuries	ant 2000	22300	5000	5000	5 %		25	190	800	1015

Documentation of assumptions and calculations, Part 2

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK. Negative numbers = negative benefit					
Nr	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
	GENERAL PURPOSE MEASURES													
8	Road safety audits	0,030	0,020	0,010	1	3	6	11	432,3					432,3
		0,030	0,020	0,010	2	6	12	20	807,0					807,0
		0,030	0,020	0,010	7	26	51	83	3411,2					3411,2
9	Motor vehicle taxes	0,030	0,040	0,050	17	159	860	1035	1531,3			4156,4	-8484,5	-2796,8
14	Automatic accident warning system	0,080	0,010	0,000	1	1	0	2	280,0					280,0
		0,080	0,010	0,000	10	10	0	20	2545,1					2545,1
		0,080	0,010	0,000	19	19	0	38	4835,6					4835,6
	ROAD DESIGN													
101	Grade separated pedestrian crossings	0,800	0,800	0,800	1	13	46	60	1391,5	1407,0				2798,5
		0,800	0,800	0,800	2	21	74	96	2242,4	2251,3				4493,7
		0,800	0,800	0,800	2	26	95	124	2883,7	2907,9				5791,5
102	Motorway class A	0,333	0,215	-0,071	7	21	-28	0	5721,5	11512,1	-1771,7	-2952,9	938,2	13447,2
	(ÅADT >8000, 70-110 km/h)	0,333	0,215	-0,071	11	31	-42	1	8505,2	16958,0	-2609,9	-4349,8	1387,8	19891,3
		0,333	0,215	-0,071	14	41	-55	1	11168,6	22403,9	-3448,0	-5746,7	1828,3	26206,2
102	Motorway class A (upgrading)	0,800	0,660	0,440	4	12	31	47	3585,5	482,1	-88,4	-176,8	190,1	3992,5
		0,800	0,660	0,440	8	22	57	88	6924,3	895,3	-164,2	-328,4	366,3	7693,3
		0,800	0,660	0,440	14	39	99	152	11915,3	1556,4	-285,4	-570,9	630,8	13246,1
103	Bypasses	0,000	0,150	0,280	0	3	29	33	805,1	3103,3	0,0	694,7		4603,0
	(ca 5 km per road)	0,000	0,150	0,280	0	9	74	82	2008,7	7758,2	0,0	1736,6		11503,5
		0,000	0,150	0,280	0	12	101	112	2723,0	10551,2	0,0	2361,8		15635,9
106	Roundabouts T-crossings	0,400	0,320	0,240	1	5	18	23	563,0					563,0
	(all junctions, AADT > 5000)	0,400	0,320	0,240	1	8	30	39	952,7					952,7
		0,400	0,320	0,240	1	10	38	50	1212,6					1212,6

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK Negative numbers = negative benefit					
No	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
106	Roundabouts X-crossings	0,600	0,450	0,340	1	11	42	54	1223,2	1330,5				2553,7
	(all junctions, AADT > 5000)	0,600	0,450	0,340	2	14	58	74	1671,8	1818,3				3490,1
		0,600	0,450	0,340	2	17	68	87	1957,2	2128,8				4086,0
108	Staggered junctions	0,250	0,250	0,250	0	0	2	3	47,8					47,8
		0,250	0,250	0,250	0	1	3	4	64,9					64,9
		0,250	0,250	0,250	0	1	4	4	78,5					78,5
109	Interchanges	0,200	0,200	0,200	0	0	3	3	34,4	719,0		-62,1		691,4
		0,200	0,200	0,200	0	0	4	5	53,3	1114,5		-96,2		1071,6
		0,200	0,200	0,200	0	0	5	6	68,8	1438,1		-124,2		1382,7
112	Roadside safety treatment	0,500	0,400	0,300	3	16	36	56	1957,2					1957,2
	(all rural roads, AADT >2000)	0,500	0,400	0,300	7	34	76	117	4142,4					4142,4
		0,500	0,400	0,300	9	48	107	165	5802,0					5802,0
114	Widening road to 13 m	0,500	0,300	0,150	2	6	9	17	858,5	207,0	-33,0	-47,2		985,3
	(AADT > 8000, 90-110 km/h)	0,500	0,300	0,150	4	11	16	30	1502,0	362,2	-57,8	-82,6		1723,9
		0,500	0,300	0,150	5	15	23	43	2123,1	517,5	-82,6	-117,9		2440,1
114	General rehabilitation of roads	0,070	0,070	0,070	0	0	1	1	39,0		34,8			73,7
	(AADT >2000, 70-110 km/h)	0,070	0,070	0,070	0	3	11	14	338,3		332,7			671,0
		0,070	0,070	0,070	1	5	19	25	593,8		595,9			1189,7
115	New guard rails on embankments (road sides)	0,500	0,400	0,300	1	3	8	11	368,6					368,6
		0,500	0,400	0,300	6	27	60	93	3339,6					3339,6
		0,500	0,400	0,300	10	50	110	169	6083,9					6083,9
115	Median guard rails (wire) on wide roads	0,500	0,300	0,150	2	2	2	6	436,7	0,0	0,0			436,7
		0,500	0,300	0,150	13	17	16	45	3561,6	0,0	0,0			3561,6
		0,500	0,300	0,150	20	26	26	72	5698,1	0,0	0,0			5698,1
116	Game fences (animal accidents)	0,250	0,250	0,250	0	0	3	3	51,4					51,4
		0,250	0,250	0,250	0	2	11	13	210,1					210,1
	(rural roads, AADT >2000)	0,250	0,250	0,250	1	5	32	38	623,7					623,7

