Michael Sørensen
Marjan Mosslemi
TØI report 1009/2009

Institute of Transport Economics
Norwegian Centre for Transport Research

Subjective and Objective Safety

The Effect of Road Safety Measures on Subjective Safety among Vulnerable Road Users

TØI report
1009/2009

Subjective and Objective Safety

The Effect of Road Safety Measures on Subjective Safety among Vulnerable Road Users

Michael Sørensen
Marian Mosslemi

ISSN 0808-1190
ISBN 978-82-480-0960-3 Paper version
ISBN 978-82-480-0959-7 Electronic version

Oslo, April 2009

Title: Subjective and objective safety - the effect of road safety measures on subjective safety among vulnerable road users

Author(s): Michael Sørensen, Marjan Mosslemi

Date: 03.2009

TØI report: 1009/2009

Pages 140

ISBN Paper: 978-82-480-0960-3

ISBN Electronic: 978-82-480-0959-7

ISSN 0808-1190

Financed by: The Research Council of Norway

Project: 3404 - Risikodiskrepans: Sikkerhet og risikopersepsjon i ulike transportformer

Project manager: Aslak Fyhri

Quality manager: Fridulv Sagberg

Key words: Cyclist, Pedestrian, Perceived risk, Safety

Summary:

The objective of the project has been to summarize the effect of 54 road safety measures on subjective safety among vulnerable road users. The assessment is based on literature and theoretical considerations. The effect has only been directly studied for 14 measures and indirectly studied for another 14 measures. 39 measures are assessed to have a positive effect of subjective safety. Among 125 submeasures it is assessed that 78 have a positive effect on both objective and subjective safety and 25 have an opposite effect on objective and subjective safety, i.e. having positive effect on one parameter and negative effect on the other. 20 measures have an unknown or unclear effect on objective or subjective safety. Further investigation is relevant for at least 50 of the submeasures. 13 measures most relevant for further studies are selected.

Language of report: English

Tittel: Trygghet og sikkerhet - trafikksikkerhetstiltaks effekt på myke trafikanters trygghetsopplevelse

Forfattere: Michael Sørensen, Marjan Mosslemi

Dato: 03.2009

TØI rapport: 1009/2009

Sider 140

ISBN Papir: 978-82-480-0960-3

ISBN Elektronisk: 978-82-480-0959-7

ISSN 0808-1190

Finansieringskilde: Norges Forskningsråd

Prosjekt: 3404 - Risikodiskrepans: Sikkerhet og risikopersepsjon i ulike transportformer

Prosjektleder: Aslak Fyhri

Kvalitetsansvarlig: Fridulv Sagberg

Emneord: Fotgjenger, Sikkerhet, Syklist, trygghet

Sammendrag:

Prosjektets formål har vært å sammenfatte effekten av 54 trafikksikkerhetstiltak og 125 varianter av disse tiltakene på myke trafikanters følelse av trygghet. Vurderingen er basert på litteraturstudier og teoretiske betraktninger. Vi fant kun 14 tiltak som er blitt direkte evaluert, samt 14 tiltak som er blitt indirekte evaluert. 39 av de 54 hovedtiltakene er vurdert å ha en positiv effekt på trygghet. Blant de 125 variantene av tiltakene er det vurdert at 78 har positiv effekt for både sikkerhet og trygghet og 25 har omvendt effekt på sikkerhet henholdsvis trygghet. Det vil si at de har positiv effekt for den ene og negativ for den andre. 20 tiltak har ukjent eller tvetydig effekt på sikkerhet eller trygghet. Ytterligere undersøkelser er relevant for minst 50 varianter av tiltakene. 13 Tiltak er valgt som de mest relevante for ytterligere evaluering.

Institute of Transport Economics
Gaustadalleen 21, 0349 Oslo, Norway
Telefon 22 57 38 00 - www.toi.no

Transportøkonomisk Institutt
Gaustadalleen 21, 0349 Oslo
Telefon 22 57 38 00 - www.toi.no

Preface

This report is part of the RiskDisk project (Risk discrepancy: Safety and risk perception of different means of transport) funded by the Research Council of Norway. The project is a follow up to the RISIT project (Risk and safety in transport) and consists of several parts. The project is planed to finish ultimo 2009. The main objective of the RiskDisk project is to study discrepancies between 1) Objective and subjective risk perception, 2) Emotional and cognitive aspects of risk perception and 3) Perceived risk for accidents (safety) and unpleasant incidents (security).

This report focuses on the first item among the above-mentioned items. The other items are and will be treated in other TØI reports.

The aim of this report has been to collect all available knowledge and studies regarding the effects of various road safety measures on subjective safety, and assess the relationship between road safety measures with confirmed positive effect on road safety and perceived risk for accidents.

The study includes 54 road safety measures that are divided into 125 submeasures. To make an assessment of the effect on subjective safety for these measures, over 200 studies or references have been included in study. For each measure, the literature study has been supplemented with theoretical consideration about the effect on subjective safety.

Senior Research Psychologist Aslak Fyhri has been project manager. Senior Research Engineer Michael Sørensen has been responsible for this report and has written the greater part of the report and appendix. Research Engineer Marjan Mosslemi has written parts of chapter 2 and parts of the appendix. Chief Research Officer Fridulv Sagberg has been responsible for quality assurance. Secretary Trude Rømming has prepared the text for printing.

Oslo, April 2009
Institute of Transport Economics

Lasse Fridstrøm
Managing Director

Marika Kolbenstvedt
Head of Department

Table of contents

TØI report 1009/2009
Authors: Michael Sørensen and Marjan Mosslemi
Oslo 2009, 140 pages English language

Summary:

Subjective and Objective Safety

The Effect of Road Safety Measures on Subjective Safety among Vulnerable Road Users

A literature study of 54 safety measures that may affect vulnerable road users reveals that the effect on subjective safety has been studied directly for only 14 measures and indirectly for another 14 measures. Supplementary theoretical considerations show that 70-80 % of the measures probably have a positive effect on subjective safety. 78 out of 125 submeasures are assessed to have a positive effect on both objective and subjective safety, while 25 have opposite effects on objective and subjective safety. Further investigation is relevant for at least 50 of the submeasures. One fourth of these measures are ranked as the measures most relevant for further studies.

Objective and subjective safety

Objective safety can be described as the actual number or risk of road accidents or injuries, while subjective safety is the feeling or perception of safety, i.e. how people subjectively experience accident risk in traffic.

The objective of this project have been to collect all available knowledge and studies regarding the effects of various road safety measures on subjective safety, and to assess relationships and discrepancies between the effects on objective and subjective safety for selected road safety measures.

54 road safety measures selected for the study

Among 111 road safety measures described in “The Handbook of Road Safety Measures” 54 measures have been selected for this study. These measures have been divided into 125 varying submeasures. The measures are selected because they are assumed to affect objective safety, subjective safety and/or mobility among cyclists and/or pedestrians.

A comprehensive literature study regarding each of the selected measures was conducted. Over 200 studies or references have been included in this study.

However, for many of the measures no evaluation studies have been found. Thus, supplementary theoretical and qualitative considerations about the effect on subjective safety have been performed for each measure.

The report can be ordered from:
Institute of Transport Economics, Gaustadalléen 21, NO 0349 Oslo
Telephone: +47 22 57 38 00   Telefax: +47 22 60 92 00

Positive effect on subjective safety

Table S.1 summarizes the number of measures and submeasures with various effects on subjective safety among vulnerable road users.

Table S.1. Number of measures and submeasures with varying effect on subjective safety among vulnerable road users. Brackets indicate the number of submeasures.

Category	Number of Measures	Effect		
		Positive	Negative	No, unknown, ambiguous
Design and road furniture	17 (45)	9 (30)	3 (10)	5 (5)
Road maintenance	5 (5)	5 (5)	0 (0)	0 (0)
Traffic control	17 (39)	12 (35)	3 (3)	2 (1)
Vehicle design and protective devices	8 (25)	6 (23)	0 (0)	2 (2)
Training, education and enforcement	7 (11)	7 (11)	0 (0)	0 (0)
Total	54 (125)	39 (104)	6 (13)	9 (8)

TØI report 1009/2009

Based on the results from the studies found in literature and the qualitative considerations, it is assessed that 39 measures or 104 submeasures to a larger or smaller extent have positive effects on subjective safety of cyclists, pedestrians or both of them. This corresponds to 70-83 % of the measures. The 39 measures with probably positive effect on subjective safety are listed in table S.2.

Table S.2. Measures with positive effect on subjective safety.

Design and road furniture
- Tracks for walking and cycling
- Motorways
- Bypasses
- Arterial roads
- Channelisation of junctions
- Staggered junctions
- Guardrails, crash cushions
- Horizontal curve treatments
- Road lighting

Road maintenance
- Ordinary resurfacing
- Improving evenness
- Improving friction
- Winter maintenance of roads
- Winter maintenance of foot and cycle tracks

Traffic control
- Traffic calming
- Environmental streets
- Pedestrian streets
- Urban play streets
- Access control
- Traffic signal control at intersections
- Signal-controlled pedestrian crossings
- Speed limits
- Speed-reducing devices
- Traffic control for Vulnerable road users
- Parking regulation
- One-way streets

Vehicle design and protective devices
- Reflective materials and protective clothing
- Cycle helmets
- Regulating automobile engine capacity and top speed
- Safety equipment on trucks
- Bicycle safety equipment

Safety standards for trailers and caravans

Training, education and enforcement
- Safety standards for transporting school children
- Education before school
- Education in schools
- Stationary speed enforcement
- Patrolling
- Automatic speed enforcement
- Red light cameras

TØI report 1009/2009

Only six measures or 13 submeasures are assessed to have negative effects on subjective safety. This corresponds to 9-10 %. The remaining nine measures have none, unknown or ambiguous effect. Measures with negative, none, unknown or ambiguous effect are listed in table S.3.

Table S.3. Measures with no, unknown, ambiguous or negative effect on subjective safety among vulnerable road users.

No, unknown, ambiguous effect	**Negative effect**
– Roundabouts	– Redesigning junctions
– Black spot treatment	– Interchanges
– Cross section improvements	– Improving road alignment and sight conditions
– Roadside safety treatment	– Yield signs at intersections
– Rehabilitation, reconstruction and resurfacing	– Stop signs at intersections
– Priority control	– Bus lanes and bus stop design
– Road markings	
– Regulating vehicle mass	
– Under-run guard rails on trucks	

TØI report 1009/2009

Positive effect on both objective and subjective safety

The 125 submeasures are classified regarding effect on objective and subjective safety. The classification is summaries in table S.4.

Fortunately most of the measures are classified as “good” measures having positive effect on both objective and subjective safety. In total, 78 (62 %) of the 125 submeasures are included in this category.

Table S.4. Total number of submeasures in each of the nine defined groups with varying effect on objective and subjective safety.

	Subjective			
Objective	**Positive**	**Negative**	**No, unknown, ambiguous**	**Total**
Positive	78	9	6	93
Negative	16	2	1	19
No, unknown, ambiguous	10	2	1	13
Total	104	13	8	125

TØI report 1009/2009

The remaining 47 (38 %) of the measures are “problem” measures. These measures should be used with caution and an assessment of the effect should be made considering the specific case.

20 measures are measures with unknown or unclear effect on objective or subjective safety.

25 measures are measures with opposite effect on objective and subjective safety. Among these 16 measures have positive effect on subjective safety and negative effect on objective safety, while nine measures have positive effect on objective safety and negative effect on subjective safety. Table S.5 lists these 25 measures.

Two measures have negative effect on both objective and subjective safety. These measures should not be used if the aim is improving objective and subjective safety.

Table S.5. Measures with opposite effect on objective and subjective safety.

Positive effect on subjective safety and negative effect on objective safety	Positive effect on objective safety and negative effect on subjective safety
– Tracks for cycling	– Roundabouts, mixed traffic
– T-junctions, full channelisation	– Redesigning, gradient on road
– T-junctions, minor road channelisation	– Redesigning, sight condition
– Curve treatments, road widening	– Interchanges (instead of crossroad)
– Curve treatments, transition curves	– Passing lanes (one side)
– Ordinary resurfacing of roads	– Road alignment, general improvement
– Improving the evenness of the surface	– Sight conditions, removing obstacles
– Winter maintenance of tracks, more	– Yield signs at intersections
– Speed-reducing, raised intersections	– Stop signs at intersections
– Wide edge line	
– Shoulder rumble line	
– Delineator posts with reflectors	
– Ordinary pedestrian crossing	
– Pedestrian crossings, mixed phases, intersection	
– One-way streets	
– Cycle equipment, spokes reflectors	

TØI report 1009/2009

Significant lack of knowledge

This project reveals lack of knowledge among several road safety measures regarding their effect on subjective safety among vulnerable road users. Among the 54 measures, the effect has been studied directly for only 14 measures (26 %) and indirectly for another 14 measures. Table S.6 summarises the number of measures studied for five categories of safety measures.

Table S.6. Number of measures where the effect on subjective safety among vulnerable road users directly or indirectly has been studied.

Category	Measures	Directly	Indirectly	No studies
1. Design and road furniture	17	3	1	13
2. Road maintenance	5	2	3	0
3. Traffic control	17	7	4	6
4. Vehicle design and protective devices	8	2	3	3
5. Training, education and enforcement	7	0	3	4
Total	54	14	14	26

TØI report 1009/2009

There is not only a lack of knowledge on the effect on subjective safety, but also on the effect on objective safety. The problem is that the effect on objective safety for cyclists and/or pedestrians has been evaluated for fewer than 20 % of the sub-measures. For the remaining 80 % the general effect for all road users are used.

Thus, it is assumed that the effect among vulnerable road users has the same sign as the effect for all road users. This may not always be the case.

Difficult to estimate the effect

This project reveals 10 varying problems with estimating the effect of road safety measures on subjective safety among vulnerable road users:

1. *Few studies:* The effect on subjective safety among vulnerable road users has only been studied directly for less than one fourth of the measures included.
2. *Amount of studies:* For each measure studied it is only possible to find one or maybe a few studies dealing with the question.
3. *Quality of studies:* The quality of the studies has not been examined, but some of the studies are based on very few respondents.
4. *Over-interpretation:* The effect on subjective safety among vulnerable road users has been studied indirectly for about another fourth of the measures included. The result of these studies may have been over-interpreted.
5. *Qualitative considerations not verified:* Assumptions about various correlations have not been verified satisfactorily.
6. *Difficult to sum up qualitative considerations:* It is difficult to assess the effect when factors having an impact on subjective safety have opposite directions. This is the case for several of the measures.
7. *Ambiguous or unknown results:* Ambiguous or unknown results about the effect on subjective safety for several measures.
8. *Magnitude of effect:* The magnitude of the effect on subjective safety is often unknown.
9. *Number:* Number of vulnerable road users in the area is not taken account for in the assessment of effect.
10. *Division of vulnerable road users:* Vulnerable road users are not divided systematically between cyclists and pedestrians. This may only be possible in the qualitative considerations.

More research needed

Due to the quality and the quantity of the evaluation studies performed further evaluation is both recommended for measures already studied and for measures not studied before.

50 measures are identified for further investigation. However, it is very ambitious to recommend further studies for 50 varying measures. Thus, 13 (one fourth) of the measures have been selected as measures where further studies are most relevant.

The measures selected are those with ambiguous, unknown, significant and/or opposite effect on objective and/or subjective safety among vulnerable road users, those where professionals and/or the public “disagree” about the effects and those dominating the current debate among professionals and in the media.

The 13 measures divided into four groups are:

1. *Infrastructure for vulnerable road users:* Track for cycling, winter maintenance of tracks and pedestrian crossings
2. *Cross sections improvements:* lane width and shoulder width
3. *Equipment for bicycle and bicyclist:* Helmet, brake blocks, spokes reflectors, and retro-reflective materials
4. *Regulations of heavy vehicles:* Weight, ban on trailers, speed, and rails.

Beside evaluation studies of specific measures some more general studies that quantify the assumed correlation between influencing factors and subjective safety used in the theoretical considerations are also needed.

Sammendrag:

Trygghet og sikkerhet

Trafikksikkerhetstiltaks effekt på myke trafikanters trygghetsfølelse

En litteraturstudie av 54 trafikksikkerhetstiltak som kan tenkes å påvirke myke trafikanters trygghetsfølelse viser at effekten kun er blitt direkte evaluert for 14 tiltak og indirekte for 14 andre tiltak. Supplerende teoretiske betraktninger viser at 70-80 % av tiltakene formodentlig har positiv effekt på trygghet. Blant 125 varianter av tiltakene er det vurdert at 78 har positiv effekt for både sikkerhet og trygghetsfølelse. 25 tiltak har omvendt effekt på sikkerhet henholdsvis trygghet. Det vil si at de har positiv effekt på der ene og negativ på der andre. Flere undersøkelser er relevant for minst 50 varianter av tiltakene. En fjerdedel av disse tiltak er rangert som de mest relevante for ytterligere evaluering.

Faktisk sikkerhet og opplevelse av utrygghet

Sikkerhet kan beskrives som det faktiske antall trafikkulykker eller skadde, eller som risiko for ulykker, mens opplevelse av trygghet er følelsen av sikkerhet, eller med andre ord hvordan folk opplever risikoen for trafikkulykker.

Prosjektets formål har vært å samle inn alle tilgjengelige undersøkelser med hensyn til den trygghetsmessige effekten av ulike trafikksikkerhetstiltak, og prøve å undersøke om det er noen sammenheng eller eventuelt diskrepans mellom effekt på sikkerhet og effekt på trygghetsfølelse for utvalgte trafikksikkerhetstiltak.

54 trafikksikkerhetstiltak inngår i undersøkelsen

54 trafikksikkerhetstiltak blant de 111 tiltak beskrevet i ”Trafikksikkerhets-håndboken” er blitt valgt til å inngå i undersøkelsen. Disse tiltakene er igjen blitt oppdelt i 125 ulike varianter. Kun tiltak som formodes å påvirke sikkerhet, trygghet, fremkommelighet eller tilgjengelighet for syklister og/eller fotgjengere er blitt behandlet i studien.

Det er foretatt en omfattende litteraturstudie for hver av de valgte tiltak. Litteraturstudien omfatter i alt over 200 ulike studier og referanser. For flere av tiltakene er det imidlertid ikke funnet noen evalueringsstudier. Gjennomgangen er derfor for hvert tiltak supplert med teoretiske og kvalitative vurderinger av den trygghetsmessige effekten.