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK Negative numbers = negative benefit					
No	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
117	Curve treatments	0,337	0,265	0,185	1	3	8	12	372,0	-227,1				145,0
		0,337	0,265	0,185	1	4	11	15	470,6	-295,2				175,4
		0,337	0,265	0,185	1	4	12	16	510,3	-329,2				181,0
118	New road lighting	0,600	0,400	0,250	14	63	142	219	7918,5					7918,5
	(all unlit roads)	0,600	0,400	0,250	23	103	234	360	13038,4					13038,4
		0,600	0,400	0,250	70	313	710	1093	39637,6					39637,6
	ROAD MAINTENANCE													
206	Improving winter maintenance of roads	0,050	0,050	0,050	1	3	21	25	36,3					36,3
	(AADT >10000)	0,050	0,050	0,050	7	39	145	192	397,7					397,7
		0,050	0,050	0,050	11	70	322	403	705,1					705,1
	TRAFFIC CONTROL													
301	30 km/h streets (Vision Zero)	0,650	0,545	0,408	4	44	180	227	4850,2	-15455,7	0,0	0,0	699,7	-9905,9
		0,650	0,545	0,408	6	64	263	333	7164,0	-22664,1	0,0	0,0	1042,6	-14457,5
		0,650	0,545	0,408	8	84	347	439	9435,9	-29872,4	0,0	0,0	1371,9	-19064,7
302	50/30 km/h streets (Vision Zero)	0,502	0,407	0,294	12	119	453	584	13320,2	-25728,6	-744,9	-993,2	4280,2	-9866,3
		0,502	0,407	0,294	30	297	1133	1461	33300,6	-64321,5	-1862,3	-2483,0	10878,8	-24487,4
		0,502	0,407	0,294	49	488	1859	2396	54572,3	-105487,3	-3054,1	-4072,1	17834,1	-40207,0
304	Walking speed streets (woonerfs)	0,802	0,704	0,556	0	1	5	6	116,4	-1266,3	-16,8	-27,9		-1194,7
	(about 20 % of urban roads)	0,802	0,704	0,556	0	6	26	32	640,4	-7035,2	-93,1	-155,2		-6643,0
		0,802	0,704	0,556	1	11	44	55	1151,1	-12241,2	-162,0	-270,0		-11522,1
308	Four way stop at urban junctions	0,600	0,500	0,400	0	2	8	11	219,6	-232,2				-12,6
		0,600	0,500	0,400	1	9	37	47	999,6	-1055,3				-55,7
		0,600	0,500	0,400	1	14	58	73	1554,0	-1639,2				-85,2
309	Traffic signal control at junctions	0,150	0,150	0,150	0	0	0	0	4,1	28,1		-1,2		31,0
	(T- junctions)	0,150	0,150	0,150	0	0	0	0	6,6	45,0		-2,0		49,6
		0,150	0,150	0,150	0	0	0	0	8,2	56,3		-2,5		62,0

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK. Negative numbers tall = negative benefit					
No	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
309	Traffic signal control at junctions	0,300	0,300	0,300	0	0	1	1	13,7	58,6		-1,6		70,7
	(X-junctions)	0,300	0,300	0,300	0	0	1	1	21,9	93,8		-2,5		113,2
		0,300	0,300	0,300	0	0	1	2	27,3	117,3		-3,1		141,5
310	Traffic signal control at pedestrian crossings	0,120	0,120	0,120	0	0	0	1	14,5					14,5
		0,120	0,120	0,120	0	0	1	1	21,0					21,0
		0,120	0,120	0,120	0	0	1	1	26,1					26,1
311	Seasonal speed limits	0,147	0,112	0,076	1	3	6	9	28,5	-24,5	15,0	30,0		48,9
	(110 km/h → 90, 90 km/h → 70)	0,151	0,115	0,078	1	5	10	17	53,2	-46,9	27,0	54,0		87,2
		0,155	0,119	0,081	7	24	52	83	267,9	-243,4	131,7	263,3		419,4
311	Optimal speed limits	0,000	0,000	0,000	0	0	0	0	0,0	0,0	0,0	0,0		0,0
		-0,134	-0,099	-0,065	-1	-3	-17	-21	-36,0	88,9	-14,0	-20,0		19,0
		0,094	0,071	0,048	0	3	17	20	26,0	-40,3	4,8	9,5		0,0
		0,518	0,421	0,306	5	11	25	41	146,3	-133,9	36,4	36,4		85,2
		0,518	0,421	0,306	4	10	27	40	121,6	-130,3	17,6	27,0		35,8
		0,094	0,071	0,048	0	1	3	3	6,3	-6,8	4,0	1,6		5,1
		0,480	0,388	0,279	16	50	92	159	579,2	-595,6	166,1	153,3		303,0
		0,497	0,403	0,291	98	385	894	1377	4117,0	-4997,1	637,5	1001,8		759,2
		0,469	0,378	0,271	52	297	830	1179	2884,7	-2882,7	248,0	297,6		547,7
		0,317	0,249	0,174	6	37	115	158	360,2	-377,1	0,0	36,6		19,7
		0,000	0,000	0,000	0	0	0	0	0,0	0,0	0,0	0,0		0,0
		0,000	0,000	0,000	0	0	0	0	0,0	0,0	0,0	0,0		0,0
					181	790	1985	2956	8205,3	-9074,8	1100,3	1543,8		1774,6