Rapporten kan bestilles fra:
Transportøkonomisk institutt, Gaustadalléen 21, NO 0349 Oslo
Telefon: 22 57 38 00   Telefax: 22 60 92 00

Positiv effekt på opplevd trygghet

I tabell S.1 sammenfattes antall tiltak og undertiltak med ulike effekt på opplevd trygghet for myke trafikanter.

Tabell S.1. Antall tiltak og ulike varianter i parentes med positiv, negativ og ingen, ukjent eller tvetydig effekt på myke trafikanters opplevelse av trygghet fordelt på fem ulike grupper av tiltak.

		Effekt		
Kategori	**Antall tiltak**	**Positiv**	**Negativ**	**Ingen, ukjent, tvetydig**
Vegutforming og utstyr	17 (45)	9 (30)	3 (10)	5 (5)
Vegvedlikehold	5 (5)	5 (5)	0 (0)	0 (0)
Trafikkregulering	17 (39)	12 (35)	3 (3)	2 (1)
Kjøretøyteknikk og personlig verneutstyr	8 (25)	6 (23)	0 (0)	2 (2)
Føreropplæring, trafikkopplæring, kontroll	7 (11)	7 (11)	0 (0)	0 (0)
I alt	54 (125)	39 (104)	6 (13)	9 (8)

TØI rapport 1009/2009

Basert på resultater i de undersøkelser som er funnet, og de mer teoretiske betraktninger vurderes det at 39 tiltak eller 104 varianter av tiltak i større eller mindre grad har positiv betydning for trygghet for syklister, fotgjengere eller begge trafikantgrupper. Det svarer til 70-85 % av tiltakene. De 39 tiltak med sannsynligvis positiv effekt for trygghet er listet i tabell S.2.

Tabell S.2. Tiltak med positiv effekt på myke trafikanters opplevelse av trygghet.

Vegutforming og utstyr
- Gang og sykkelveger
- Motorveger
- Omkjøringsveger
- Hovedveger og innfartsveger i byer
- Kanalisering av kryss
- Oppdeling av X-kryss til to T-kryss
- Vegrekkverk og støtputer
- Tiltak i horisontalkurver
- Vegbelysning

Vegvedlikehold
- Alminnelig reasfaltering
- Bedring av jevnhet
- Bedring av friksjon
- Vintervedlikehold av veger
- Vintervedlikehold av gang og sykkelveger

Trafikkregulering
- Trafikksanering
- Miljøgater
- Gågater
- Gatetun
- Avkjørselsregulering
- Signalregulering i kryss
- Signalregulering av gangfelt
- Fartsgrenser
- Fysisk fartsregulering
- Regulering for myke trafikanter
- Parkeringsregulering
- Envegsregulering

Kjøretøyteknikk og personlig verneutstyr
- Reflekterende materialer og vernetøy
- Sykkelhjelm
- Regulering av bilers motorstyrke og toppfart
- Sikkerhetsutstyr på tunge biler
- Syklers sikkerhetsutstyr
- Krav til kjøretøys tilhengere

Føreropplæring, trafikkopplæring, kontroll
- Sikkerhetskrav til skoleskyss
- Opplæring av førskolebarn
- Opplæring i skolen
- Stasjonære fartskontroller
- Patruljering
- Automatisk fartskontroll
- Automatisk rødlyskontroll

TØI rapport 1009/2009

Kun seks tiltak eller 13 varianter av tiltak er vurdert å ha negativ effekt på trygghet. Det svarer til 9-10 %. De resterende ni tiltak har ingen, ukjent eller tvetydig effekt. Tiltak med negativ, ingen, ukjent eller tvetydig effekt er listet i tabell S.3.

Tabell S.3. Tiltak med ingen, ukjent, tvetydig eller negativ effekt på myke trafikanters opplevelse av trygghet.

Ingen, ukjent, tvetydig effekt	Negativ effekt
– Rundkjøringer	– Endret geometrisk utformning av kryss
– Utbedring av ulykkesbelastede steder	– Toplanskryss
– Utbedring av vegers tverrprofil	– Utbedring av vegers linjeføring og siktforhold
– Utbedring av vegers sideterreng	– Vikepliktregulering i kryss
– Generell utbedring av eksisterende veg	– Stoppliktregulering i kryss
– Forkjørsregulering av vegstrekninger	– Kollektivfelt og sikring av stoppesteder
– Vegoppmerking	
– Regulering av bilers masse	
– Underkjørringshinder og sidehinder på lastebiler	

TØI rapport 1009/2009

Positiv effekt på både sikkerhet og trygghet

De 125 varianter av tiltak er blitt klassifisert i forhold til sin effekt på sikkerhet og trygghet. Klassifiseringen er sammenfattet i tabell S.4.

De fleste av tiltakene er klassifisert som ”gode” tiltak som har positiv betydning for både sikkerhet og trygghet. I alt er 78 (62 %) av de 125 tiltaksvarianter å finne i denne kategori.

Tabell S. 4. Antall varianter av tiltak i hver av de ni definerte grupper med ulike effekt på sikkerhet og trygghet.

	Trygghet			
Sikkerhet	**Positiv**	**Negativ**	**Ingen, ukjent, tvetydig**	**I alt**
Positiv	78	9	6	93
Negativ	16	2	1	19
Ingen, ukjent, tvetydig	10	2	1	13
I alt	104	13	8	125

TØI rapport 1009/2009

De resterende 47 (38 %) varianter av tiltak er ”problem-tiltak”. Disse tiltakene skal benyttes med forsiktighet, og hver gang tiltakene brukes bør det foretas en konkret vurdering av effekten på trygghet og sikkerhet.

20 av disse tiltakene er tiltak med ingen, ukjent eller tvetydig effekt på sikkerhet eller trygghet.

25 av tiltakene er tiltak med omvendt effekt på sikkerhet henholdsvis trygghet. Blant disse er det 16 tiltak som har positiv effekt på trygghet og negativ effekt på sikkerhet og ni tiltak som har positiv effekt på sikkerhet og negativ effekt på trygghet. De 25 tiltakene er listet i tabell S.5.

To tiltak har negativ effekt på både sikkerhet og trygghet. Disse tiltak bør ikke brukes hvis målet er å forbedre sikkerhet og/eller trygghet.

Tabell S.5. Varianter av tiltak med omvendt effekt på sikkerhet henholdsvis opplevelse av trygghet.

Positiv effekt på trygghet og negativ effekt på sikkerhet	Positiv effekt på sikkerhet og negativ effekt på trygghet
– Sykkelveger	– Rundkjøringer, blandet trafikk
– T-kryss, full kanalisering	– Endring av stigningsforhold på vegarmer inn mot kryss
– T-kryss, kanalisering på sideveg	– Siktforbedrende tiltak i kryss
– Breddeutvidelse i kurve	– Toplanskryss
– Overgangskurver	– Forbikjøringsfelt
– Alminnelig reasfaltering	– Utbedring av vegers linjeføring
– Bedring av vegdekkers jevnhet	– Utbedring av siktforhold
– Vintervedlikehold av gang og sykkelveger	– Vikepliktregulering i kryss
– Fysisk fartsregulering, opphøyd kryss	– Stoppliktregulering i kryss
– Bred kantlinje	
– Profilert kantlinje	
– Kantstolpe med refleks	
– Vanlig gangfelt	
– Gangfelt med blandet fase i signalregulert kryss	
– Envegsregulering	
– Sykkelutstyr, eikerefleks	

TØI rapport 1009/2009

Betydelig mangel på kunnskap

Dette prosjekt avslører mangel på kunnskap for atskillige trafikksikkerhetstiltak med hensyn til den trygghetsmessige effekt for myke trafikanter. Blant de 54 tiltakene er effekten kun blitt direkte evaluert ved eller etter gjennomføring for 14 tiltak (26 %) og indirekte for andre 14 tiltak. I tabell S.6. er antall tiltak som er blitt evaluert sammenfattet for fem overordnete grupper av tiltak.

Tabell S.6. Antall tiltak der effekten på trygghet for myke trafikanter er blitt undersøkt direkte eller indirekte.

Kategori	Tiltak	Direkte	Indirekte	Ikke undersøkt
1. Vegutforming og utstyr	17	3	1	13
2. Vegvedlikehold	5	2	3	0
3. Trafikkregulering	17	7	4	6
4. Kjøretøyteknikk og personlig verneutstyr	8	2	3	3
5. Føreropplæring, trafikkopplæring, kontroll	7	0	3	4
I alt	54	14	14	26

TØI rapport 1009/2009

Det er ikke kun mangel på viten i forhold til den trygghetsmessige effekten, men også i forhold til effekten på sikkerhet. Problemet er at den sikkerhetsmessige effekten for syklister og/eller fotgjengere kun er blitt evaluert for under 20 % av de ulike varianter av tiltak. For de resterende tiltak er den generelle effekten for alle trafikanter benyttet i klassifiseringen. Det er således antatt at effekten i forhold til myke trafikanter har samme fortegn som effekten for alle trafikanter. Det er ikke nødvendigvis alltid tilfellet.

Vanskelig å estimere effekt

I dette prosjektet er det identifisert 10 ulike problemer med å estimere effekten av trafikksikkerhetstiltak på trygghet for myke trafikanter:

1. *Få studier:* Effekten på trygghet for myke trafikanter er kun direkte blitt undersøkt for under en fjerdedel av de inkluderte tiltak.
2. *Antall studier:* For hvert av tiltakene som er blitt undersøkt er det gjerne bare en eller to studier som behandler problemstillingen.
3. *Kvalitet på studier:* Kvaliteten på de inkluderte studier er ikke blitt undersøkt systematisk, men flere av studiene er gjennomført med et lavt antall respondenter.
4. *Overfortolkning:* Effekten på trygghet for myke trafikanter er indirekte blitt undersøkt for omkring en fjerdedel av tiltakene. Resultatet av disse undersøkelser kan kanskje være overfortolket.
5. *Kvalitative vurderinger er ikke verifisert:* Antagelse om sammenheng mellom trygghet og faktorer som påvirker trygghet er ikke blitt verifisert på en tilfredsstillende måte.
6. *Vanskelig å summere vurderinger:* Det er vanskelig å vurdere den samlede effekt når faktorer som påvirker trygghet har ulik retning. Det er tilfellet for atskillige tiltak.
7. *Tvetydige eller ukjente resultater:* For flere tiltak er det tvetydige eller ukjente resultater om den trygghetsmessige effekt.
8. *Størrelse av effekt:* Størrelsen av den trygghetsmessige effekt er ofte ukjent.
9. *Mengde:* Mengden av syklister og fotgjengere i området er ikke inkludert i effektvurderingen.
10. *Oppdeling av myke trafikanter:* Myke trafikanter er ikke oppdelt systematisk mellom syklister og fotgjengere. Det er ofte kun mulig i de kvalitative vurderinger.

Behov for mer forskning

På grunn av manglende kvalitet og kvantitet på gjennomførte evalueringer anbefales det å gjennomføre flere undersøkelser både av tiltak som tidligere er blitt evaluert og tiltak som ikke tidligere er blitt evaluert.

Det er identifisert 50 ulike varianter av tiltak som det bør foretas flere undersøkelser av. De 13 (en fjerdedel) mest relevante tiltak for grundigere undersøkelser er blitt utpekt.

Disse tiltak har tvetydig, ukjent, betydelig og/eller omvendt effekt på sikkerhet og/eller trygghet for syklister og/eller fotgjengere. I tillegg er det tiltak der fagfolk er ”uenige” om effekter eller der ikke fagfolk ikke ”forstår eller aksepterer” de funne resultater. Endelig er det tiltak som dominerer den nåværende debatt blant fagfolk og i medier.

De 13 tiltak oppdelt i fire grupper er:

1. *Infrastruktur for myke trafikanter:* Sykkelveger, gangfelt og vintervedlikehold av sykkelveger
2. *Vegens tverrprofil:* Kjørefeltsbredde og skulderbredde
3. *Sikkerhetsutstyr på syklist og sykkel:* Sykkelhjelm, brems, reflekser på sykkel, reflekser på syklist
4. *Regulering av tung trafikk:* Vekt, forbud mod tilhenger, fart, underkjøringshinder.

Ut over evaluering av konkrete tiltak er det også behov for mer generelle undersøkelser som kan verifisere og kvantifisere de antatte sammenhengene mellom trygghet og faktorer som kan tenkes å påvirke trygghet.

1 Introduction

1.1 Background and objective

This report is part of the RiskDisk project (Discrepancies in risk perception), which is a follow up to the RISIT project (Risk and safety in transport) (Forskningsrådet 2008).

The main objective of the RiskDisk project is to study discrepancies between:

- Objective and subjective risk perception
- Emotional and cognitive aspects of risk perception
- Perceived risk for accidents (safety) and unpleasant incidents (security).

This report focuses on the first item among the above-mentioned items. The objective is primarily to study the relationship between road safety measures with confirmed positive effect on road safety and perceived risk for accidents. In other words, the objective is to collect all available knowledge and studies regarding the effects of different road safety measures on subjective safety and make an overall overview of all the measures.

Secondly, the objective is to identify road safety measures where the effect on subjective safety has not been studied, or the conclusions from different studies differ and are not unambiguous, or professionals are disagreeing about the effects. This will be used for selection of road safety measures in further investigations of the RiskDisk project.

There are three reasons why this work is needed:

1. *Subjective safety related to different road safety measures:* Several studies as part of the RiskDisk and the RISIT projects (Amundsen and Bjørnskau 2003, Backer-Grøndahl, Amundsen, Fyhri and Ulleberg 2007, Backer-Grøndahl, Fyhri and Ulleberg 2008, Bjørnskau 2004, Elvik and Bjørnskau 2005) as well as some other projects (Alm and Lindberg 2000, 2002, 2004, Bouyer, Bagdassarian, Chaabanne and Mullet 2001) have studied subjective safety for different cases and from different aspects:
   - For different transport modes as for example plane, train, boat, bus, car, motorcycle, bicycle and walking
   - For different situation as for example day and night
   - In different places as for example stations and bus stops
   - For people with different characteristic as sex and age.

   However, subjective safety related to different road design, road operation and maintenance and for different road (safety) measures have been studied to a lesser extent and summarized in a macro level. It has only been carried out in the micro level regarding the evaluation of concrete measures and projects. A literature search by Sælensminde (2002) illustrates how few studies have been carried out in this respect. A search using the words "insecur?" and "bicycle?" in three bibliographical databases; "ISI Web of Science", "PsycINFO" and "MEDLINE" gave only two hits. A similar literature search by Elvik (2000) in the database www.transportconnect.net gave only one hit. Amundsen and Bjørnskau (2003) therefore recommend more research on how people react to different road measures to increase objective and partly subjective safety.

2. *Effect catalogue:* Effect catalogue or handbooks with summary and overview of the effect of road safety measures on objective safety (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008), and the effect of different measures on the environment regarding noise, energy consumption, climate, pollution, barrier, land use and aesthetics (Amundsen and Kolbenstvedt 2008) exist. However, no comprehensive and complete effect catalogue for road traffic measures on subjective safety has been made.
3. *Traffic planning:* Traffic planning is very complex and it is getting ever more complex as a result of increasing traffic and the progressive focus on its negative effects. The objective of traffic planning is to make the infrastructure as effective as possible by maximising the positive effects such as high mobility and accessibility and minimising the negative effects such as road accidents, insecurity, noise, energy consumption, climate change, pollution, barrier, land use and aesthetics as well as the traffic-related problems such as traffic queue and lack of parking. To make a systematic assessment and selection of the routing of roads, road design and road measures, it is necessary to know the nature and size of the effects including the effects on subjective safety.

1.2 Method

In order to fulfil the project's objective, four different methods are employed through the project as following:

1. Selection of road safety measures
2. Literature study of existing studies and evaluations
3. Theoretical and qualitative considerations
4. Classification of road safety measures.

The purpose of the first part of the project is to select relevant road safety measures for this study. Some criteria for selection are outlined, and all the road safety measures described in "The Handbook of Road Safety Measures" (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008) which fulfil these criteria are chosen. The criteria for selection of road safety measures and the actual selection are described in chapter 3.

Afterwards, a comprehensive literature study regarding each of the selected measures is conducted. The purpose of the literature study is to collect the available knowledge and studies concerning the effects of each measure on subjective safety so that it becomes possible to make an overall estimate of each measure.

The studies have been gathered by means of a systematic literature search consisting of a fixed part and a variable part. The fixed part is a comprehensive search for studies in a sample of sources. The fixed part of the search was conducted for the following samples:

- The bibliographical databases Science Direct, ISI web of Science, Worldcat and Silverplatter, Transport
- www.google.com
- The library of the Institute of Transport Economics
- Scandinavian journals
- Proceedings from selected conferences
- Reports issued by selected research institutes.

The literature search was conducted using the name for the actual measure and a variation of the following key words:

- Subjective safety
- Perceived safety
- Anxiety
- Insecurity
- Public perception/opinion
- Community attitudes.

The variable part of the literature search comprises references found in the reference lists in the studies which were retrieved in the fixed part of the search.

For many of the selected road safety measures, none of the available studies have investigated their effects on the subjective safety of vulnerable road users. Thus, theoretical and qualitative considerations about factors having impact on subjective safety are made in this report for each measure to assess if the measures have positive or negative effects, as well as whether the effects are large, medium or small. The focus in this project is primarily on these assessments.

The last part of the project is a classification of the selected measures based on their effects on objective and subjective safety. The lack of knowledge concerning the subjective safety effects of some measures is also considered and included in this classification.

1.3 Delimitation

The delimitation of the project emerges indirectly from the described objective and methods. However, this is clarified in the following.

– *Road traffic:* The project focuses only on road traffic and not plane, train or boat traffic.

– *Vulnerable road users:* The project focuses only on subjective safety among vulnerable road users, i.e. cyclists and pedestrians. The reason for this is firstly due to the fact that the percentage of road users feeling unsafe is highest among cyclists and pedestrians. It is only motorcyclists that feel more unsafe (Amundsen and Bjørnskau 2003, Bjørnskau 2004). Secondly the discrepancies between objective and subjective safety are especially interesting among vulnerable road users because they have the most discrepancies (Elvik and Bjørnskau 2005).

– *Road safety:* The feeling of subjective unsafety and insecurity is influenced by the possible outcome of a road accident as well as fear for terror and incidents like mugging, harassment or other unpleasant experiences. A study by Backer-Grøndahl, Amundsen, Fyhri and Ulleberg (2007) shows for example that road users worry more about accidents than incidents on private transport modes including bicycles, and more about unpleasant incidents than accidents on public transport modes and as pedestrians. Subjective unsafety in this project primarily refers to the perceived risk and fear of road accidents.

- *Subjectivity:* It is difficult to calculate the subjective safety numerically. In this project it is not tried to make or suggest a method for calculating numerical values for the subjective safety effects. Instead, the effect on subjective safety will be described in terms of positive effect, negative effect, large effect, middle effect, little effect, no effect or unknown effect.

- *Variation:* Subjective safety for different transport modes and situations varies from person to person and may even change for one person over time. The subjective safety for a person is influenced by knowledge, experience, life situation and technological development (Drottz-Sjøberg 1991). In this project it is only tried to identify a kind of average effect on subjective safety.

- *North Europe:* The description of the effects on objective and subjective safety in this study is primarily based on the situation in North Europe, but all the available evaluations from the western world are included in the literature study.

- *Road safety measures:* The included road safety measures are not described thoroughly. To get a thorough description of each measure, we refer to Elvik and Vaa (2004).

- *First version:* This is the first attempt to make a catalogue regarding the effects of road safety measures on subjective safety. Thus, it should not be considered as a complete work at this stage. It is recommended to systematise, extend and update the catalogue regularly.

1.4 Report structure

This report is divided into eight chapters and one appendix.

The next chapter is a clarification of the objective and subjective safety concepts and the correlation between them. Objective and subjective safety for cyclists and pedestrians are also described in this chapter.

Selecting the relevant road safety measures are accomplished in chapter 3. Chapter 4 and 5 summarise the effects on objective and subjective safety for the selected measures.

Based on the results from chapter 4 and 5, the selected measures are classified in different categories in chapter 6.

Gaps of knowledge are clarified in chapter 7, and chapter 8 is the conclusion.

The appendix consists of a comprehensive clarification of the effects on subjective safety among vulnerable road users for each of the 54 selected road safety measures. Thus, if the reader wants to read more about specific road measures we refer to the appendix. The appendix also includes a lot of references to relevant studies about each measure.

2 Subjective and objective safety

This chapter describes objective and subjective safety concepts regarding cyclists and pedestrians. Correlation between objective and subjective safety is also described in this chapter. Finally, factors influencing subjective safety are described.

2.1 Objective safety

2.1.1 Definition

Objective or statistic road safety is a measure for road safety which is based on the recorded numbers of road accidents and injuries. Objective safety can be described as the actual numbers, but it can also be described as risk. Risk is normally understood as the probability of road accident or injury per unit of road traffic exposure. Road traffic risk is normally calculated as the number of accidents or injuries per distance travelled. Risk figures are useful in order to compare how different groups are at risk in road traffic. Thus, it is also useful in order to select road safety measures which may be most efficient (Bjørnskau 2008).

2.1.2 Cyclists

Every year about 730 cyclists are injured and 7-8 killed in Norway according to the official statistics for road accidents. However, the real numbers are much higher as many of the accidents, especially single accidents, are not recorded by the police. Table 2.1 summarizes the police recorded number of killed and injured cyclists in Norway in 2005-2007.

Table 2.1. Killed and injured cyclists in Norway (Statistisk sentralbyrå 2008).

	2005	2006	2007
Fatalities	7	8	7
Critically injured cyclists	1	4	4
Seriously injured cyclists	52	64	56
Slightly injured cyclists	675	596	607
Unknown injury	8	67	67
Total	743	739	741

Table 2.2 summarizes the risk for cyclists in Norway calculated as killed and injured cyclists per million person kilometre. In 2005, 0.82 cyclists were killed or injured per million person kilometres. 0.011 cyclists were killed per million person kilometres.

In the last 20 years the risk for cyclists has decreased from 1.43 to 0.82 killed or injured per million person kilometres.

Compared to other groups of road users, the risk for cyclists is the third highest. It is only riders of mopeds and light motorcycles that have a higher risk. Compared to car drivers and passengers, cyclists have 5-6 times higher risk. On average, the injury rate for cyclists in the six countries of Norway, Denmark, Sweden, Germany, The Netherlands and Great Britain is about 9 times higher than the injury rate for car drivers based on studies from 1990 to 2002 (Elvik and Vaa 2004).

The calculation of risk is based on the police recorded road accidents, so the real risk is much higher. At the same time, the number for exposure is uncertain (Bjørnskau 2008).

Table 2.2. Killed and injured road users in Norway per million person kilometres in 1985, 1992, 1998, 2001 and 2005 divided on different groups of road users (Bjørnskau 2008).

	1985	1992	1998	2001	2005
Car drivers	0.19	0.19	0.19	0.18	0.15
Car passengers	0.19	0.17	0.16	0.14	0.13
Pedestrians	0.64	0.79	0.68	0.63	0.47
Cyclists	1.43	1.22	1.23	1.08	0.82
Moped riders	2.12	1.45	1.22	1.31	1.29
Light motorcycle riders	4.23	1.56	1.48	1.38	1.27
Heavy motorcycle riders	4.20	1.69	1.33	0.91	0.61

2.1.3 Pedestrians

Table 2.3 summarizes the number of killed and injured pedestrians in Norway in 2005, 2006 and 2007. The number of annual killed pedestrians varies between 23 and 35 and the annual numbers of injured pedestrians recorded by the police varies between 790 and 870.

Table 2.2 shows the number of killed and injured pedestrians per million person kilometres. In 2005 0.47 pedestrians were killed or injured per million person kilometres. At the same time, 0.017 pedestrians were killed per million person kilometres. In the last 20 year the risk for pedestrians has varied between 0.79 killed or injured per million person kilometres in 1992 and 0.47 in 2005.

Compared to other groups of road users, the risk for pedestrians is the third lowest. It is almost half the risk for cyclist. Compared to car drivers and passengers, pedestrians 3-4 times higher risk. In Norway, Denmark, Sweden, Germany, the Netherlands and Great Britain the injury rate for pedestrians is in average about seven times as high as the injury rate for car drivers (Elvik and Vaa 2004).

Table 2.3. Killed and injured pedestrians in Norway (Statistisk sentralbyrå 2008).

	2005	2006	2007
Fatalities	32	35	23
Critically injured pedestrians	9	10	9
Seriously injured pedestrians	93	114	75
Slightly injured pedestrians	738	676	632
Unknown injury	11	67	75
Total	883	902	814

2.2 Subjective safety

2.2.1 Definition

Subjective safety is also termed as perceived safety, insecurity or anxiety. In this project the subjective safety term is used. There are several definitions and descriptions regarding subjective safety. Six examples are as following:

- Feeling of safety, i.e. how people subjectively experience accident risk in traffic. How much do people believe that the risk of accident exists, and how uncomfortable they feel about it? The answer to this combined question is an expression for subjective safety. In other words, subjective safety has two dimensions: How dangerous do people perceive traffic and how unpleasant is this belief (Elvik, Erke and Vaa 2008).
- Insecurity in traffic is a feeling of discomfort that occurs when a person feels overruled or looses control in a traffic situation. This is related to the feeling of traffic safety and accident risk in a specific situation and/or location. Insecurity can also occur when walking along a road or crossing it, but also on footpaths with separate paths (Nielsen, Thesberg, Jensen and Sørensen 2007).
- Perceived risk in transport depends mainly on: a) the potential of catastrophe, b) the likelihood of being killed in an accident c) the degree to which we individually control the activity and possible outcome (Amundsen and Bjørnskau 2003).
- The concept consists of two parts; an emotional component which among other factors include insecurity, fear, anxiety and worry, and a cognitive component which represents the perceived risk of an accident or injury (Sjöberg 1993).
- Subjective safety is the sum of two thoughts; the possibility for an accident and the consequence of a possible accident (Værø 1992).
- Subjective safety is also the feeling of unsafety for other people. For example parents worry for their children when they walk and play nearby traffic (Køltzow 1986, Elvik, Kolbenstvedt and Strangeby 1999).

2.2.2 Cyclists

Subjective safety of different road users including vulnerable road users has been studied in some projects. Results from two projects are summarized in the following.

In the first study by Bjørnskau (2004), 1,000 Norwegians were asked how safe they think it is to travel by eight different modes of transport. The results are summarized in table 2.4.

3 % think that it is very unsafe to cycle and 25.1 % think it is a little unsafe. This is the second highest percentage of unsafety. Only the percentage of unsafety for motorcycling is higher.

In the other study by Backer-Grøndahl, Amundsen, Fyhri and Ulleberg (2007) respondents were asked how much on a scale from one to five they worry about accidents and/or unpleasant incidents for nine different means of transport. The number of people which were interviewed was between 568 and 833 for each mode of transport.

Respondents reported to worry most about accidents when travelling with motorcycle, followed by car and bicycle. 7 % find cycling very unsafe (rank 5) and 12 % find cycling a little unsafe (rank 4).

Regarding unpleasant incidents, cycling gets the third lowest level. Only 5 % of the respondents associated cycling with unpleasant incidents.

Table 2.4. Results of a sample survey in Norway concerning how safe various modes of transport are perceived to be. Percentage distribution of answers (Bjørnskau 2004, Elvik and Bjørnskau 2005).

	Very safe	Safe	A little unsafe	Very unsafe	Do not know	Total
Air	57.4	37.3	3.1	1.3	1.1	100
Train	55.2	39.9	2.7	0.2	1.6	100
Boat	44.6	48.8	4.6	0.3	1.7	100
Bus	49.4	48.4	1.4	0.1	0.7	100
Car	21.3	68.0	9.4	0.8	0.5	100
Motorcycle	2.5	24.8	53.3	14.8	4.6	100
Bicycle	18.2	50.7	25.1	3.0	3.0	100
Walking	22.4	57.8	15.7	2.3	1.8	100

Table 2.5. Worry about accidents and unpleasant incidents on different means of transport. Means on a scale from one to five (Backer-Grøndahl, Amundsen, Fyhri and Ulleberg 2007, Backer-Grøndahl, Fyhri and Ulleberg 2008).

Transport mode	Accidents	Unpleasant incidents
Bus	1.94	1.80
Train	1.56	1.65
Metro	1.81	2.38
Tram	1.68	2.10
Taxi	2.36	1.91
Car	2.58	1.29
Motorcycle	3.85	1.54
Bicycle	2.55	1.59
Pedestrian	1.88	2.14

2.2.3 Pedestrians

Table 2.4 and table 2.5 describe subjective safety for pedestrians. According to Bjørnskau (2004), 2.3 % of the respondents think that it is very unsafe to walk and 15.7 % think it is a little unsafe. This means that walking is perceived a little more safe than cycling.

According to Backer-Grøndahl, Amundsen, Fyhri and Ulleberg (2007), people do not worry much about accidents when walking. Only 7 % find walking very unsafe or a little unsafe. On the contrary, walking gets a high score regarding unpleasant incidents. It is only travelling by metro which gets a higher score. 12 % of the respondents associate walking with unpleasant incidents.

2.3 Correlation between objective and subjective safety

The nature of correlation between objective and subjective safety depends on parameters being analysed. The nature of correlations varies for:

- Area
- Locations
- Means of transport
- Road safety measures.

An analysis of correlation between car drivers' objective risk and reported feeling of risk in 19 Norwegian counties has been made. No correlation was found. However, the result should be taken with caution due to difficulties with measuring of subjective safety and because the calculation of correlation was done on aggregate level rather than individual level (Elvik 1997, Vaa 1991a).

Figure 2.1 shows an example on correlations between number of times a location has been mentioned as dangerous and number of recorded accidents at the location. The figure shows only a very weak correlation. This means that the locations people find dangerous are not necessary those which most road accidents happen (Elvik, Erke and Vaa 2008). Maybe there is a larger correlation between risk where traffic volume is included and subjective safety, but this has not been investigated.

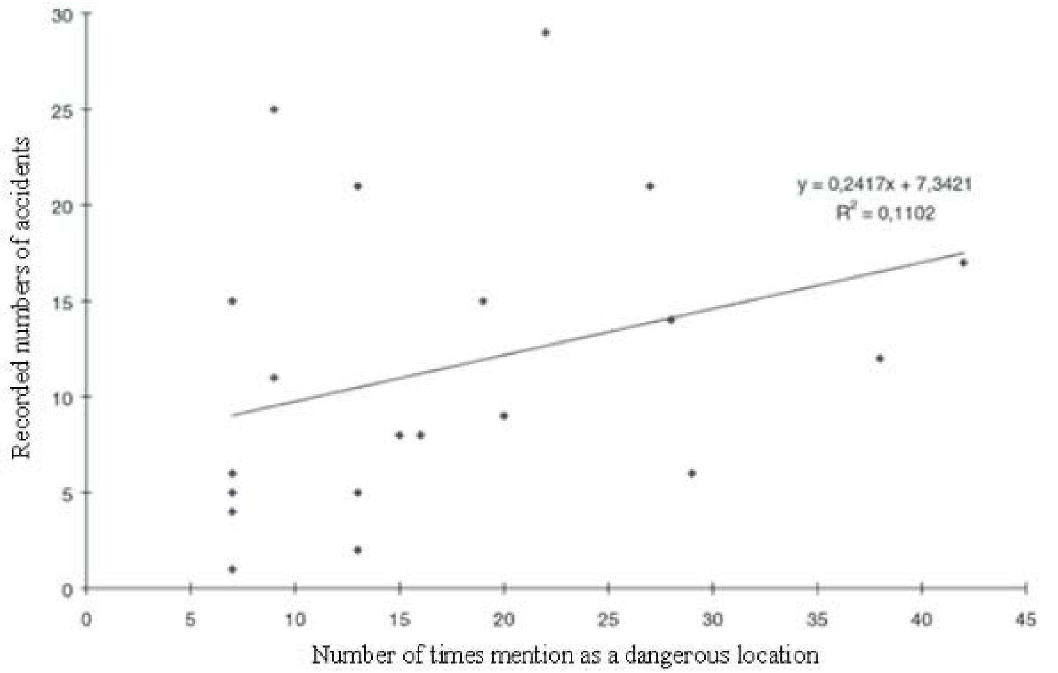

Figure 2.1. Correlation between number of times a location has been mentioned as dangerous and number of recorded accidents at the location (Hvoslef 1980).

Figure 2.2 shows an example on correlations between actual and perceived fatality risk for various modes of transport in Norway. The figure shows that the differences in fatality rate between different modes of transport are quite well perceived by the Norwegian public (Elvik and Bjørnskau 2005).

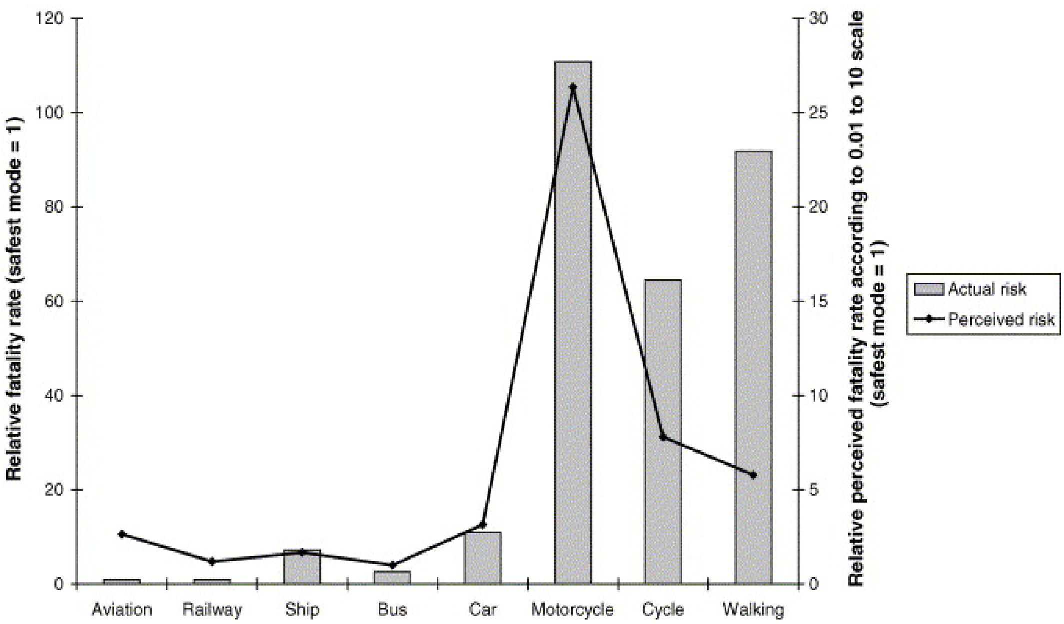

Figure 2.2. Relationship between actual and perceived fatality risk for various modes of transport in Norway (Elvik and Bjørnskau 2005).

Regarding road safety measures the correlation between the effect on objective and subjective safety will probably vary a lot. Some measures have positive effect on both objective and subjective safety, some have positive effect on objective safety and negative effect on subjective safety, and others have negative effect on objective safety while positive effect on subjective safety.

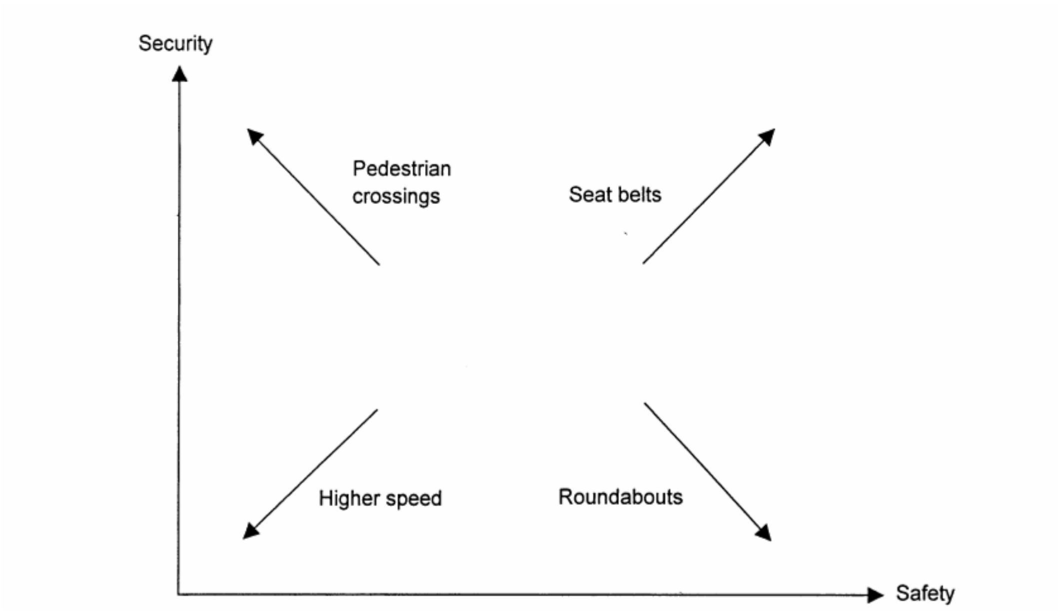

Figure 2.3. Potential relationship between effects on safety (objective safety) defined as the actual number of accidents and effects on security (subjective safety) defined as feeling of safety for four safety measures (Elvik 2000).