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK. Negative numbers tall = negative benefit					
No	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
311	Vision Zero speed limits	0,292	0,228	0,158	6	26	87	118	276,9	-849,3	185,0	318,2		-69,2
		0,000	0,000	0,000	0	0	0	0	0,0	0,0	0,0	4,0		4,0
		0,469	0,378	0,271	1	14	95	110	138,5	-276,1	23,8	28,5		-85,3
		0,824	0,728	0,580	7	20	48	75	245,1	-363,3	49,4	70,2		1,4
		0,717	0,612	0,468	5	14	41	60	174,0	-242,0	27,0	45,0		3,9
		0,469	0,378	0,271	0	3	15	19	33,2	-46,5	4,0	4,8		-4,5
		0,810	0,712	0,564	28	93	186	306	1034,4	-1723,1	230,0	332,2		-126,6
		0,705	0,600	0,457	140	574	1405	2118	6058,4	-9518,4	1092,9	1639,4		-727,7
		0,469	0,378	0,271	52	297	830	1179	2884,7	-2882,7	248,0	297,6		547,7
		0,317	0,249	0,174	6	37	115	158	360,2	-377,1	0,0	54,9		38,0
		0,502	0,407	0,294	60	589	2248	2897	5317,7	-10263,5	-1485,8	-1386,7		-7818,2
		0,650	0,545	0,408	1	17	69	87	148,0	-962,5	-92,0	-96,6		-1003,1
					307	1682	5136	7126	16671,1	-27504,3	282,3	1311,4		-9239,6
					294	1645	5032	6972	16218,8	-26852,5	201,9	1191,4	0,0	-9240,4
					216	1036	2756	4009	10971,2	-18175,4	-371,9	196,0	0	-7380,0
314	Upgrading pedestrian crossings	0,600	0,450	0,300	1	8	17	26	803,7					803,7
		0,600	0,450	0,300	3	26	57	85	2696,5					2696,5
		0,600	0,450	0,300	7	69	152	229	7292,3					7292,3
314	Cycle lanes, and stop line in junctions	0,200	0,200	0,200	1	12	48	62	518,4					518,4
		0,200	0,200	0,200	4	43	168	216	1812,8					1812,8
		0,200	0,200	0,200	6	62	240	308	2588,7					2588,7
320	Feedback signs	0,082	0,062	0,042	0	1	3	5	139,3	-124,2	15,8	27,6		58,6
	(AADT > 5000)	0,082	0,062	0,042	1	2	5	8	232,2	-206,9	26,3	46,0		97,6
		0,082	0,062	0,042	7	24	53	84	2334,5	-2080,5	264,5	462,8		981,4

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK. Negative numbers tall = negative benefit					
No	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
	VEHICLE DESIGN													
404	High mounted stop lamps	0,125	0,125	0,125	0	7	64	71	816,0					816,0
		0,125	0,125	0,125	1	18	181	200	2294,9					2294,9
		0,125	0,125	0,125	1	18	181	200	2294,9					2294,9
407	Self levelling head lamp requirement	0,040	0,040	0,040	0	3	10	13	290,1					290,1
		0,040	0,040	0,040	3	23	91	117	2637,0					2637,0
		0,040	0,040	0,040	6	43	173	222	5010,3					5010,3
408	Pedestrian reflective devices (law)	0,450	0,330	0,250	5	17	30	51	831,9					831,9
		0,450	0,330	0,250	7	25	45	76	1247,8					1247,8
		0,450	0,330	0,250	9	33	60	102	1663,8					1663,8
408	Reflective devices on bicycles (law)	0,200	0,200	0,200	0	4	14	18	163,6					163,6
		0,200	0,200	0,200	1	8	25	34	300,0					300,0
		0,200	0,200	0,200	1	9	31	41	368,2					368,2
410	Bicycle helmets, campaign and law	0,400	0,200	0,200	11	64	207	281	2897,3					2897,3
		0,400	0,200	0,200	14	85	276	375	3863,1					3863,1
		0,400	0,200	0,200	18	106	345	469	4828,8					4828,8
412	Seal belt reminder in light cars	0,500	0,450	0,250	1	7	16	24	829,7					829,7
		0,500	0,450	0,250	13	61	146	220	7543,2					7543,2
		0,500	0,450	0,250	24	107	257	388	13319,1					13319,1
412	Ignition interlock device for seat belts	0,500	0,450	0,250	2	10	23	35	1185,4					1185,4
		0,500	0,450	0,250	19	87	208	314	10776,0					10776,0
		0,500	0,450	0,250	37	165	395	597	20474,3					20474,3
414	Air bags	0,200	0,150	0,100	3	9	14	26	1204,7					1204,7
		0,200	0,150	0,100	9	27	46	82	3839,9					3839,9
		0,200	0,150	0,100	9	27	46	82	3839,9					3839,9
418	Intelligent cruise control (headway control)	0,500	0,500	0,500	0	5	61	65	635,9					635,9
		0,500	0,500	0,500	2	41	552	595	5781,1					5781,1
		0,500	0,500	0,500	3	78	1049	1131	10984,2					10984,2

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK. Negative numbers tall = negative benefit					
No	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
420	Intelligent speed adaptation for cars	0,149	0,114	0,077	3	13	42	58	1686,6	-1139,4	918,7	459,4		1925,2
		0,427	0,341	0,243	2	11	63	77	1495,8	-1373,4	744,9	744,9		1612,2
		0,554	0,455	0,332	2	16	116	134	2028,1	-585,2	589,7	412,8		2445,4
		0,140	0,107	0,073	1	3	6	10	463,0	-96,4	64,6	32,3		463,4
		0,414	0,330	0,234	3	8	21	31	1164,9	-333,4	167,6	139,7		1138,8
		0,554	0,455	0,332	1	4	18	23	484,2	-98,6	99,3	69,5		554,5
		0,126	0,096	0,065	4	12	21	38	1773,5	-554,9	317,2	158,6		1694,4
		0,403	0,321	0,227	80	307	699	1086	40025,2	-14817,9	6784,2	4522,8		36514,3
		0,554	0,455	0,332	62	357	1017	1436	42031,7	-6110,2	6157,8	4310,5		46389,8
		0,154	0,118	0,080	3	17	53	73	2078,6	-1723,0	0,0	-227,2		128,4
		0,245	0,190	0,131	29	276	1003	1308	30209,3	-25868,4	-7378,2	-1229,7		-4267,0
		0,681	0,576	0,436	1	18	73	92	1901,1	-675,8	-114,2	-571,1		540,0
		0,360	0,279	0,192	191	1042	3133	4366	125342,1	-53376,5	8351,6	8822,4		89139,6
		0,360	0,279	0,192	11	57	172	240	6893,8	-2935,7	459,3	485,2		4902,7
		0,360	0,279	0,192	95	521	1566	2183	62671,1	-26688,2	4175,8	4411,2		44569,8
		0,360	0,279	0,192	181	990	2976	4148	119075,0	-50707,6	7934,0	8381,3		84682,6
422	Improving under run guard rails on truck	0,120	0,060	0,000	0	1	0	1	131,5		-72,9			58,7
		0,120	0,060	0,000	4	7	0	11	1183,9		-655,8			528,1
		0,120	0,060	0,000	7	12	0	18	1999,5		-1107,6			891,9
423	Front impact protections on truck	0,200	0,150	0,100	1	3	9	13	440,0		-72,9			367,2
		0,200	0,150	0,100	10	26	82	117	3960,3		-655,8			3304,5
		0,200	0,150	0,100	16	43	139	198	6688,5		-1107,6			5580,9
429	Crash data recorder	0,070	0,070	0,070	2	14	64	81	1709,0					1709,0
		0,070	0,070	0,070	19	130	586	734	15536,1					15536,1
		0,070	0,070	0,070	35	246	1114	1395	29518,5					29518,5