The possible different effect on objective and subjective safety is illustrated in figure 2.3 for four different measures. It is seen that the use of seat belts is assumed to improve both safety and security. Higher speed is assumed to reduce both safety and security. The other two cases present a conflict. An ordinary marked pedestrian crossing makes pedestrians feel safer but actually increases the number of accidents. The opposite is the case for roundabouts. It seems likely that roundabouts make drivers feel a little more insecure at the same time that the effect on objective safety is positive (Elvik 2002).

2.4 Factors influencing subjective safety

For many of the selected road safety measures, none of the available literature has studied their effects on the subjective safety of vulnerable road users. To overcome this problem it is tried to make a more "theoretical consideration" about the possible effects. For this purpose, all factors having impacts on subjective safety of vulnerable road users are identified and listed here.

According to Amundsen and Bjørnskau (2003) only few projects have studied how the percentage of road users feeling unsafe or the degree of subjective safety is influenced by different factors. However, among the few available studies it seems that traffic volume is an important factor regarding subjective safety. The more the traffic, the higher percentage states that they feel unsafe. Lower speed is also mentioned frequently when people are asked about what can be done to increase their sense of safety in traffic.

Slippery and icy road conditions also increase the percentage of road users feeling unsafe. Finally, car drivers feel safer if they consider themselves as good drivers (Amundsen and Bjørnskau 2003).

According to a study by Backer-Grøndahl, Amundsen, Fyhri and Ulleberg (2007), carelessness of other road users as well as bad road conditions are factors which respectively contribute most to the feeling of unsafety among bicyclists. Dense traffic also contributes to the sense of unsafety. When it is dark, bad road lighting increases the percentage of both bicyclists and pedestrians feeling unsafe. Note that this feel of unsafety regards both road accidents and other unpleasant experiences.

Elvik and Sælensminde (2000) describes that subjective safety among vulnerable road users primarily is determined by traffic volume, speed and the number of road accidents.

A study by Kolbenstvedt (1986) showed that people living in areas where pedestrians and cars are separate feel less unsafe than people living in areas where pedestrians and cars are integrated.

According to Sælensminde (2002), subjective safety of cyclists and pedestrians is to a great extent dependent on whether they have their own tracks for cycling and walking, or they should share paths with motorized traffic. However, tracks for cycling and walking do not completely eliminate the sense of unsafety because of the crossings between tracks and roads. Different designs of the crossings are also associated with different levels of perceived unsafety. Additionally, parameters such as width, sight and maintenance of the tracks including holes and cracks, sand and gravel in the road surface, and winter maintenance do also influence the feel of safety. Comfort is also influenced by these parameters.

A study regarding attitudes for substitution of car trips with walking and cycling concludes that one of the barriers towards this purpose is the feeling of unsafety. The most central source to feeling unsafe is small distance between vulnerable road users along the road and a large traffic volume (Lodden 2002, Stangeby 1997). Thus, the most important infrastructural and political measures to improve the conditions for vulnerable road users including promotion of subjective safety are shown in following (Stangeby 1997):

Infrastructural measures:

- More footpaths and cycling lanes
- Wider pavement
- Improved pedestrian subways and crossings
- Smoother road surface.

Political measures:

- Prohibit cycling on pavements
- City centres free of cars
- Priority for walkers at crossings
- Different measures to reduce car traffic.

In Denmark a formula for calculation of subjective safety of people cycling or working in or along a road have also been developed. The formula is (Miljøministeriet 1992, Lahrmann and Leleur 1994, Værø 1992):

$$S = 0.5 \cdot 0.1 \cdot \sqrt{ÅDT} \cdot \left(\frac{V}{50}\right)^3 \cdot (1.87 \cdot La + 0.63) \cdot (C + F)\text{, where}$$

S: Subjective safety. The factor 0.5 indicates that the calculation is done for each road side. The total number for subjective safety is calculated as the sum of the calculation for each side. Depending on the number subjective safety classifies as insignificant, small, medium or large

ÅDT: Traffic volume

V: Speed

La: Percentage of heavy vehicles

C: Factor for existence of cycle path or cycle lane. The factor varies between 0.1 for no cycling path to 0.5 for cycling path at the same side

F: Factor for existence of foot path. The factor varies between 0.1 for no walking path to 0.5 for walking path at the same side.

According to this formula, traffic volume, speed, heavy vehicles and the existence of cycle and foot path have impact on subjective safety of vulnerable road users. In addition, Miljøministeriet (1992) describes that distance between motor vehicles and vulnerable road users influence the feeling of safety. This means that subjective safety, for example, can be improved by making the cycle or foot paths wider or having a verge and parking area between them and the road. Værø (1992) also mentions that besides traffic volume, thoughtfulness of drivers has the most influence on the subjective safety.

Vejdirektoratet (2009) has made a model regarding how to prioritise cycle tracks outside cities. The model is based on a point system where different road design parameters are assigned with different points. Subjective safety is included in the model as one of the seven parameters.

Table 2.6 explains how points for subjective safety are estimated. The calculation is based on information about traffic volume, volume of heavy vehicle, lane width, speed limit, shoulder width and number of crossings. It is explained that different parameters have different importance. The most important parameters in prioritised order is: 1) lane width, 2) volume of heavy vehicles, 3) speed limit, 5) shoulder width and 6) number of crossings. It is not indicated how important traffic volume is.

Table 2.6. Assignment of the points for subjective safety in the Danish model to prioritise cycle tracks outside cities. Each column is given a point, and the total points for subjective safety is the sum of the points in the six columns (Vejdirektoratet 2009).For example a road with traffic volume = 3000, heavy vehicle = 500, lane width = 10, speed limit = 50, shoulder width = 1.5 and crossing = 3 gets 0.8+1.2+0.8+1.6+0.8+0.4 = 5.6 points. These points are summarises with points for other parameters. Cycle tracks are planned for roads with most points.

Traffic volume (AADT)	Heavy vehicle (AADT)	Lane width (m)	Speed limit (km/t)	Shoulder width (m)	Crossings pr. km	Point
0 - 2000	0 - 200			> 2	0 - 4	0.4
2001 - 4000	201 - 400	> 9.0	< 50	1.6 - 2	5 - 8	0.8
4001 - 6000	401 - 600			1.1 - 1.5	9 - 12	1.2
6001 - 8000	601 - 800	8.51 - 9.0	50	0.6 - 1.0	13 - 16	1.6

Fyhri (2002, 2005) has made two studies about children’s journey to school in 2002 and 2005 respectively among 6,900 and 7,500 primary school pupils aged 6, 8 and 12 years. The pupils were chosen from representative sample of schools in Norway. The results show that the pupils considered the following factors as “unsafe” in traffic:

1. Difficult road to cross (stated by 31 % in 2002 and 29 % in 2005)
2. No footpaths or bicycle lane (stated by 24 % in 2002 and 23 % in 2005)
3. High speed (stated by 19 % in both 2002 and 2005)
4. High traffic volume (stated by 17 % in both 2002 and 2005)
5. Too narrow road (stated by 11 % in 2002 and 12 % in 2005)
6. Other reasons (stated by 9 % in 2002 and 8 % in 2005)
7. No road light (stated by 7 % in both 2002 and 2005).

Similarly, Fyhri and Hjorthol (2006) studied the factors which are considered by parents as “unsafety” for children on their way to school. 734 parents answered the questionnaire. The most unsafe factors expressed by the parents were respectively as following:

1. High traffic volume and high speed along the road (stated by 63 %)
2. No bicycle lane (stated by 52 %)
3. No footpath (stated by 48 %)
4. No pedestrian crossing (stated by 43 %)
5. Bad winter maintenance (stated by 35 %)
6. High traffic volume and high speed at intersections (stated by 31 %)
7. No signal-controlled pedestrian crossings (stated by 29 %)
8. Lack of light on the road (stated by 29 %)
9. No tunnel or bridge for vulnerable road users (stated by 16 %)
10. Cycle and moped traffic with high speed (stated by 13 %)
11. Other factors (stated by 17 %).

Nielsen, Thesberg, Jensen and Sørensen (2007) have analyzed existing school route surveys carried out in Denmark from 2002 to 2007 in nine of the 13 old municipalities. It comprised 152 schools, and 31,513 children were interviewed. Among almost 32,000 children the following factors were pointed out as unsafe:

1. Many cars (stated by 21 %)
2. High speed (stated by 19 %)
3. Difficult to cross road (stated by 13 %)
4. Cars do not stop (stated by 12 %)
5. Bad sight conditions (stated by 8 %)
6. No footpaths or bicycle lane (stated by 7 %)
7. No light on paths (stated by 4 %)
8. Dangerous junction (stated by 1 %)
9. Many lorries (stated by 1 %).

Regarding the geometry of crossings, 3-leg junctions were stated as “unsafe” by 44%, 4-leg junctions were mentioned as “unsafe” by 15 %, and junctions between roads and paths were pointed out as “unsafe” by 13 % of the children (Nielsen, Thesberg, Jensen and Sørensen 2007).

Another study (Landis 2003) sought to mathematically express intersections’ geometry as well as operational and traffic characteristics which affect bicyclists’ perception of quality of service. A special event was created to place a significant number of bicyclists on a roadway course which would take them through various intersection configurations. The purpose was to obtain the cyclists’ real-time responses to the roadway environment stimuli and to create and test a mathematical relationship between measurable factors and the participants’ reactions. The study reveals that roadway traffic volume, total width of the outside through lane, and intersection’s crossing distance are the primary factors affecting the cyclists’ perception of safety and comfort through movements at intersections.

Crossing distance is the measure of the cross street's width. It includes the widths of all lanes (through and auxiliary lanes) and medians of a cross street.

Shortening crossing distances is recommended by Toole and Zimny (1999) as the pedestrian and bicycle-friendly design solution for intersections.

According to Steinman (2003), the shorter distance one has to walk to cross a street, the easier and more comfortable it is perceived to be. The primary impediments to comfort and safety of pedestrians which cross signalized intersections are the crossing distance as well as their conflicts with turning vehicles.

In table 2.7 it is tried so summarize the factors influencing subjective safety of vulnerable road users and the way they affect it. Total 14 different factors have been identified previously as affecting factors.

In this report, two other factors which can have impacts on the subjective safety of vulnerable road users are also supplemented to the previous 14 factors. These two factors are:

- Personal protection equipment
- Volume of cyclists and pedestrians.

Table 2.7. Factors influencing subjective safety of vulnerable road users.

Factor	Impact	
Traffic volume	More traffic → more unsafety	↑ Large significance
Speed	Higher speed → more unsafety	
Heavy vehicle	More heavy vehicle → more unsafety	
Thoughtfulness	More thoughtfulness from drivers → less unsafety	
Distance (width of lanes and shoulders)	More distance between vehicles and vulnerable road users → less unsafety	
Crossing distance	Less crossing distance → less unsafety	
Vulnerable road users	More cyclists and pedestrians → less unsafety	
Cycle and foot path	Cycle and foot path → less unsafety	
Separation/integration	Separation → less unsafety	
Design of intersections	3-leg and 4 leg junction → more unsafety	
Number of crossings	More crossings → more unsafety	
Road conditions	Slippery, icy and holes → more unsafety	
Sight conditions	More sight → less unsafety	
Road light	More light → less unsafety at night	
Skills	More skills → less unsafety	
Personally protection	More protection equipment → less unsafety	↓ Small significant

TØI report 1009/2009

In table 2.7 it is tried to indicate how important each factor is regarding the subjective safety of vulnerable road users. But it should be considered that this list may vary for different people in different places and situations. However, it still gives a general idea of the factors which normally have the most and least impact on the subjective safety of vulnerable road users.

2.5 Summary

Objective safety can be described as the actual number of road accidents or injured, but it can also be described as risk, which is the probability of accident or injury usually expressed per unit of road traffic exposure.

Subjective safety is the feeling of safety, i.e. how people subjectively experience accident risk in traffic. Several definitions and explanations of subjective safety exist.

Every year about 7-8 cyclists and 23-35 pedestrians are killed in Norway, and 730 cyclists and 790-870 pedestrians are injured according to the official statistics for road accidents. However, the real number is much higher particularly regarding cyclists as many of accidents, especially single accidents, are not recorded by the police.

Subjective safety of vulnerable road users has been studied in different projects. In one study (Bjørnskau 2004) 3 % answered that they think it is very unsafe to cycle. 2.3 % believed that it is unsafe to walk. These were respectively the second and third highest percentages regarding subjective unsafety of different modes of traffic. Only the percentage for motorcycling was higher than these. In another study, 19 % of participants found cycling very unsafe or little unsafe. Only 7 % of the participants found walking very unsafe or a little unsafe (Backer-Grøndahl, Amundsen, Fyhri and Ulleberg 2007).

The nature of correlation between objective and subjective safety depends on different parameters:

- *Area:* Probably no correlation
- *Locations:* Bad correlation in many cases
- *Means of transport:* Normally good correlation
- *Road safety measures:* Different correlation for different measures.

To sum up, 16 different factors which have been identified to have impacts on subjective safety of vulnerable road users to larger or lesser extends. In table 2.7 these factors are ranked by their importance for subjective safety.

3 Selection of road safety measures

In this chapter the criteria for selection of road safety measures are summarize for further investigation. Afterwards, the selection of measures is made.

3.1 Criteria

The following three criteria are formulated for selection of road safety measures:

1. *Effect on vulnerable road users:* The measure has or is expected to have some direct, immediate, logical and/or significant effect on cyclists and/or pedestrians. Measures which are expected to have indirect and/or insignificant effect on cyclists and/or pedestrians are not included. An example is roadside rest and service areas which may provide much awareness and concentration for car drivers and therefore leads indirectly to higher level of objective and subjective safety among vulnerable road users.
2. *Effect on objective or subjective safety or mobility:* The measure has or is expected to have some effects on 1) objective safety 2) subjective safety, or 3) mobility and accessibility for vulnerable road users. Objective and subjective safety should be obviously included in the criteria. Mobility and accessibility are also included because several measures are implemented with the initial objective of improving mobility and accessibility for vulnerable road users to encourage more people to bike and/or walk.
3. *Measures under the specific approaches:* Road safety measures are normally divided into road measures, vehicle measures and road user measures. At the same time, a road accident is divided into the following three phases: Pre crash, crash and post crash. As illustrated in table 3.1, Haddon has combined these two divisions in the Haddon matrix, which offers nine different approaches for road safety work (Haddon 1970).

Table 3.1. The Haddon-Matrix which offers nine different approaches for road safety work (Haddon 1970).

	Road	Vehicle	Road user	Method
Pre-crash phase	1a	2a	3a	Crash prevention
Crash phase	1b	2b	3b	Loss reduction
Post-crash phase	1c	2c	3c	Damage control
Method	Site specific	Not site specific		

In this project it is more sensible to add a third dimension to the two dimensional Haddon-Matrix. The third dimension is the different groups of road users. The measures are then divided into the following three groups:

- General improvement for all road users
- Specific improvement for vulnerable road users
- Specific improvement for non-vulnerable road users.

Based on this classification the study is delimited to measures under the following approaches:

I. Road measures (pre-crash and crash phase):
   - General improvement of road safety for several road users
   - Specific improvement of objective safety among vulnerable road users
   - Specific improvement of subjective safety among vulnerable road users
   - Specific improvement of mobility and accessibility for vulnerable road users.

II. Vehicle measures (pre-crash and crash phase):
   - Specific improvement of objective safety among vulnerable road users
   - Specific improvement of subjective safety among vulnerable road users
   - Specific improvement of objective safety for vehicles is not included because it is not assumed to have any or only small effect on the subjective safety among vulnerable road users. An example is ABS brakes on motor vehicles
   - Specific improvement of mobility for vulnerable road users (bikes) is not included. An example is less number of heavy bikes that can improve mobility.

III. Road user measures (pre-crash and crash phase):
   - Specific improvement of objective safety among vulnerable road users (primarily cyclists). An example is bicycle helmet
   - Specific improvement of subjective safety among vulnerable road users (primarily cyclists). An example is safety vest
   - General legislation, information and campaigns are not included.

4. *Special attention:* Special attention in the selection is made on the following measures or situations:
   - The situation is known to have a high objective risk for vulnerable road users
   - Risk compensation is expected or know to play a central role
   - Professionals disagree about the effect of the measure on objective or subjective safety.

3.2 Selection

The selection is carried out by going through all road safety measures described in "The Handbook of Road Safety Measures" (Elvik and Vaa 2004) as well as the new measures which have been updated in the new version of the online handbook (Elvik, Erke and Vaa 2008). The measures which fulfil the described criteria are selected for further investigation.

The handbook includes the following eight categories of safety measures:

1. Road design and road furniture
2. Road maintenance
3. Traffic control
4. Vehicle design and protective devices
5. Vehicle and garage inspection
6. Driver training and regulation of professional drivers
7. Public education and information
8. Police enforcement and sanctions.

In the selection of safety measure in this report, the same category titles are used. Table 3.2 summarize the road safety measures which are selected under each title. Table 3.3 summarizes the total number of road safety measures selected under each category. Note, that the possible effects on objective and subjective safety of vulnerable road users are described in chapter 4, chapter 5 and the appendix.

Besides the measures under the eight categories, the handbook also includes a section regarding so called "General-Purpose Policy Instruments". This for example includes exposure control, land use plans, road plans, changes in the modal split of travel and environmental zones. These instruments may affect subjective safety of vulnerable road users. However, as such instruments are not considered as traditional road safety measures, they are therefore not included in this project.

Among the 20 road design and road furniture measures in "The Handbook of Road Safety Measures", 17 are selected for further investigation. Measures to avoid accidents involving wild animals, improving tunnel safety and roadside rest and service areas have not been selected. The first and third measures are not relevant to vulnerable road user, and the second measure has not been included because there are usually few or no vulnerable road users in road tunnels.

Among the nine road maintenance measures, five have been included in the study. The four remaining measures are assessed to have no or very little effect on objective or subjective safety of vulnerable road users. This are measures as for example correcting erroneous traffic signs.