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK. Negative numbers tall = negative benefit					
No	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
430	New safety standards for front and bumpers on light cars	0,070	0,210	-0,090	0	4	-4	0	284,4					284,4
		0,070	0,210	-0,090	2	32	-34	0	2585,9					2585,9
		0,070	0,210	-0,090	3	61	-64	1	4913,1					4913,1
503	Roadside motor vehicle inspections	0,014	0,014	0,014	2	7	34	43	84,7	-5,2				79,6
		0,045	0,045	0,045	6	23	109	139	272,3	-28,4				243,9
		0,068	0,068	0,068	10	34	165	209	411,5	-51,7				359,8
	TRAINING AND EDUCATION													
604	Reforming basic driver training	0,100	0,100	0,100	6	38	196	240	755,7					755,7
605	Training of problem drivers	0,080	0,070	0,060	6	33	101	139	329,5					329,5
608	Training of bus and truck drivers	0,200	0,200	0,200	1	3	10	14	60,7					60,7
		0,200	0,200	0,200	6	27	94	127	552,1					552,1
		0,200	0,200	0,200	11	51	179	242	1049,0					1049,0
702	Training of school age children (7-12 year)	0,150	0,150	0,150	0	6	16	22	49,4					49,4
	ENFORCEMENT AND SANCTIONS													
801	Stationary speed enforcement	0,080	0,060	0,040	42	224	652	919	2231,7		198,0	462,0		2891,7
		0,120	0,080	0,060	64	299	978	1341	3115,8		264,0	660,0		4039,8
		0,200	0,150	0,100	106	561	1631	2298	5579,2		264,0	726,0		6569,2
		0,250	0,187	0,125	133	699	2039	2870	6962,4		264,0	726,0		7952,4
804	Random breath testing I	0,016	0,013	0,006	8	49	98	155	457,8					457,8
	(increased testing)	0,024	0,019	0,010	13	71	163	247	680,9					680,9
		0,040	0,032	0,016	21	120	261	402	1138,7					1138,7
		0,050	0,040	0,020	27	150	326	502	1423,4					1423,4
805	Seat belt enforcement	0,022	0,019	0,006	7	45	74	126	405,6					405,6
	(increased enforcement)	0,034	0,029	0,009	11	68	111	190	620,4					620,4
		0,056	0,048	0,014	18	113	172	303	1021,6					1021,6
		0,070	0,060	0,018	23	141	221	385	1279,2					1279,2
806	Automatic speed enforcement	0,302	0,237	0,165	8	37	90	135	3299,9		438,5	657,7		4396,0
	(increased enforcement)	0,239	0,185	0,128	28	124	300	453	11241,7		1704,7	2651,7		15598,1
		0,168	0,129	0,088	35	152	364	551	13798,5		2665,8	4331,9		20796,2

		Effect (proportion)			Reduction of number of injured				Calculated benefit in mill SEK. Negative numbers tall = negative benefit					
No	Measure	Killed	Seriously injured	Slightly injured	Killed	Seriously injured	Slightly injured	All injured	Accidents	Time	Vehicle	Environ-ment	Traffic	Sum benefit
807	Automatic red light enforcement	0,200	0,150	0,100	0	5	25	31	421,7					421,7
		0,200	0,150	0,100	1	8	37	46	632,4					632,4
		0,200	0,150	0,100	3	41	154	198	3064,2					3064,2
810	Demerit point system	0,072	0,060	0,048	6	35	113	153	338,7					338,7
812	Ignition interlock system for alcohol	0,250	0,250	0,250	4	29	61	95	511,0					511,0
813	Vehicle impoundment to prevent unlicensed driving	0,300	0,300	0,300	8	57	240	305	1054,7			317,4		1372,1

Documentation of assumptions and calculations, Part 3

		Total cost mill SEK					Cost-
No	Measure	Investment	Operating	Tax	Total costs	B/C-ratio	effectiveness
	GENERAL PURPOSE MEASURES						
8	Road safety audits	700,0		371,0	1071,0	0,40	0,048
		1400,0		742,0	2142,0	0,38	0,045
		7000,0		3710,0	10710,0	0,32	0,038
9	Motor vehicle taxes		8931,0	0,0	8931,0	-0,31	0,020
14	Automatic accident warning system	500,0		0,0	500,0	0,56	0,055
		4625,0		0,0	4625,0	0,55	0,054
		9025,0		0,0	9025,0	0,54	0,052
	ROAD DESIGN						
101	Grade separated pedestrian crossings	1400,0	86,9	297,4	1784,3	1,57	0,097
		2450,0	152,1	520,4	3122,5	1,44	0,090
		3500,0	217,3	743,5	4460,7	1,30	0,080
102	Motorway class A	30000,0	6630,8	7326,2	43956,9	0,31	0,016
	(ÅADT >8000, 70-110 km/h)	49400,0	10918,6	12063,7	72382,4	0,27	0,015
		68800,0	15206,5	16801,3	100807,8	0,26	0,014
102	Motorway class A (upgrading)	1800,0	397,8	1164,9	3362,7	1,19	0,119
		3700,0	817,8	2394,4	6912,2	1,11	0,111
		7400,0	1635,6	4788,9	13824,4	0,96	0,096
103	Bypasses	3000,0	568,4	1891,2	5459,6	0,84	0,016
	(ca 5 km per road)	10200,0	1932,4	6430,2	18562,6	0,62	0,012
		17500,0	3315,4	11032,1	31847,5	0,49	0,009
106	Roundabouts T-crossings	400,0	0,0	212,0	612,0	0,92	0,111
	(all junctions, AADT > 5000)	800,0	0,0	424,0	1224,0	0,78	0,094
		1200,0	0,0	636,0	1836,0	0,66	0,080

No	Measure	Total cost mill SEK Investment	Operating	Tax	Total costs	B/C-ratio	Cost-effectiveness
106	Roundabouts X-crossings	800,0	0,0	424,0	1224,0	1,83	0,120
	(all junctions, AADT > 5000)	1200,0	0,0	636,0	1836,0	1,67	0,109
		1600,0	0,0	848,0	2448,0	1,47	0,096
108	Staggered junctions	112,5	0,0	59,6	172,1	0,28	0,032
		166,5	0,0	88,2	254,7	0,25	0,030
		225,0	0,0	119,3	344,3	0,23	0,027
109	Interchanges	200,0	6,2	109,3	315,5	2,19	0,010
		340,0	10,6	185,8	536,3	2,00	0,009
		500,0	15,5	273,2	788,7	1,75	0,008
112	Roadside safety treatment	1000,0	0,0	530,0	1530,0	1,28	0,157
	(all rural roads, AADT >2000)	2500,0	0,0	1325,0	3825,0	1,08	0,133
		4000,0	0,0	2120,0	6120,0	0,95	0,116
114	Widening road to 13 m	1100,0	68,3	619,2	1787,5	0,53	0,056
	(AADT > 8000, 90-110 km/h)	1950,0	121,0	1097,7	3168,7	0,52	0,055
		2800,0	173,8	1576,1	4549,9	0,51	0,054
114	General rehabilitation of roads	245,0	0,0	129,9	374,9	0,20	0,012
	(AADT >2000, 70-110 km/h)	2572,5	0,0	1363,4	3935,9	0,17	0,010
		4900,0	0,0	2597,0	7497,0	0,16	0,009
115	New guard rails on embankments (road sides)	275,0	74,5	185,2	534,7	0,69	0,086
		2653,8	718,8	1787,5	5160,0	0,65	0,079
		5032,5	1363,2	3389,7	9785,4	0,62	0,076
115	Median guard rails (wire) on wide roads	150,0	46,6	104,2	300,7	1,45	0,149
		1825,0	566,4	1267,5	3658,9	0,97	0,098
		3500,0	1086,3	2430,7	7017,1	0,81	0,082
116	Game fences (animal accidents)	15,0	3,4	9,7	28,1	1,83	0,188
		82,5	18,4	53,5	154,4	1,36	0,141
		300,0	67,0	194,5	561,6	1,11	0,116
117	Curve treatments	50,0	0,0	26,5	76,5	2,51	0,589
		75,0	0,0	39,8	114,8	2,07	0,496
		100,0	0,0	53,0	153,0	1,63	0,404

		Total cost mill SEK					Cost-
No	Measure	Investment	Operating	Tax	Total costs	B/C-ratio	effectiveness
118	New road lighting	2000,0	1241,5	1718,0	4959,5	1,60	0,192
	(all unlit roads)	4000,0	2483,0	3436,0	9919,0	1,31	0,158
		36000,0	22347,0	30923,9	89270,9	0,44	0,053
	ROAD MAINTENANCE						
206	Improving winter maintenance of roads	0,0	8,9	4,7	13,6	2,67	0,287
	(AADT >10000)	0,0	501,2	265,6	766,8	0,52	0,060
		0,0	750,8	397,9	1148,6	0,61	0,070
	TRAFFIC CONTROL						
301	30 km/h streets (Vision Zero)	6500,0	6455,8	6866,6	19822,4	-0,50	0,030
		9550,0	9485,1	10088,6	29123,6	-0,50	0,030
		12600,0	12514,3	13310,6	38424,9	-0,50	0,030
302	50/30 km/h streets (Vision Zero)	12000,0	9311,3	11295,0	32606,2	-0,30	0,050
		36000,0	27933,8	33884,9	97818,6	-0,25	0,042
		72000,0	55867,5	67769,8	195637,3	-0,21	0,034
304	Walking speed streets (woonerfs)	562,5	465,6	544,9	1572,9	-0,76	0,009
	(about 20 % of urban roads)	3281,3	2715,8	3178,4	9175,5	-0,72	0,009
		6000,0	4966,0	5812,0	16778,0	-0,69	0,008
308	Four way stop at urban junctions	2,3	0,0	1,2	3,4	-3,65	7,682
		12,4	0,0	6,6	18,9	-2,94	6,328
		22,5	0,0	11,9	34,4	-2,47	5,388
309	Traffic signal control at junctions (T)	4,0	3,1	3,8	10,9	2,85	0,044
		6,4	5,0	6,0	17,4	2,85	0,044
		8,0	6,2	7,5	21,7	2,85	0,044
309	Traffic signal control at junctions (X)	5,0	4,7	5,1	14,8	4,79	0,107
		8,0	7,4	8,2	23,6	4,79	0,107
		10,0	9,3	10,2	29,5	4,79	0,107