21 traffic control measures are described in "The Handbook of Road Safety Measures". Among these, 17 measures have been selected for further investigation. Reversible lanes are normally used on roads without vulnerable road users. Dynamic route guidance, variable message signs and protecting railway-highway grade crossings normally address motor vehicle users.

Table 3.2. Selection of measures in the eight categories of safety measures category of road design and furniture.

Road design and furniture	
1	Tracks for walking and cycling
2	Motorways
3	Bypasses
4	Arterial roads in and around cities
5	Channelisation of junctions
6	Roundabouts
7	Redesigning junctions
8	Staggered junctions
9	Interchanges
10	Black spot treatment
11	Cross section improvements
12	Roadside safety treatment
13	Improving road alignment and sight conditions
14	Rehabilitation, reconstruction and resurfacing of roads
15	Guardrails and crash cushions
16	Horizontal curve treatments
17	Road lighting
Road maintenance	
1	Ordinary resurfacing of roads
2	Improving the evenness of the road surface
3	Improving road surface friction
4	Winter maintenance of roads
5	Winter maintenance of pavements and foot and cycle paths
Traffic control	
1	Area-wide traffic calming
2	Environmental streets
3	Pedestrian streets
4	Urban play streets
5	Access control
6	Priority control
7	Yield signs at intersections
8	Stop signs at intersections
9	Traffic signal control at intersections
10	Signal-controlled pedestrian crossings
11	Speed limits
12	Speed-reducing devices
13	Road markings
14	Traffic control for pedestrians and cyclists
15	Parking regulations
16	One-way streets
17	Bus lanes and bus stop design
Vehicles and protective devices	
1	Reflective materials and protective clothing
2	Cycle helmets
3	Regulating vehicle mass
4	Regulating automobile engine capacity and top speed
5	Under-run guard rails on trucks
6	Safety equipment on trucks
7	Bicycle safety equipment
8	Safety standards for trailers and caravans
Driver training and regulation	
1	Safety standards for transporting school children
Education and information	
1	Education of pre-school children
2	Education in schools
Enforcement and sanctions	
1	Stationary speed enforcement
2	Patrolling
3	Automatic speed enforcement
4	Red light cameras

TØI report 1009/2009

Among the 29 measures regarding vehicle design and protective devices, eight have been chosen for further investigation in this project. The remaining 21 focus on safety of motorists.

None of the four measures dealing with vehicle and garage inspection are included in this study because they all deal with inspection of cars or lorries.

The study only includes one of the 13 measures under the category of driver training and regulation of professional drivers. The reason is that the other measures just focus on drivers of motor vehicles.

Two of the four public education and information measures are selected. Education and information dealing with vehicle drivers are not included here.

Among the 11 police enforcement and sanctions measures, four are selected for further investigation in this project.

3.3 Summary

Table 3.3 summarizes the number of selected measures for investigation. Totally, 54 out of 111 measures have been selected. This correspondent to almost 50 % of the total measures.

Most measures are those regarding road design and road furniture or measures about traffic control. 17 out of the 20 road design measures and 17 out of the 21 traffic control measures have been selected.

No measures about vehicle and garage inspection have been selected and only few measures under the category of "Driver training and regulation of professional drivers" and "Police enforcement and sanctions" have been selected.

Table 3.3. Number of selected measures under the nine different categories.

Road Design and Road Furniture	17
Road Maintenance	5
Traffic Control	17
Vehicle Design and Protective Devices	8
Vehicle and Garage Inspection	0
Driver Training and Regulation of Professional Drivers	1
Public Education and Information	2
Police Enforcement and Sanctions	4
Total	54

TØI report 1009/2009

4 The effects on objective safety

This chapter summarises the effects of the 54 selected road safety measures on objective safety for. The effects are particularly summarized for vulnerable road users if possible; otherwise, the general effects are indicated.

This chapter is included in this report to let the reader follow it without the need for referring to "The Handbook of Road Safety Measures".

This chapter is in fact a very short summary of the results from "The Handbook of Road Safety Measures" (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008). Not all the effects for different types of accident and road design are included in this report, but just those which are most relevant to the topic. For further information regarding the effects on number and severity of road accidents, "The Handbook of Road Safety Measures" is recommended as the reference.

To provide an applicable overview of the effects, they are divided into positive and negative effects as well as small, medium and large effects. Small, medium and large effects are defined as:

- Small effect: 1-9 %
- Medium effect: 10-19 %
- Large effect: Over 19 %.

It is also indicated if the effect is significant.

4.1 Road Design and Road Furniture

Table 4.1 summarizes the effects on road accidents for the selected 17 road design and road furniture measures.

It is only for distinct cyclist and pedestrian measures, i.e. track for walking and cycling, pavement, cycle lanes and cycle lanes in intersections that the effects exclusively on cyclist and pedestrian accidents are summarised by Elvik and Vaa (2004). Even though the measures are regarding cyclists and pedestrians, they only have a small positive effect on objective safety of vulnerable road users. Tracks for cycling have a negative effect.

Most of the measures have positive effects on the number of injury accidents as it is expected. However some of them such as channelisation of t-junctions, some improvement of sight conditions and some curve treatments have negative effects on the objective safety.

*Table 4.1. Effect of 17 road design and furniture measures on objective safety (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008). Note that some of the 17 measures in accordance with the handbook have been divided into submeasures. * indicates significant effect.*

	Measures	Accident affected	Best effect estimate (%)	Effect, summary
1a	**Track for walking and cycling**	Cycle accidents	+1	Small negative
		Pedestrian accidents	-10	Medium positive
1b	**Pavement**	Cycle accidents	-30*	Large positive
		Pedestrian accidents	-5	Small positive
1c	**Cycle lanes**	Cycle accidents	-2	Small positive
		Pedestrian accidents	-5	Small positive
1d	**Cycle lanes in intersections**	Cycle accidents	-12	Medium positive
2	**Motorways**	Injury accidents	-7*	Small positive
3	**Bypasses**	Injury accidents	-25*	Large positive
4	**New arterial roads**	All accidents	-1	Small positive
5a	**T-junctions, full channelisation**	Injury accidents	+16	Medium negative
5b	**Crossroads, full channelisation**	Injury accidents	-27*	Large positive
5c	**T-junctions, minor road channelisation**	Injury accidents	+18*	Medium negative
5d	**Crossroads, minor road channelisation**	Injury accidents	-17	Large positive
5e	**T-junctions, physical left-turn lane**	Injury accidents	-27	Large positive
5f	**Crossroads, physical left-turn lane**	Injury accidents	-4	Small positive
5g	**T-junctions, physical right-turn lane**	Injury accidents	-2	Small positive
5h	**Crossroads, physical left-turn lane**	Injury accidents	-13	Medium positive
6	**Roundabouts, different designs**	Injury accidents	-11 to -41*	Positive
7a	**Redesigning, change angles**	Injury accidents	-50 to +80	Very different
7b	**Redesigning, gradient on road**	Injury accidents	-17*	Medium positive
7c	**Redesigning, sight condition**	Injury accidents	-3	Small positive
8	**Staggered junctions**	Injury accidents	-20*	Large positive
9	**Interchanges (instead of crossroad)**	Injury accidents	-50*	Large positive
10	**Black spot treatment**	Injury accidents	-14	Medium positive
11a	**Number of lanes**	Injury accidents	- 17 to + 75	Very different
11b	**Lane width**	Injury accidents	- 5 to + 11	Different
11c	**Shoulder width**	Injury accidents	- 8 to + 14	Different
11d	**Passing lanes (one side)**	Injury accidents	-18*	Medium positive
11e	**Constructing of hard shoulders**	Injury accidents	-8	Small positive
11f	**Hard shoulders, width (+ 0.3 m)**	Injury accidents	-21*	Large positive
11g	**Lanes and shoulder width**	Injury accidents	-5 to -7	Small positive
11h	**Central reservations, urban areas**	Injury accidents	-22 to -39*	Large positive
11i	**Width of bridges**	Injury accidents	-30	Large positive
12	**Roadside treatment, distance to obstacles**	All accidents	-22 to -44*	Large positive
13a	**Road alignment, general improvement**	All accidents	-23*	Large positive
13b	**Sight conditions, improving**	All accidents	+23*	Large negative
13c	**Sight conditions, removing obstacles**	All accidents	-20	Large positive
14	**Rehabilitation, reconstruction and resurfacing of roads, urban area**	Injury accidents	-7*	Small positive
15a	**Guardrails alone roadside, new**	Injury accidents, running-off-the-road	-47*	Large positive
15b	**Crash cushions**	Injury accidents, with obstacles	-69	Large positive
16a	**Curve treatments, signs**	Injury accidents, curves	-30	Large positive
16b	**Curve treatments, recommended speed**	Injury accidents, curves	-13*	Medium positive
16c	**Curve treatments, Road widening**	Injury accidents, curves	+15	Medium negative
16d	**Curve treatments, transition curves**	Injury accidents, curves	+21	Medium negative
17	**Road lighting**	Injury accidents, in dark	-28	Large positive

4.2 Road maintenance

Table 4.2 summarizes the effects on accidents for road maintenance measures.

Effects for vulnerable road users are only described for winter maintenance of tracks for cycling and walking, and these effects are only described for pedestrians. It is concluded that intensified winter maintenance of walking tracks increased falling accidents with 57 %. However, this conclusion is only based on one study. Less winter maintenance may reduce pedestrian traffic and thereby the number of falls.

The first two measures have a negative effect on the number of injury accidents and the next three have a positive effect.

*Table 4.2. Effects of five road maintenance measures on objective safety (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008). Note, that one of the measures in accordance with the handbook has been divided into submeasures. * indicates significant effect.*

	Measures	Accident affected	Best effect estimate (%)	Effect, summary
1	**Ordinary resurfacing of roads**	Injury accidents	+6	Small negative
2	**Improving the evenness of the surface**	Injury accidents	+10	Medium negative
3	**Improving road surface friction**	Injury accidents, wet road	-15 to -40*	Large positive
4	**Winter maintenance of roads, general**	Injury accidents	-12	Medium positive
5a	**Winter maintenance of tracks, more**	Pedestrian fall accidents	+57	Large negative
5b	**Winter maintenance of tracks, less**	Pedestrian fall accidents	-15 to -52*	Medium positive

4.3 Traffic control

The effect on road accident for the selected 17 traffic control measures are summarised in table 4.3.

Among the 41 summarised submeasures the effects on pedestrian accidents have been described directly for 13 measures and the effects on cycle accidents described for three measures. The 13 pedestrian measures and three cycle measures are:

- Different pedestrian crossings in intersections and on stretches of road
- Regulation of pedestrian crossings
- Refuges on pedestrian crossings
- Pedestrian guard rails
- School crossing patrols
- Pavement widening at intersections
- One-way streets
- Cycle lanes, sections and intersections
- Advanced stop lines.

The effects of these measures vary much from significantly positive to significantly negative.

*Table 4.3. Effects of 17 traffic control measures on objective safety (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008). Note that some of the measures in accordance with the handbook have been divided into submeasures. * indicates significant effect.*

	Measures	Accident affected	Best effect estimate (%)	Effect, summary
1a	**Area-wide traffic calming**	Injury accidents, whole area	-15*	Medium positive
1b	**Area-wide traffic calming**	Injury accidents, local roads	-24*	Large positive
2	**Environmental streets**	Injury accidents	-38*	Large positive
3a	**Pedestrian streets**	Injury accidents, whole area	-25*	Large positive
3b	**Pedestrian streets**	Injury accidents, pedestrian street	-60*	Large positive
4	**Urban play streets**	Injury accidents	-25*	Large positive
5	**Access control**	Injury accidents	-31 to -25*	Large positive
6	**Priority control**	Injury accidents	+5	Small negative
7	**Yield signs at intersections**	Injury accidents	-3	Small positive
8	**Stop signs at intersections**	Injury accidents	- 45 to -19	Large positive
9a	**Traffic signal control, new**	Injury accidents, intersection	-30 to -15	Large positive
9b	**Traffic signal control, upgrading**	Different, intersection	-75 to +55	Very different
9c	**Traffic signal control, separate phase for pedestrians**	Pedestrian accidents	-30*	Large positive
10	**Signal-controlled midblock pedestrian crossings,**	Pedestrian accidents	-12*	Medium positive
11	**Speed limits, all reductions**	Injury accidents	-14*	Medium positive
12a	**Speed-reducing, humps**	Injury accidents, road with humps	-48*	Large positive
12b	**Speed-reducing, raised intersections**	Injury accidents, intersections	+5	Small negative
12c	**Speed-reducing, rumble strips**	Injury accidents, intersections	-33*	Large positive
12d	**Speed-reducing, speed zones**	Injury accidents	-27*	Large positive
13a	**Normal edge line**	Injury accidents	-3	Small positive
13b	**Wide edge line**	Injury accidents	+5	Small negative
13c	**Shoulder rumble line**	Injury accidents	+2	Small negative
13d	**Raised pavement markers**	Injury accidents	-5	Small positive
13e	**Delineator posts with reflectors**	Injury accidents	+4	Small negative
13f	**Edge line and centre line**	Injury accidents	-24*	Large positive
13g	**Edge line, centre line, delineator**	Injury accidents	-45*	Large positive
14a	**Ordinary pedestrian crossing**	Pedestrian accidents	+28*	Large negative
14b	**Signal-controlled midblock pedestrian crossings,**	Pedestrian accidents	-12*	Medium positive
14c	**Pedestrian crossings with mixed phases at intersection**	Pedestrian accidents	+8	Small negative
14d	**Pedestrian crossings with separate phases at intersection**	Pedestrian accidents	-29*	Large positive
14e	**Raised pedestrian crossings**	Pedestrian accidents	-49	Large positive
14f	**Refuges on pedestrian crossings**	Pedestrian accidents	-18*	Medium positive
14g	**Pedestrian guard rails**	Pedestrian accidents	-24*	Large positive
14h	**School crossing patrols**	Pedestrian accidents	-35	Large positive
14i	**Pavement widening, intersection**	Pedestrian accidents	-5	Small positive
14j	**Advanced stop lines, intersection**	Cycle accidents	-27	Large positive
14k	**Cycle lanes, intersection**	Cycle accidents	-12	Medium positive
14l	**Cycle lanes**	Cycle accidents	-10	Medium positive
		Pedestrian accidents	-30	Large positive
15	**Parking regulations**	Injury accidents	-35 to -6	Medium positive
16	**One-way streets**	Pedestrian accidents	+1	Small negative
17	**Bus lanes and bus stop design**	Injury accidents	-74 to + 61	Mostly negative

4.4 Vehicle design and protective devices

Table 4.4 summarizes the effects on road accidents for the selected eight measures dealing with vehicle design and protective devices.

Among the 25 summarised submeasures the effects on cycle accidents have been described regarding half of the measures.

For several of the heavy vehicle measures the effects are more or less unknown.

*Table 4.4. Effects of eight vehicle design and protective device measures on objective safety (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008). Note, that some of the measures in accordance with the handbook have been divided into submeasures. * indicates significant effect.*

	Measures	Accident affected	Best effect estimate (%)	Effect, summary
1a	Pedestrian reflectors	Pedestrian accidents, darkness	-85	Large positive
1b	Retro-reflective materials, cycles	Cycle accidents, darkness	-	Probably small or medium positive
2	Cycle helmets, mandatory wearing	Cyclists	-22	Large positive
3	Regulating vehicle mass	Injury accidents	-	Probably small or medium positive
4a	Regulating car engine effect	Injury accidents	-	Probably small or medium positive
4b	Regulating top speed	Injury accidents	-15	Medium positive
5	Under-run guard rails on lorries	Injury accidents, between lorry and other road users	About -30	Large positive
6a	Total weight of lorries, increasing	Injury accidents, lorries	+22*	Large negative
6b	Total length of lorries, increasing	Injury accidents, lorries	+2	Small negative
6c	Extra mirrors on lorries	Injury accidents, right turn	-17	Medium positive
6d	Side marker lamps on lorries	Injury accidents, side impacts, dark	-8	Small positive
7a	Cycle equipment, pedal reflectors	Multi-party accident, darkness	-75*	Large positive
7b	Cycle equipment, Spokes reflectors	Multi-party accident, darkness	+9*	Small negative
7c	Cycle equipment, ankle light	Multi-party accident, darkness	-22*	Large positive
7d	Cycle equipment, jacket reflectors	Multi-party accident, darkness	-10*	Medium positive
7e	Cycle equipment, taillight	Rear-end collisions, darkness	-80*	Large positive
7f	Cycle equipment, brakes	Cycle accidents	-48 to -5*	Medium positive
7g	Cycle equipment, brake blocks	Cycle accidents, dry weather	-20 to -5	Medium positive
		Cycle accidents, wet weather	-40 to +190	Very different
7h	Cycle equipment, high handlebars	Overturning cycle accidents	+55*	Large negative
7i	Cycle equipment, small wheel	Overturning cycle accidents	+30*	Large negative
7j	Cycle equipment, distance markers	Cycle accidents, Multi-party accident	-7*	Small positive
8a	Ban on driving with trailers	Injury accidents, lorries	-	Unknown
8b	Special speed limits for lorries	Injury accidents, lorries	-	Unknown
8c	Total weight limits for trailers	Injury accidents, lorries	-	Unknown
8d	Better stability, control and tracking for trailers	Injury accidents, lorries	-	Unknown

4.5 Driver training, education and enforcement

Table 4.5 summarises the effects of relevant measures for driver training, education and enforcement on objective safety.

The effects are unknown for several measures. Enforcement has a positive effect.

*Table 4.5. Effects of driver training, education and enforcement on objective safety (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008). Note, that some of the measures in accordance with the handbook have been divided into submeasures. * indicates significant effect.*

	Measures	Accident affected	Best effect estimate (%)	Effect, summary
1a	**School transport with buses**	Injury accidents, children	-	Positive
1b	**Safety standards for school buses**	Injury accidents, children	-	Medium positive
1c	**Improving bus stops**	Injury accidents, children	-	Unknown
1d	**Training bus drivers**	Injury accidents, children	-	Unknown
2	**Education of pre-school children**	Injury accidents, children	-	Unknown
3a	**School education, crossing a road**	Injury accidents, crossing a road	-20 to -11*	Medium positive
3b	**School education, Cycling**	Cycle accidents	-6	Small positive
4	**Stationary speed enforcement**	Injury accidents	-5*	Small positive
5	**Patrolling**	Injury accidents	-16*	Medium positive
6	**Automatic speed enforcement**	Injury accidents	-17*	Medium positive
7	**Red light cameras**	Injury accidents, signal intersection	-12*	Medium positive

4.6 Summary

In total, the effects on objective road safety have been summarised for 54 measures. These measures have been divided into 126 submeasures. As shown in table 4.6, the effects for cyclists and pedestrians have been only evaluated for 21 and 25 submeasures respectively. This is under 20 % of the submeasures. For the remaining 80 % of the measures the effects for vulnerable road users are either unknown or inexistent.