No	Measure	Total cost mill SEK Investment	Operating	Tax	Total costs	B/C-ratio	Cost-effectiveness
310	Traffic signal control at pedestrian crossings	5,0	9,3	7,6	21,9	0,66	0,084
		7,6	14,2	11,5	33,3	0,63	0,080
		10,0	18,6	15,2	43,8	0,60	0,076
311	Seasonal speed limits	22,4	0,0	11,9	34,3	1,36	0,097
	(110 km/h → 90, 90 km/h → 70)	44,8	0,0	23,7	68,5	1,22	0,090
		271,9	0,0	144,1	416,0	0,97	0,075
311	Optimal speed limits	0,0	0,0	0,0	0,0	0,00	0,000
		0,9	11,0	6,3	18,2	1,04	-0,217
		0,4	0,0	0,2	0,6	0,03	4,439
		0,3	55,0	29,3	84,6	1,01	0,190
		0,6	22,0	12,0	34,6	1,04	0,385
		0,2	3,0	1,7	4,9	1,04	0,150
		25,1	172,0	104,5	301,5	1,00	0,221
		158,5	335,0	261,5	755,0	1,01	0,640
		0,0	355,0	188,2	543,2	1,01	0,643
		20,4	0,0	10,8	31,2	0,63	1,382
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		206,3	953,0	614,5	1773,8	1,00	0,548

No	Measure	Total cost mill SEK Investment	Operating	Tax	Total costs	B/C-ratio	Cost-effectiveness
311	Vision Zero speed limits	0,0	55,0	29,2	84,2	-0,82	0,376
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	20,0	10,6	30,6	-2,79	0,491
		0,3	25,0	13,4	38,7	0,04	0,699
		0,6	20,0	10,9	31,5	0,13	0,606
		0,0	10,0	5,3	15,3	-0,30	0,253
		25,1	110,0	71,6	206,7	-0,61	0,581
		158,5	610,0	407,3	1175,7	-0,62	0,607
		0,0	190,0	100,7	290,7	1,88	1,201
		10,2	25,0	18,7	53,9	0,70	0,801
		172,1	670,0	446,3	1288,4	-6,07	0,504
		90,0	65,0	82,2	237,2	-4,23	0,077
		456,7	1800,0	1196,1	3452,8	-2,68	0,576
		455,8	1745,0	1166,4	3367,3	-2,74	0,576
		301,6	1186,7	788,8	2277,0	-3,24	0,550
314	Upgrading pedestrian crossings	320,0	39,7	190,7	550,4	1,46	0,190
		1375,0	170,7	819,2	2364,9	1,14	0,149
		5400,0	670,4	3217,3	9287,7	0,79	0,102
314	Cycle lanes, and stop line in junctions	1890,0	0,0	1001,7	2891,7	0,18	0,022
		9975,0	0,0	5286,8	15261,8	0,12	0,015
		18060,0	0,0	9571,8	27631,8	0,09	0,011
320	Feedback signs	18,0	15,8	17,9	51,7	1,13	0,315
	(AADT > 5000)	36,0	31,6	35,8	103,4	0,94	0,263
		898,0	787,5	893,3	2578,7	0,38	0,106
	VEHICLE DESIGN						
404	High mounted stop lamps	90,0	0,0	0,0	90,0	9,07	0,935
		291,0	0,0	0,0	291,0	7,89	0,814
		291,0	0,0	0,0	291,0	7,89	0,814

No	Measure	Total cost mill SEK Investment	Operating	Tax	Total costs	B/C-ratio	Cost-effectiveness
407	Self levelling head lamp requirement	200,0	0,0	0,0	200,0	1,45	0,176
		1850,0	0,0	0,0	1850,0	1,43	0,173
		3610,0	0,0	0,0	3610,0	1,39	0,169
408	Pedestrian reflective devices (law)	132,8	20,0	10,6	163,4	5,09	0,601
		199,1	30,0	15,9	245,0	5,09	0,601
		265,5	40,0	21,4	326,9	5,09	0,601
408	Reflective devices on bicycles (law)	241,5	20,0	10,6	272,1	0,60	0,076
		442,8	30,0	15,9	488,7	0,61	0,078
		543,5	40,0	21,4	604,9	0,61	0,077
410	Bicycle helmets, campaign and law	900,0	20,0	10,6	930,6	3,11	0,372
		1200,0	30,0	15,9	1245,9	3,10	0,370
		1500,0	40,0	21,4	1561,4	3,09	0,369
412	Seal belt reminder in light cars	70,0	0,0	0,0	70,0	11,85	1,446
		647,5	0,0	0,0	647,5	11,65	1,421
		1175,0	0,0	0,0	1175,0	11,34	1,383
412	Ignition interlock device for seat belts	40,0	0,0	0,0	40,0	29,63	3,615
		370,0	0,0	0,0	370,0	29,12	3,553
		722,0	0,0	0,0	722,0	28,36	3,459
414	Air bags	3000,0	0,0	0,0	3000,0	0,40	0,047
		9700,0	0,0	0,0	9700,0	0,40	0,047
		9700,0	0,0	0,0	9700,0	0,40	0,047
418	Intelligent cruise control (headway control)	1320,0	0,0	0,0	1320,0	0,48	0,044
		12450,0	0,0	0,0	12450,0	0,46	0,043
		23640,0	0,0	0,0	23640,0	0,46	0,043