Most of the measures have a positive effect on the number of accidents. However, 23 of the measures probably have a negative effect on road safety. The effect is unknown or may both be positive and negative for 13 measures.

Table 4.6. Number of measures where the effects on objective safety are summarised for cyclists and pedestrians. The number of measures with positive, negative and unknown effects in general is also indicated.

	Measures	Sub-measures	Effect for cyclist	Effect for pedestrian	Posi-tive	Nega-tive	Unknown or different
Road design and furniture	17	43	4	3	33	6	4
Road maintenance	5	6	0	2	3	3	0
Traffic control	17	41	3	13	31	9	1
Vehicle design and protective devices	8	25	13	1	15	5	5
Driver training, education and enforcement	7	11	1	(6)	8	0	3
Total	54	126	21	25	90	23	13

TØI report 1009/2009

5 The effects on subjective safety

In the appendix a thorough assessment of the effects on subjective safety among vulnerable road users are made for each of the 54 selected road safety measures. The results of these assessments are summarised in this chapter. If the reader wants to read more about specific road measures we refer to the appendix.

The assessment of the effect on subjective safety is based on two parts:

1. Literature study of existing studies and evaluations
2. Theoretical, qualitative considerations.

For many of the selected road safety measures, none of the available literature has studied their effects on the subjective safety of vulnerable road users. Thus, the literature study has been supplemented with theoretical considerations about factors having an impact on subjective safety. For each of the measures it is assessed which impact it probably has on the 16 parameters listed in table 2.7.

The following symbols are used in the assessment:

↑: Positive effect on subjective safety of cyclists and pedestrians

↓: Negative effect on subjective safety of cyclists and pedestrians

↕: Both positive and negative effects on subjective safety of cyclists and pedestrians is possible

(): Maybe a small or very small effect

- : Probably no effect on subjective safety of cyclists and pedestrians

?: Unknown effect on subjective safety of cyclists and pedestrians.

The assessment for each of the 16 parameter is made qualitatively. The total effect is made as a qualitative assessment which is a summation of the effects on the 16 included parameters. Note that it is not possible to sum up the total effect by a simple summation because the parameters have different importance.

5.1 Road Design and Road Furniture

This chapter summarise the effects of the 17 measures under the category of road design and furniture on subjective safety.

5.1.1 Tracks for walking and cycling

The effect of tracks for walking and cycling on subjective safety for pedestrians and cyclists has been evaluated directly or indirectly in several projects. The general conclusion of these studies is that the tracks increase the subjective safety of vulnerable road users.

The theoretical, qualitative assessments are summarised in table 5.1. This assessment also show that the tracks increase subjective safety because tracks separate and the increase the distance between vulnerable road users and cars and heavy vehicles. Track may also have a speed reducing effect and contribute to more people cycling and walking in stead of driving.

5.1.2 Motorways

No studies about possible effects of motorways on subjective safety have been found. This was expected because motorways have no direct impact on vulnerable road users as this group is not allowed to use motorways.

However, motorways may indirectly have some small positive effects as summarized in table 5.1. Motorways may change the traffic pattern and traffic volume on the roads of the surrounding area. This means that the traffic volume may be reduced on the other roads which can improve the condition for vulnerable road users on these roads. On the other hand, motorways sometimes results in higher speed level at adjacent roads.

5.1.3 Bypasses

Several evaluations of bypasses have been preformed. But, even though one of the objectives of designing bypasses is to improve the conditions for vulnerable road users in the city, none of the available studies are regarding this theme.

The conclusion of the qualitative considerations is that bypasses alone or in combination with environmental streets have positive effects on subjective safety of vulnerable road users at the original main road through the city. The most important argument for that is decreased volume of traffic which has no destination in the city. While traffic volume is reduced, the speed level might increase on the city’s roads due to lesser congestion.

5.1.4 Arterial roads in and around cities

Different evaluations of building new arterial roads conclude that it increase the subjective safety of vulnerable road users at old local roads

The qualitative assessment comes to the same conclusion. The volume of traffic and heavy vehicles on the old ways in the local area is reduced and speed is probably reduced because building of new arterial roads is often supplemented with speed reducing measures at the local roads.

5.1.5 Channelisation of junctions

No literature which studied possible effects of channelisation of intersections on subjective safety among vulnerable road users have been found.

Considering a general evaluation, the effect of channelisation of junctions on subjective safety of vulnerable road users is assessed to be positive. Channelisation reduces areas of conflict between vehicles and vulnerable road users by separating or regulating traffic movements into definite paths of travel. Moreover, channelisation islands reduce the crosswalk distance in which pedestrians are exposed to moving motor vehicles. The measure also narrowing the street and thereby forces drivers to reduce the speed. However, narrowing may reduce the distance between cyclists along the road and motor vehicles. Finally, traffic volume may seem reduced due to the separation in different channels.

5.1.6 Roundabouts

The conclusion of the reviewed literature is that roundabouts often have a negative effect on subjective safety.

Summarizing the qualitative assessments, the overall effect of roundabouts on subjective safety of cyclists is negative when there is no bicycle facility and more or less positive when roundabout has bicycle facility especially if it is cycle paths outside the roundabouts. It is difficult to conclude whether the total effect of roundabout design on subjective safety of pedestrians is positive or negative. One of the main approved benefits of roundabouts is that it makes drivers reduce their speeds when entering and driving trough the roundabout.

5.1.7 Redesigning junctions

No literature which studied possible effects of redesigning junctions on subjective safety among vulnerable road users has been found.

Considering a general evaluation, the effect of redesigning junctions on subjective safety of vulnerable road users is not easy to judge as the effects on speed and sight are dependent on different scenarios. However, in case of negative effects on speed or sight, the general effect will be also negative.

5.1.8 Staggered junctions

No literature has been found studying the effects of staggered junctions on the subjective safety of vulnerable road users.

Summarizing the qualitative assessments, the overall effect of staggered junctions on subjective safety of vulnerable road users is positive. The reasons are that staggered T-intersections may reduce the speed level and make the intersection seems less complicated for the vulnerable road users.

5.1.9 Interchanges

If interchanges are built as intersections between motorways the measure have no influence on vulnerable road users. However, if interchanges are implemented as intersections between motorways and smaller roads or between two smaller roads where cyclists and pedestrians are allowed the measure may affect subjective safety. However, no studies directly evaluation the effects on subjective safety have been found.

Summarizing the qualitative assessments, the overall effect of interchanges on subjective safety of vulnerable road users is assessed as negative. The primarily reasons are high speed and that interchanges may be difficult locations for pedestrians and bicyclists to navigate. Moreover, the sight may be reduced.

5.1.10 Black spot treatment

Several evaluations of black spot management have been performed worldwide, but none of these evaluations has evaluated the effect on subjective safety.

It is very difficult to conclude with a general assessment regarding the effect of black spot management on subjective safety since black spot management consists of a wide range of road safety measures with very different characteristics. Depending on the measures, black spot management can both have positive, neutral and negative effect on subjective safety. However, in the majority of cases the effect is probably positive. The explanation is that the main objective of black spot management is typically to reduce speed and often also to reduce the numbers of crossings, improve road conditions, and improve sight and road light. All these improvements will also a positive effect on subjective safety.

5.1.11 Cross section improvements

Cross sections improvement consists of several measures. No studies which directly evaluate the effects of the above-mentioned measures on subjective safety of vulnerable road users have been found.

The conclusion of the qualitative considerations is that measures can be divided into three groups with different effects on subjective safety. The three groups are increasing the number of lanes, reconstructing shoulders and central reservations and increasing the width of road.

The first group has likely a negative effect on subjective safety of vulnerable road users. The first measure; increasing the number of traffic lanes will have the greatest effect. The second group of measures probably has a positive effect on subjective safety of vulnerable road users. The third group of measures can both have positive and negative effects on subjective safety depending on specific designs and situations.

5.1.12 Roadside safety treatment

No studies regarding the effects on subjective safety have been found.

Table 5.1 summarizes possible effects of roadside safety treatment. On one hand, speed may increase due to more “open” roads. On the other hand, the sight is probably improved and it is possible that the distance between vulnerable road users along the road and vehicles driving on the road increase. Thus, the total effect on subjective safety is not clear, but the effect is probably not significant.

5.1.13 Improving road alignment and sight conditions

No studies about the possible effects of the measures on safety among vulnerable road users have been found. However, improving road alignment and sight conditions could have small negative effects on subjective safety due to higher speed.

5.1.14 Rehabilitation, reconstruction and resurfacing of roads

No studies that evaluate the effect of the measure on subjective safety of vulnerable road users have been found. Like the previous measure, the measures increase the speed level if nothing else changes. Road conditions and sight are improved. Depending on different cases, the measures can have positive, neutral and negative effect.

5.1.15 Guardrails and crash cushions

No studies have been found which indicate the effects of different types of guardrails and crash cushions on subjective safety. It is assessed that guardrails most likely will have a positive effect on subjective safety because it may separate the road from the foot and cycle paths and reduce speed.

5.1.16 Horizontal curve treatments

The effects of different curve treatment on subjective safety have not been studied in any known project. The reason is probably that the objective is not normally to improve the conditions for vulnerable road users.

However, curve treatments may have some small positive effects. The treatments can reduce speed as a result of danger warning, recommended speeds or maybe speed limits. Widening of roads at curves can increase the distance between vulnerable road users and vehicles while widening of roads and changes of alignments improve sight conditions. On the other hand, it is also possible that the speed increases if the alignment or width of the road is changed.

5.1.17 Road lighting

Both the literature study and the qualitative considerations indicate that road lighting increases the subjective safety of vulnerable road users. However, the positive effect may be reduced due to higher speed on lighted roads.

5.1.18 Summary

Table 5.1 summarizes the most likely effects of 17 road design and furniture measures on subjective safety of vulnerable road users.

Table 5.1. Summarise of the literature study and the qualitative assessment of the effect on subjective safety for 17 road design and road furniture measures.

	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Qualitative assessment**	**Literature**
Tracks	(↑)?	-	↑?	↑?	↑	-	↑	↑	-	-	(↓)?	-	-	-	-	-	↑	↑
Motorways	(↑)?	↑?	-	(↓)?	-	-	-	-	-	-	-	-	-	-	-	-	(↑)?	-
Bypasses	↑	↑	(↑)	(↓)	-	-	-	(↑)	-	-	-	-	-	-	-	-	↑	-
Arterial roads	↑	↑	(↑)	↑	-	-	-	(↑)	-	-	-	-	-	-	-	-	↑	↑
Channelisation	↑	↑	-	↑	↓	↑	↑	↑	-	-	-	-	-	-	-	-	↑	-
Roundabouts	-	-	-	↑	-	-	↕	↕	↕	-	-	↕	-	-	-	-	↕	↓
Redesigning junctions	-	-	-	↕	-	-	-	-	-	-	-	↕	-	↓	-	-	↓ ?	-
Staggered junctions	↑	-	-	↑	↑	-	-	-	-	-	-	(↓)	-	-	-	-	↑	-
Interchanges	↑	-	-	↓	-	↓	↓	-	-	-	-	↓	-	-	-	-	↓	-
Black spot treatment	-	-	-	↑	↕	↕	↕	↕	↕	↑	↑	↑	↑	-	-	-	↕/↑	-
Cross section	↓	↓	-	↕	↕	↕	↑	↑	↓	↑	↑	↕	-	-	-	-	↕	-
Roadside	-	-	-	↓	(↑)	-	-	-	-	-	-	↑	-	-	-	-	(↕)?	-
Road alignment, sight	-	-	-	↓	-	-	-	-	-	-	(↑)	↑	-	-	-	-	(↓)	-
Rehabilitation of roads	-	-	-	↓	-	-	-	-	-	-	↑	↑	-	-	-	-	(↕)	-
Guardrails	-	-	-	(↕)	(↑)	-	-	↑	-	-	-	-	-	-	-	-	↑	-
Horizontal curve	-	-	-	↕	↑	-	-	-	-	-	(↑)	↑	-	-	-	-	(↑)	-
Road lighting	-	-	-	(↓)	-	-	-	-	-	-	-	-	↑	-	-	-	↑	↑

TØI report 1009/2009

The effects have only to a larger or lesser extend been studied for four measures. These measures are tracks for walking and cycling, arterial roads in and around cities, roundabouts and partly road light.

Nine measures most likely have positive effects on subjective safety while only three have negative effects. For five of the measures, both positive and negative effects are possible depending on different designs and situations.

5.2 Road maintenance

This chapter describes subjective safety effects of five measures under the category of road maintenance.

5.2.1 Ordinary resurfacing of roads

No studies are available which directly have evaluated the effects of resurfacing of roads and tracks on subjective safety. However, different handbooks, cycle strategies and reports describe indirectly the negative effects to subjective safety if resurfacing is not carried out.

The qualitative assessments are summarised in table 5.2. This assessment also show concluded that bad road surface maintenance probably reduces subjective safety. In other words, ordinary regular resurfacing of roads and tracks can particularly contribute to improved subjective safety of bicyclists.

Bad surface maintenance increases the fear of accidents as a result of holes in the road surface; cyclists are maybe forced to use roads instead of cycle tracks; cyclists will probably try to steer around holes in the road surface, which may give conflicts and reduce the distance between vehicles and cycles and finally bad road surface may distract cyclists and make it more difficult to cycle. On the other hand good road surface may increase the speed level.

5.2.2 Improving the evenness of road surface

Like ordinary resurfacing of roads the effect of repairing the road surface have not directly been studied.

Ordinary regular improvement and repairing of road surface are very similar measures, and therefore the effects on subjective safety are quite identical. Thus it is concluded that improving the evenness of road surfaces probably contribute to improved subjective safety of vulnerable road users especially cyclists.

5.2.3 Improving road surface friction

No studies about possible effects of improving road surface friction on subjective safety of vulnerable road users have been found.

If improving of road surface friction is carried out as a part of an ordinary regular resurfacing or as a part of improving the evenness of road surfaces, which is normally the case, the measure will have the same effects on subjective safety as these two measures.

5.2.4 Winter maintenance of roads

Both the literature study and the qualitative considerations show that winter maintenance of roads increases subjective safety of vulnerable road users.

The distance between vulnerable road users on the road and vehicles are reduced by bad winter maintenance because cyclists are forced to cycle more to the left on the road. Bad winter maintenance also increases the fear of accidents due to icy and slippery roads and increases the required tasks for cycling. Good winter maintenance may encourage more people to cycle, which improve subjective safety because more cycle volume increases the vehicle drivers' attention. On the other hand good winter maintenance increases the speed of traffic.

5.2.5 Winter maintenance of pavements and foot and cycle paths

Both the literature study and qualitative considerations show that winter maintenance of pavements, foot and cycle paths as well as other public areas increases subjective safety of vulnerable road users.

Icy and slippery roads conditions are in general and for vulnerable road users in particular associated with increased feeling of unsafety. In addition, bad winter maintenance of tracks forces vulnerable road users to use roads instead of tracks which also reduce the feeling of safety.

5.2.6 Summary

Table 5.2 summarizes most possible effects of the five road maintenance measures on the subjective safety of vulnerable road users.

No studies are available which directly have evaluated effects of the three first measures on subjective safety. However, the issue discussed in different handbooks and reports indirectly describe the possible effects.

Based on the results from the literature survey and the qualitative considerations it is concluded that all five measures have probably a positive effect on subjective safety of vulnerable road users.

Table 5.2. Summarise of the literature study and the qualitative assessment of the effect on subjective safety for five road maintenance measures. The rectangular bracket implies that the literature just indirectly indicated effect.

	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Qualitative assessment**	**Literature**
Ordinary resurfacing	-	-	-	↓	↑	-	-	↑	-	-	↑	-		-	(↑)	-	↑?	[↑]
Evenness of surface	-	-	-	↓	↑	-	-	↑	-	-	↑	-		-	(↑)	-	↑?	[↑]
Road surface friction	-	-	-	↓	↑	-	-	↑	-	-	↑	-		-	(↑)	-	↑?	[↑]
Maintenance of roads	-	-	(↑)	↓	↑	-	-	-	-	-	↑	-		-	(↑)	-	↑	↑
Maintenance of tracks	(↑)	-	↑	-	-	-	-	↑	-	-	↑	-		-	(↑)	-	↑	↑

TØI report 1009/2009

5.3 Traffic control

This chapter describes the subjective safety effects of 17 measures under the category of traffic control. The assessments are summarised in Table 5.3.

5.3.1 Area-wide traffic calming
Both the literature study and qualitative considerations show that area-wide traffic calming increases subjective safety of vulnerable road users in residential streets. Speed and traffic volume is normally reduced, while cycle volume may increase on the residential streets.

5.3.2 Environmental streets
Both the literature study and the qualitative considerations show that environmental streets most likely increase the subjective safety among vulnerable road users at the reconstructed streets.

Most of the measures that could be part of environmental streets are described separately elsewhere in this report. Most of these measures are assessed to have a positive effect on subjective safety. Thus, the combination of different measures probably has a positive effect as well.

5.3.3 Pedestrian streets
Concluding the literature survey, traditional pedestrian streets have positive effect on subjective safety of vulnerable road users. Shared space that is a new alternative for traditional pedestrian streets have negative effect in the beginning while the effect becomes neutral after some time.

The conclusion of the qualitative considerations is also that pedestrian streets have positive effect on subjective safety of vulnerable road users. Motor vehicles are not permitted on pedestrian streets. Thus, the volume of motorized traffic and speed decrease while the volume of vulnerable road users increases. The required tasks for walking and cycling may be also reduced. One problem is more conflicts between cyclists and pedestrians.

5.3.4 Urban play streets
It is concluded that urban play streets improve subjective safety of vulnerable road users in these streets. The reasons are that mean speed is reduced on these streets and traffic volume especially the volume of heavy vehicles declined as well. This is the case in particular if arterial roads are improved or constructed.

5.3.5 Access control
Summarizing the literature survey and the qualitative assessments, the overall effect of access control on subjective safety is possibly positive. The main reasons are reduction in the number of access points and improving of the design of the remaining access point such as improved sight.

5.3.6 Priority control
No literature which studied possible effects of priority control on subjective safety has been found. In fact, priority control has probably no significant effect on any of the factors influencing subjective safety beside maybe speed, but no studies verifying this possible effect have been found.

5.3.7 Yield signs at intersections
No literature which studied possible effects of priority control on subjective safety has been found.

Summarizing the qualitative assessments, the overall effect of yield signs at intersections on subjective safety of vulnerable road users is possibly negative. The main reason is that yield signs create “through” streets where speed tends to increase and attentiveness tends to decrease.

5.3.8 Stop signs at intersections

No literature studying possible effects of stop signs at intersections have been found. However, it is assessed that the effect of stop signs is similar to the effect of yield signs. In other words the overall effect of stop signs at intersections on subjective safety is possibly negative.

5.3.9 Traffic signal control at intersections

No literature studying possible effects of traffic signal control on subjective safety among vulnerable road users have been found.

Summarizing the qualitative assessments, the overall effect of traffic signal control at intersections on subjective safety is possibly positive. Traffic signal separate traffic streams, and let the vulnerable road users to cross the street more easily.

5.3.10 Signal-controlled pedestrian crossings

Both the literature study and qualitative considerations conclude that pedestrians feel safer crossing roads with signalised pedestrian crossings than other crossing points. Speed decreases and pedestrian and motor vehicles are separated in time. Moreover, road lighting is often implemented together with the signal-control.

5.3.11 Speed limits

The conclusion is that speed limits reduce mean speeds in traffic and thus decrease the feeling of unsafety among cyclists and pedestrians.

5.3.12 Speed-reducing devices

Speed-reducing devices normally have positive effect on subjective safety of vulnerable road users. But if the mean speed does not decrease significantly while the distance between vulnerable road users and motor vehicles decreases considerably, the effect may be negative.

5.3.13 Road markings

Road markings consist of several measures. The conclusion of the literature study and the qualitative considerations is that road marking can both have positive and negative effects on subjective safety depending on the measure used. A positive effect is the most likely effect of road marking.

5.3.14 Traffic control for pedestrians and cyclists

Traffic control for pedestrians and cyclists includes several different measures that are intended to separate pedestrians and cycle traffic in time and /or space from car traffic, direct pedestrians and cyclists to crossing points with good visibility conditions and in general improve the condition for pedestrians and cyclists by reserving parts of the road for such traffic.

The conclusion of the qualitative considerations is that the different measures in general probably have positive effect on subjective safety. For most of the measures these assessments are verified in different studies.

5.3.15 Parking regulations

No studies regarding the effects of these measures on subjective safety have been published in the reviewed journals and reports.

Based on the qualitative considerations, it is classified that parking regulations may have a small positive impact on subjective safety. Parking regulations may reduce traffic volume in areas with parking regulations. This is normal in city centres where there are a great number of vulnerable road users. Sight may also be improved when no cars park along the street. On the other hand speed level may increases after banning on-street parking.

5.3.16 One-way streets

Summarizing the literature review and the qualitative assessments, the overall effect of one-way streets on subjective safety of vulnerable road users is possibly positive.

One-way streets have the obvious advantage that vulnerable road users and drivers need only look one way when watching for traffic. Traffic volume probably will decrease, but the speed level may increase.

5.3.17 Bus lanes and bus stop design

Summarizing the literature review and the qualitative assessments, the overall effect of bus lanes on subjective safety of vulnerable road users is possibly negative.

Bus lanes increase average travel speed of buses. From this point of view, bus lanes shared with bicycles have negative effect on subjective safety. Bus lanes enthuses also some bus drivers to drive more aggressively. On the other hand traffic volume are normally smaller in bus lanes that normal lanes for motor vehicle traffic.

5.3.18 Summary

Table 5.3 summarizes the most possible effects of 17 traffic control measures on subjective safety of vulnerable road users.

The effect has been studied for seven measures and partly for four measures.

It is assessed that 12 measures possibly have positive effect on subjective safety. Three measures; yield and stop signs at intersections and bus lanes, probably have a negative effect. One measure, priority control, has probably no effect. Road marking consists of very different measures and may therefore have both positive and negative effects.

Table 5.3. Summarise of the literature study and the qualitative assessment of the effect on subjective safety for 17 traffic control measures. The rectangular bracket implies that the literature just indirectly indicated effect.

	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Qualitative assessment**	**Literature**
Traffic calming	↑	↑	↑	↑	-	-	-	(↑)	-	-	-	-	-	-	-	-	↑	↑
Environmental streets	(↕)	(↑)	↑	↑	(↕)	↑	↑	(↑)	↑	-	(↑)	-	(↑)	-	-	-	↑	↑
Pedestrian streets	↑	↑	↑	↑	-	-	-	↕	-	-	-	-	(↑)	-	(↑)	-	↑	↑
Urban play streets	↑	↑	↑	↑	-	-	-	↕	-	-	-	-	(↑)	-	(↑)	-	↑	[↑]
Access control	↓	-	-	(↓)	-	↑	-	-	-	↑	-	↑		-	-	-	↑	[↑]
Priority control	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yield signs	-	-	-	↓	-	-	-	-	-	-	-	-	-	↓	-	-	↓	-
Stop signs	-	-	-	↓	-	-	-	-	↑	-	-	-	-	↓	-	-	↓	-
Traffic signal control	↑	-	-	-	-	-	-	↑	-	-	-	-	-	-	-	-	↑	-
Pedestrian crossings	-	-	-	↑	-	-	-	↑	↑	-	-	-	(↑)	-	-	-	↑	↑
Speed limits	-	-	-	↑	-	-	-	-	-	-	-	-	-	-	-	-	↑	↑
Speed-reducing	-	-	-	↑	↓	(↑)	-	-	-	-	-	-	-	-	-	-	↑/↕	↑(↓)
Road markings	-	-	-	↕	↕	-	-	(↑)	(↑)	-	-	-	-	(↑)	-	-	↑/↕	[↕]
Traffic control	(↑)	-	(↑)	↕	↑	↑	↑	↑	↑	↑	(↓)	(↑)	(↑)	(↑)	(↑)	-	↑	↑
Parking regulations	↑	-	-	(↓)	-	-	-	-	-	-	-	↑	-	-	-	-	(↑)	-
One-way streets	↑	-	-	↓	-	-	-	-	↑	-	-	-	-	-	-	-	↑?	-
Bus lanes, bus stop	↑	-	-	↓	-	-	↓	-	-	-	-	-	-	↓	-	-	↓	[↓]

TØI report 1009/2009

5.4 Vehicle design and protective devices

This chapter describes the subjective safety effects of eight measures under the category of vehicle design and protective devices. The assessments are summarised in table 5.4.

5.4.1 Reflective materials and protective clothing

Reflective materials and protective clothing consist of several measures. Among these it is only pedestrian reflectors and retro-reflective material on bicycles that are relevant in this project.

No studies have been found which directly evaluates the effects of these two measures on subjective safety, but some studies indirectly indicate that they may have a positive influence.

The conclusion of the qualitative considerations is also that reflective material on bicycles and pedestrians may have a small positive effect on subjective safety. The measures improve visibility of vulnerable road users which may lead to more thoughtfulness of car users and thereby much feeling of safety among vulnerable road users. In table 5.4, this is stated as improved sight, improved road light and improved thoughtfulness.

5.4.2 Cycle helmets

The effect of cycle helmets on subjective safety for cyclists has been evaluated directly or indirectly in several projects. Both the literature study and partly the theoretical, qualitative assessment show that cycle helmets increase the subjective safety for cyclists due to personally protection. Promoting use of use of cycle helmets is by law may however reduce cycling and led to traffic getting significantly closer when overtaking. In other words have a negative effect on subjective safety.

5.4.3 Regulating vehicle mass

The conclusion is that according to the literature study, regulating vehicle mass has a positive effect on subjective safety of vulnerable road users, but the qualitative considerations could not provide any clear conclusion in this respect.

The measure probably gives less traffic by heavy vehicles. On the other hand the measure will also produce more traffic by light vehicles because one big heavy vehicle may be replaced by two or three small heavy vehicles. Also it is not unambiguous if speed will increase or decrease.

5.4.4 Regulating automobile engine capacity and top speed

No studies about the possible effects of these regulations on subjective safety have been found. However, the objective of the regulation is to reduce traffic speed. If successful, it will have a positive effect on subjective safety.

5.4.5 Under-run guardrails on trucks

Even though the measure addresses safety among vulnerable road users, no literature studying possible effects of the measure on subjective safety have been found. Additionally, it is assessed that side under-run guardrails has no effect on any of the factors influencing subjective safety of vulnerable road users.

5.4.6 Safety equipment in trucks

Safety equipment in heavy vehicles includes several types of equipment and regulations. Among these it is only total weight limit for heavy vehicles, length limit for heavy vehicles and extra mirrors and wide angle mirrors that are relevant in this project. It is concluded that these measures probably contribute to better subjective safety among vulnerable road users. However, no studies verify this assessment.

5.4.7 Bicycle safety equipment

Bicycle safety equipment includes measures as lamps, reflectors, brakes, handlebars, wheels, gear, bells, distance marker, spoke protection, child seats and child bicycle wagons. Among this equipment, it is probably only the distance markers and bicycle lamps that directly affect the possible influencing factors on subjective safety listed in this report. However, reflectors, bells, brakes, wheel, handlebars and child seats and wagons may also have some small effects.

Although the objective of this equipment is to improve conditions for cyclists, it is only lamps and indirectly distance marker that have been evaluated.

Based on very few evaluations and the qualitative considerations, the conclusion is that some of the bicycle safety equipment may have small positive effect on the feeling of safety among cyclists. But it does not affect pedestrians.

5.4.8 Safety standards for trailers and caravan

Safety standards for trailers and caravan include several measures. No studies that evaluate effects of these measures on subjective safety have been found.

It is assessed that the most relevant measures may have a small positive effect.

A ban on driving with trailers and partly a total weight limit for trailers may reduce volume of the large heavy vehicles on the actual parts of a road network. This is typically in city centres with lots of vulnerable road users. The volume of small heavy vehicles may increase.

Speed limit may reduce the average speed.

Better stability and control of trailers may reduce unintended swings of the trailer, which improve the distance between the trailer and vulnerable road users.

5.4.9 Summary

Table 5.4 summarizes the most possible effects of the eight measures regarding vehicle design and protective devices on subjective safety.

Table 5.4. Summarise of the literature study and the qualitative assessment of the effect on subjective safety for eight vehicle design and protective devices. The rectangular bracket implies that the literature just indirectly indicated effect.

	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Qualitative assessment**	**Literature**
Reflective materials	-	-	-	-	-	-	-	-	-	-	-	(↑)	(↑)	(↑)	-	-	(↑)	[↑]
Cycle helmets	-	-	(↓)?	-	(↓)	-	-	-	-	-	-	-	-	(↓)?	-	↑	(↑)	↑
Vehicle mass	(↓)?	(↑)?	-	(↓)?	-	-	-	-	-	-	-	-	-	-	-	-	(↕)?	[↑]
Engine and top speed	-	-	-	↑	-	-	-	-	-	-	-	-	-	-	-	-	↑	-
Under-run guard rails	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Truck safety equipment	-	(↑)	-	-	-	-	-	-	-	-	-	(↑)	-	-	-	-	(↑)	[↑]
Cycle safety equipment	-	-	-	-	↑	-	-	-	-	-	-	(↑)	(↑)	(↑)	(↑)	-	(↑)	↑
Safety standards	-	(↑)	-	(↑)	(↑)	-	-	-	-	-	-	-	-	-	-	-	(↑)	-

TØI report 1009/2009

Among the eight measures the effect on subjective safety has more or less been studied regarding five of them. No studies about regulating automobile engine capacity and top speed, under-run guard rails on trucks and safety standards for trailers and caravans have been found.

It is assessed that six of the measures most likely have a positive effect on subjective safety. Regulating vehicle mass can both have positive and negative effects, while under-run guard rails probably have no effect on subjective safety.

5.5 Driver training, education and enforcement

This chapter describes the effects on subjective safety for seven measures under the three categories of:

- Driver training and regulation of professional drivers (1 measure)
- Public education and information (2 measures)
- Police enforcement and sanctions (4 measures).

5.5.1 Safety standards for transporting school children

Even though subjective safety is a very important issue for school children, no literature has been found studying the effects of safety standard for transporting school children on the subjective safety of vulnerable road users. However, based on the qualitative considerations, it is classified that the measures may have a small positive impact on subjective safety of school children.

Special safety standards for school buses as warning indicators and stopping signal arms are may improve thoughtfulness of other road users and thereby improve subjective safety of the children walking from the bus to the school.

Suitable locating and design of bus stops may also have a positive effect, if bus stops are located so pedestrians can use footpaths or other areas which are separate from vehicle traffic. Finally, training of bus drivers may lead to a more careful driving.

5.5.2 Education of pre-school children

A few studies have attempted to measure the effect of education of pre-school children on the number of accidents, but not the effect on subjective safety.

Summarizing the qualitative assessments, the overall effect education of pre-school children on subjective safety is possibly positive due to improved skills and knowledge about how to protect themselves when moving as a pedestrian or cyclists. For example, it can encourage them to use helmets when cycling.

5.5.3 Education in schools

Education in schools probably has the same effect on subjective safety as education of pre-school children. However, no studies verify this assessment.

5.5.4 Stationary speed enforcement

It is concluded that stationary speed enforcement has positive effect on subjective safety in a limited area and for a limited period of time.

5.5.5 Patrolling

Like other kinds of speed enforcement and speed-reducing devices, the measure has a positive effect on subjective safety if traffic speed is reduced. In addition, it may have a little positive effect on thoughtfulness because it is not only speed which is controlled. This is however not documented in any studies.

5.5.6 Automatic speed enforcement

The conclusion is that automatic speed enforcement reduces mean speeds in traffic and thus decreases the feeling of unsafety among cyclists and pedestrians.

5.5.7 Red light cameras

The effect of red light cameras on subjective safety of vulnerable road users has not been studied in any reviewed project.

Red light camera may have a little positive effect on subjective safety. It may reduce the number of vehicles going against a red light. This may improve the separation of crossing pedestrians and motor vehicles in time. It is also possible that speed is decreased because some drivers stop at yellow traffic signal instead of driving through the intersection. Finally, thoughtfulness may improve due to the surveillance system. This is however more doubtful.

5.5.8 Summary

The most possible effects of the seven measures regarding driver training, public education and information, and police enforcement and sanctions are summarized in table 5.5. Among the seven measures, the effect on subjective safety has indirectly been studied for three measures. Based on the results from the literature survey and the qualitative considerations, it is concluded that all the seven measures probably have positive effect on subjective safety.

Table 5.5. Summarise of the literature study and the qualitative assessment of the effect on subjective safety for driver training, education and enforcement. The rectangular bracket implies that the literature just indirectly indicated effect.

	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Qualitative assessment**	**Literature**
Transporting of children	-	-	-	(↑)?	-	-	-	(↑)?	-	-	-	-	-	(↑)?	-	-	(↑)?	-
Education before school	-	-	-	-	-	-	-	-	-	-	-	-	-	-	↑	↑	↑	-
Education in school	-	-	-	-	-	-	-	-	-	-	-	-	-	-	↑	↑	↑	-
Speed control	-	-	-	↑	-	-	-	-	-	-	-	-	-	-	-	-	↑	[↑]
Patrolling	-	-	-	↑	-	-	-	-	-	-	-	-	-	(↑)	-	-	↑	[↑]
Automatic speed control	-	-	-	↑	-	-	-	-	-	-	-	-	-	-	-	-	↑	[↑]
Red light cameras	-	-	-	(↑)	-	-	-	(↑)	-	-	-	-	-	(↑)	-	-	(↑)	-

TØI report 1009/2009

5.6 Summary

The effect on subjective safety among vulnerable road users described as positive, negative, neutral, ambiguous or unknown is summarised in table 5.6 for 54 road safety measures in seven different categories. Table 5.6 also shows the number of measures have been studied regarding their effects on subjective safety.

Note that several of the 54 measures consist of more submeasures. Some of the measures as for example cross sections improvements and traffic control for pedestrians and cyclists consist of up to nine different submeasures that might have different effects on subjective safety. However, in table 5.6 the "originally" merging of submeasures into 54 measures is maintained. For groups of submeasures the effect is stated as positive or negative if the effects of all the submeasures are assessed to respectively positive or negative. Otherwise, the effect is stated as ambiguous or unknown.

Among the 54 measures the effect on subjective safety of cyclists and/or pedestrians has been studied for only 14 of them. Additionally, for other 14 measures the effects have been studied more indirectly. In total, the effects have been studied directly or indirectly for half of the measures. For these 28 measures the assessment of possible effects is based on both results from these studies as well as some supplementary qualitative considerations. For the remaining 26 measures, the assessment is only based on speculation.

Based on the results from the earlier studies and the supplementary qualitative considerations, it is assessed that 39 measures to a larger or smaller extent have positive effect of subjective safety of cyclists, pedestrians or both of them. This almost corresponds to three fourth of the measures.

Only five measures are assessed to have definite negative effects on subjective safety while seven measures have unknown or ambiguous effects.

Table 5.6. Number of measures with positive, negative, none and ambiguous or unknown effect on subjective safety among vulnerable road users for seven categories of measures. Measures indicate the number of measures assessed and literature indicate for how many measures evaluations of effect on subjective safety exists.

			Effect			
Category	**Measures**	**Literature**	**Positive**	**Negative**	**no**	**Unknown or ambiguous**
Design and road furniture	**17**	3-4	9	3	0	5
Road maintenance	**5**	2-5	5	0	0	0
Traffic control	**17**	7-11	12	3	1	1
Vehicle design and protective devices	**8**	2-5	6	0	1	1
Driver training and regulation of professionals	**1**	0	1	0	0	0
Public education and information	**2**	0	2	0	0	0
Police enforcement and sanctions	**4**	0-3	4	0	0	0
Total	**54**	14-28	39	6	2	7

TØI report 1009/2009

6 Classification of the measures

Based on the results from chapters 4 and 5 the 54 selected measures are in this chapter classified in different categorises regarding their effects on objective and subjective safety. Firstly, the different categories are made and described, and then the classification of the measures is made.

6.1 Different categories

Road safety measures may have positive, negative, neutral, ambiguous or unknown effects on the number and severity of road accidents.

At the same time they may also have positive, negative, neutral, ambiguous or unknown effects on subjective safety of vulnerable road users.

If neutral, ambiguous and unknown effects due to clarity are merged to one group, the combination of different effects on objective and subjective can be considered in nine different categories. The nine possible categories are illustrated in table 6.1.