No	Measure	Total cost mill SEK Investment	Operating	Tax	Total costs	B/C-ratio	Cost-effectiveness
420	Intelligent speed adaptation for cars	0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		0,0	0,0	0,0	0,0	0,00	0,000
		2200,0	5462,6	0,0	7662,6	0,73	0,110
		20750,0	51522,3	0,0	72272,3	0,70	0,106
		39400,0	97830,2	0,0	137230,2	0,70	0,106
422	Improving under run guard rails on truck	300,0	0,0	0,0	300,0	0,20	0,049
		2700,0	0,0	0,0	2700,0	0,20	0,049
		4560,0	0,0	0,0	4560,0	0,20	0,049
423	Front impact protections on truck	300,0	0,0	0,0	300,0	1,22	0,162
		2700,0	0,0	0,0	2700,0	1,22	0,162
		4560,0	0,0	0,0	4560,0	1,22	0,162
429	Crash data recorder	1100,0	0,0	0,0	1100,0	1,55	0,184
		10375,0	0,0	0,0	10375,0	1,50	0,177
		19700,0	0,0	0,0	19700,0	1,50	0,177
430	New safety standards for front and bumpers on light cars	40,0	0,0	0,0	40,0	7,11	1,163
		370,0	0,0	0,0	370,0	6,99	1,143
		722,0	0,0	0,0	722,0	6,80	1,113

		Total cost mill SEK					Cost-
No	Measure	Investment	Operating	Tax	Total costs	B/C-ratio	effectiveness
	TRAINING AND EDUCATION						
503	Roadside motor vehicle inspections	0,0	23,4	12,4	35,8	2,22	0,253
		0,0	128,7	68,2	196,9	1,24	0,148
		0,0	234,0	124,0	358,0	1,0	0,123
604	Reforming basic driver training	0,0	530,0	0,0	530,0	1,43	0,160
605	Training of problem drivers	0,0	800,0	0,0	800,0	0,41	0,049
608	Training of bus and truck drivers	0,0	85,0	0,0	85,0	0,71	0,082
		0,0	1925,0	0,0	1925,0	0,29	0,033
		0,0	3850,0	0,0	3850,0	0,27	0,031
702	Training of school age children (7-12 year)	0,0	72,5	38,4	110,9	0,44	0,058
	ENFORCEMENT AND SANCTIONS						
801	Stationary speed enforcement	0,0	200,0	106,0	306,0	9,45	0,872
		0,0	400,0	212,0	612,0	6,60	0,593
		0,0	1000,0	530,0	1530,0	4,29	0,436
		0,0	1800,0	954,0	2754,0	2,89	0,302
804	Random breath testing I	0,0	200,0	106,0	306,0	1,50	0,187
	(increased testing)	0,0	400,0	212,0	612,0	1,11	0,137
		0,0	1000,0	530,0	1530,0	0,74	0,092
		0,0	1800,0	954,0	2754,0	0,52	0,064
805	Seat belt enforcement	0,0	50,0	26,5	76,5	5,30	0,677
	(increased enforcement)	0,0	100,0	53,0	153,0	4,05	0,518
		0,0	250,0	132,5	382,5	2,67	0,342
		0,0	450,0	238,5	688,5	1,86	0,238
806	Automatic speed enforcement	118,5	1039,1	613,5	1771,2	2,48	0,222
	(increased enforcement)	651,5	5713,0	3373,2	9737,7	1,60	0,137
		1185,0	10391,3	6135,4	17711,7	1,17	0,092
807	Simple traffic tickets	12,5	109,6	64,7	186,8	2,26	0,272
		25,0	219,2	129,4	373,7	1,69	0,204
		250,0	2192,3	1294,4	3736,6	0,82	0,102
810	Demerit point system	27,3	54,7	43,4	125,4	2,70	0,323

		Total cost mill SEK					Cost-
No	Measure	Investment	Operating	Tax	Total costs	B/C-ratio	effectiveness
812	Ignition interlock system for alcohol	25,0	144,6	0,0	169,6	3,01	0,382
813	Vehicle impoundment to prevent unlicensed driving	111,5	201,6	165,9	479,0	2,86	0,260

Appendix 3: List of abbreviations

AADT = Annual average daily traffic

Ag = almän gata (public street, urban areas)

Av = almän väg (highway, rural areas)

CBA = cost-benefit analysis

Div = diverse annan väg (unclassified roads)

Ev = enskild väg (private road)

Km = kilometre

Mtl = motortrafikled (motor traffic road)

Mv = motorway

NA = not available, or not applicable

PAR = population attributable risk

SEK = Swedish kroner