For example a measure with positive effect on objective safety may have positive effect (1a), negative effect (2a) or neutral, ambiguous or unknown effect (3a) on subjective safety.

Table 6.1. Nine possible categories of road safety measures regarding their effect on objective and subjective safety among vulnerable road users.

		Subjective		
		Positive	**Negative**	**Neutral, ambiguous, unknown**
Objective	**Positive**	1a	1b	1c
	Negative	2a	2b	2c
	Neutral, ambiguous, unknown	3a	3b	3c

TØI report 1009/2009

Besides the merging of neutral, ambiguous and unknown effects this classification contains some other simplifications:

- *Magnitude of effects:* The magnitude of the effects on objective and subjective safety is not included in this classification. The magnitude of effect on road accidents is known for most of the measures, but it is normally not quantified regarding subjective safety. The result of this simplification is that road measures with either large or small positive effects on objective or subjective safety are classified in a same category.
- *Different effects for different road user groups:* In this project cyclists and pedestrians are mainly treated as one “uniform” group. However, the effects on objective and subjective safety may differ for cyclists and pedestrians. In

this report, whenever possible, the effect on objective and subjective safety is stated for the road user group which the measure is most relevant for. For example, the effect on cycle lanes is described for cyclists and the effect of pedestrian crossings is described for pedestrians.

- *Unknown objective safety effects:* As summarised in chapter 4.6 the effect on objective safety of vulnerable road users is only known clearly for about one fifth of the measures. Obviously, the effect for these road user groups is used in the categorisation. For the remaining 80 % the general effect for all road users are used. Thus, it is assumed that the effect for vulnerable road users have the same sign as the effect for all road users. It should be noted that this may not always be the case.
- *Different number of measures:* The project includes assessment on subjective safety for 54 different road measures. In chapter 4 some of these measures have been divided into several submeasures with different effect on objective safety. The 54 measures have been divided into 126 submeasures. Due the different effect on objective safety for the submeasures the classification is based on submeasures. In other words for some measures only one estimate for subjective safety and several estimates for objective safety have been described. For these measures it is assumed that the effect on subjective safety is the same for all the submeasures. Please also note that in the classification it has been suitable to make some very small changes to the division of submeasures. Thus, the division is based on 125 instead of 126 submeasures.

6.2 Classification

6.2.1 Road Design and road furniture

Table 6.2 summarises the classification of the 17 included road design and road furniture measures according to the nine categories described in table 6.1.

The 17 measures have been divided into 45 different sub-measures. The number of measures in each category is summarized in table 6.3.

35 measures have positive effect on objective safety. Among these, 24 measures have also positive effect on subjective safety while seven measures have negative effect.

Six measures have negative effect on objective safety. Among these, one measure has also negative effect on subjective safety.

Four measures have none, an ambiguous or an unknown effects on objective safety, while five measures have none, ambiguous or unknown effects on subjective.

Table 6.2. Classification of 17 (45) road design and road furniture measures regarding their effect on objective and subjective safety. () indicate small effect.

	Measures	Objective	Subjective	Category
1a	Tracks for cycling	(↓)		2a
	Tracks for walking	↑		1a
1b	Pavement	↑	↑	1a
1c	Cycle lanes	(↑)		1a
1d	Cycle lanes in intersections	↑		1a
2	Motorways	(↑)	(↑)	1a
3	Bypasses	↑	↑	1a
4	New arterial roads	(↑)	↑	1a
5a	T-junctions, full channelisation	↓		2a
5b	Crossroads, full channelisation	↑		1a
5c	T-junctions, minor road channelisation	↓		2a
5d	Crossroads, minor road channelisation	↑	↑	1a
5e	T-junctions, physical left-turn lane	↑		1a
5f	Crossroads, physical left-turn lane	(↑)		1a
5g	T-junctions, physical right-turn lane	(↑)		1a
5h	Crossroads, physical left-turn lane	↑		1a
6a	Roundabouts, mixed traffic	↑	↓	1b
6b	Roundabout, separate cycle track	↑	↑	1a
7a	Redesigning, change angles	↕		3b
7b	Redesigning, gradient on road	↑	↓	1b
7c	Redesigning, sight condition	(↑)		1b
8	Staggered junctions	↑	↑	1a
9	Interchanges (instead of crossroad)	↑	↓	1b
10	Black spot treatment	↑	↕	1c
11a	Number of lanes	↕	↓	3b
11b	Lane width	↕	↕	3c
11c	Shoulder width	↕	↑	3a
11d	Passing lanes (one side)	↑	(↓)	1b
11e	Constructing of hard shoulders	(↑)	↑	1a
11f	Hard shoulders, width (+ 0.3 m)	↑	↑	1a
11g	Lanes and shoulder width	(↑)	↑	1a
11h	Central reservations, urban areas	↑	(↑)	1a
11i	Width of bridges	↑	↕	1c
12	Roadside treatment, distance to obstacles	↑	↕	1c
13a	Road alignment, general improvement	↑		1b
13b	Sight conditions, improving	↓	(↓)	2b
13c	Sight conditions, removing obstacles	↑		1b
14	Rehabilitation, reconstruction and resurfacing	(↑)	(↕)	1c
15a	Guardrails alone roadside, new	↑	↑	1a
15b	Crash cushions	↑		1a
16a	Curve treatments, signs	↑		1a
16b	Curve treatments, recommended speed	↑	(↑)	1a
16c	Curve treatments, Road widening	↓		2a
16d	Curve treatments, transition curves	↓		2a
17	Road lighting	↑	↑	1a

TØI report 1009/2009

Table 6.3. Number of road design and road furniture measures in each category.

		Subjective			
		Positive	Negative	Neutral, ambiguous, unknown	Total
Objective	Positive	24	7	4	35
	Negative	5	1	0	6
	Neutral, ambiguous, unknown	1	2	1	4
	Total	30	10	5	45

TØI report 1009/2009

6.2.2 Road maintenance

Table 6.4 summarises the classification of the five included road maintenance measures. The number of measures in each category is summarized in table 6.5.

Two measures have positive effects on objective safety and three measures have negative effects on objective safety. All five measures are assessed to have positive effect on subjective safety of vulnerable road users.

Table 6.4. Classification of five road maintenance measures regarding their effect on objective and subjective safety. () indicate small effect.

	Measures	Objective	Subjective	Category
1	Ordinary resurfacing of roads	(↓)	↑	2a
2	Improving the evenness of the surface	↓	↑	2a
3	Improving road surface friction	↑	↑	1a
4	Winter maintenance of roads, general	↑	↑	1a
5	Winter maintenance of tracks, more	↓	↑	2a

TØI report 1009/2009

Table 6.5. Number of road maintenance measures in each category.

		Subjective			
		Positive	Negative	Neutral, ambiguous, unknown	Total
Objective	Positive	2	0	0	2
	Negative	3	0	0	3
	Neutral, ambiguous, unknown	0	0	0	0
	Total	5	0	0	5

TØI report 1009/2009

6.2.3 Traffic control

Table 6.6 summarises the classification of the 17 included traffic control measures. The 17 measures have been divided into 39 different submeasures. The number of measures in each category is summarized in table 6.7.

29 measures have positive effect on objective safety. Among these, 27 measures have also positive effect on subjective safety while only two measures have negative effect on subjective safety.

Nine measures have negative effect on objective safety. Among these, one measure has also negative effect on subjective safety while seven measures have positive effect and one measure has probably no effect.

Only one measure has none, ambiguous or unknown effect on objective safety. This is the same number of measures having none, an ambiguous or an unknown effect on subjective safety.

Table 6.6. Classification of 17 (39) traffic control measures regarding their effect on objective and subjective safety. () indicate small effect.

	Measures	Objective	Subjective	Category
1	Area-wide traffic calming	↑	↑	1a
2	Environmental streets	↑	↑	1a
3	Pedestrian streets	↑	↑	1a
4	Urban play streets	↑	↑	1a
5	Access control	↑	↑	1a
6	Priority control	(↓)	-	2c
7	Yield signs at intersections	(↑)	↓	1b
8	Stop signs at intersections	↑	↓	1b
9a	Traffic signal control, new	↑		1a
9b	Traffic signal control, upgrading	↕	↑	3a
9c	Traffic signal control, separate phases, pedestrians	↑		1a
10	Signal-controlled midblock pedestrian crossings	↑	↑	1a
11	Speed limits, all reductions	↑	↑	1a
12a	Speed-reducing, humps	↑		1a
12b	Speed-reducing, raised intersections	(↓)	↑	2a
12c	Speed-reducing, rumble strips	↑		1a
12d	Speed-reducing, speed zones	↑		1a
13a	Normal edge line	(↑)		1a
13b	Wide edge line	(↓)		2a
13c	Shoulder rumble line	(↓)		2a
13d	Raised pavement markers	(↑)	↑	1a
13e	Delineator posts with reflectors	(↓)		2a
13f	Edge line and centre line	↑		1a
13g	Edge line, centre line, delineator	↑		1a
14a	Ordinary pedestrian crossing	↓	↑	2a
14b	Signal-controlled midblock pedestrian crossings,	↑		1a
14c	Pedestrian crossings, mixed phases, intersection	(↓)	↑	2a
14d	Pedestrian crossings, separate phases, intersection	↑		1a
14e	Raised pedestrian crossings	↑	↑	1a
14f	Refuges on pedestrian crossings	↑	↑	1a
14g	Pedestrian guard rails	↑	↑	1a
14h	School crossing patrols	↑	↑	1a
14i	Pavement widening, intersection	(↑)	↑	1a
14j	Advanced stop lines, intersection	↑	(↑)	1a
14k	Cycle lanes, intersection	↑	↑	1a
14l	Cycle lanes	↑		1a
15	Parking regulations	↑	(↑)	1a
16	One-way streets	(↓)	↑	2a
17	Bus lanes and bus stop design	(↓)	↓	2b

TØI report 1009/2009

Table 6.7. Number of traffic control measures in each category.

		Subjective			
		Positive	Negative	Neutral, ambiguous, unknown	Total
Objective	Positive	27	2	0	29
	Negative	7	1	1	9
	Neutral, ambiguous, unknown	1	0	0	1
	Total	35	3	1	39

TØI report 1009/2009

6.2.4 Vehicle design and protective devices

The classification of the eight measures regarding vehicle design and protective devices is summarised in table 6.8.

The eight measures have been divided into 25 different submeasures. The number of measures in each category is summarized in table 6.9.

19 measures have positive effect on objective safety. Among these, 17 measures have also positive effect on subjective safety. None of these measures have negative effect on subjective safety.

Only one measure has negative effect on objective safety. This measure has positive effect on subjective safety.

Five measures have none, ambiguous or unknown effect on objective safety. All these measures have probably positive effect on subjective safety.

Table 6.8. Classification of eight (25) vehicle design and protective measures regarding their effect on objective and subjective safety. () indicate small effect.

	Measures	Objective	Subjective	Category
1a	Pedestrian reflectors	↑	(↑)	1a
1b	Retro-reflective materials, cycles	↑ (?)		1a
2	Cycle helmets, mandatory wearing	↑ (?)	↑	1a
3	Regulating vehicle mass	↑ (?)	(↕)	1c
4a	Regulating car engine effect	↑ (?)	↑	1a
4b	Regulating top speed	↑		1a
5	Under-run guard rails on lorries	↑	-	1c
6a	Total weight of lorries, decreasing	↑	(↑)	1a
6b	Total length of lorries, decreasing	(↑)		1a
6c	Extra mirrors on lorries	↑		1a
6d	Side marker lamps on lorries	(↑)		1a
7a	Cycle equipment, pedal reflectors	↑	(↑)	1a
7b	Cycle equipment, Spokes reflectors	(↓)		2a
7c	Cycle equipment, ankle light	↑		1a
7d	Cycle equipment, jacket reflectors	↑		1a
7e	Cycle equipment, taillight	↑		1a
7f	Cycle equipment, brakes	↑		1a
7g	Cycle equipment, brake blocks	(↕)		3a
7h	Cycle equipment, normal handlebars	↑		1a
7i	Cycle equipment, normal wheel	↑		1a
7j	Cycle equipment, distance markers	(↑)		1a
8a	Ban on driving with trailers	-	(↑)	3a
8b	Special speed limits for lorries	-		3a
8c	Total weight limits for trailers	-		3a
8d	Better stability, control and tracking for trailers	-		3a

TØI report 1009/2009

Table 6.9. Number of vehicle design and protective measures in each category.

		Subjective			
		Positive	Negative	Neutral, ambiguous, unknown	Total
Objective	Positive	17	0	2	19
	Negative	1	0	0	1
	Neutral, ambiguous, unknown	5	0	0	5
	Total	23	0	2	25

TØI report 1009/2009

6.2.5 Driver training, education and enforcement

Table 6.10 summarises the classification of the seven included driver training, education and enforcement measures. The number of measures in each category is summarized in table 6.11.

Eight measures have positive effect on both objective and subjective safety while three measures have unknown effect on objective safety and positive effect on subjective safety.

Table 6.10. Classification of seven (11) driver training, education and enforcement measures regarding their effect on objective and subjective safety. () indicate small effect.

	Measures	Objective	Subjective	Category
1a	School transport with buses	↑		1a
1b	Safety standards for school buses	↑	(↑) ?	1a
1c	Improving bus stops	-		3a
1d	Training bus drivers	-		3a
2	Education of pre-school children	-	↑	3a
3a	School education, crossing a road	↑	↑	1a
3b	School education, Cycling	(↑)		1a
4	Stationary speed enforcement	(↑)	↑	1a
5	Patrolling	↑	↑	1a
6	Automatic speed enforcement	↑	↑	1a
7	Red light cameras	↑	(↑)	1a

TØI report 1009/2009

Table 6.11. Number of driver training, education and enforcement measures in each category.

		Subjective			
		Positive	Negative	Neutral, ambiguous, unknown	Total
Objective	Positive	8	0	0	8
	Negative	0	0	0	0
	Neutral, ambiguous, unknown	3	0	0	3
	Total	11	0	0	11

TØI report 1009/2009

6.3 Summary

In table 6.12 the total number of road safety submeasures in each of the nine defined categories is summarized.

Table 6.12. Total number of measures in each of the nine defined groups. () indicate percentage of the total number of submeasures.

		Subjective			
		Positive (a)	Negative (b)	Neutral, ambiguous, unknown (c)	Total (d)
Objective	Positive (1)	78 (62.4)	9 (7.2)	6 (4.8)	93 (74.4)
	Negative (2)	16 (12.8)	2 (1.6)	1 (0.8)	19 (15.2)
	Neutral, ambiguous, unknown (3)	10 (8.0)	2 (1.6)	1 (0.8)	13 (10.4)
	Total (4)	104 (83.2)	13 (10.4)	8 (6.4)	125 (100.0)

TØI report 1009/2009

Column (d) shows that almost 75 % of the measures have positive effect on objective safety, while 15 % of the measures are assessed to have negative effect. 10 % of the measures have neutral, ambiguous or unknown effect.

As shown in row 4, about 83 % of the measures have probably positive effect on subjective safety, 10 % have negative effect, and 6 % have neutral, ambiguous or unknown effect.

Note that the small number of measures with neutral, ambiguous or unknown effect is the result of qualitative considerations regarding subjective effect for all measures. In fact, the review of the measures shows that the effect on subjective safety for cyclists and/or pedestrian has been directly studied only for one fourth of the measures and indirectly for another fourth of the measures. From this point of view, the effect on subjective safety is unknown for 50 % of the measures.

Fortunately most of the measures are classified in category (1a). In total, 78 out of 125 sub-measures are included in this category. These are the best measures regarding that they have positive effect on both objective and subjective safety. This part of the classification may be considered as a surprising result due to all the debate among professionals and non-professionals about road safety measures having a negative effect on subjective safety among vulnerable road users.

For the remaining 47 sub-measures different "problems" exists.

The first group of problems includes the measures in row 3 and column c. For these measures it is unclear if they have any effect on objective safety and what effect they have on subjective safety. In total this group includes 20-submeasures.

Table 6.13. Measures with neutral, ambiguous or unknown effect on objective safety, subjective safety or both.

	Objective safety	Subjective safety
– Redesigning intersection, change angles	✓	
– Cross section improvements, number of lanes	✓	
– Cross section improvements shoulder width	✓	
– Traffic signal control, upgrading	✓	
– Cycle equipment, brake blocks	✓	
– Ban on driving with trailers	✓	
– Special speed limits for lorries	✓	
– Total weight limits for trailers	✓	
– Better stability, control and tracking for trailers	✓	
– Improving bus stops	✓	
– Training bus drivers	✓	
– Education of pre-school children	✓	
– Cross section improvements, lane width	✓	✓
– Black spot treatment		✓
– Width of bridges		✓
– Roadside treatment, distance to obstacles		✓
– Rehabilitation, reconstruction and resurfacing		✓
– Priority control		✓
– Regulating vehicle mass		✓
– Under-run guard rails on lorries		✓

TØI report 1009/2009

Table 6.13 summarizes the measures with neutral, ambiguous or unknown effects. Five out of eight measures with unclear effect on subjective safety are road design and road furniture measures, one measure is traffic control and two are vehicle design measures. For many of these measures further studies should be made.

The second group of problems includes measures in category (2b). These are the measures with probably negative effects on both objective and subjective safety. Fortunately, the category only includes two sub-measures:

- Sight conditions in curves, improving
- Bus lanes and bus stop design

These measures should not be used if the aim is improving objective and subjective safety. However, they have positive effects on other parameters.

The last group of problems includes measures in category (2a) or (1b). These are the measures with opposite effects on objective and subjective safety. In total these two categories include 25 sub-measures. 16 sub-measures are assessed to have positive effects on subjective safety and negative effect on objective safety while nine sub-measures are assessed to have positive effect on objective safety and negative effect on subjective safety.

Table 6.14 summarizes the measures with opposite effects on objective and subjective safety. Among the 16 sub-measures which have positive effect on subjective safety and negative effect on objective safety, seven measures are traffic control measures, five measures are road design and road furniture measures, three measures are road maintenance measures and one measure is protective device measures. Among the nine other measures, seven measures are road design and road furniture measures and two measures are traffic control measures.

Table 6.14. Measures with opposite effect on objective and subjective safety.

Positive effect on subjective safety and negative effect on objective safety	**Positive effect on objective safety and negative effect on subjective safety**
– Tracks for cycling	– Roundabouts, mixed traffic
– T-junctions, full channelisation	– Redesigning, gradient on road
– T-junctions, minor road channelisation	– Redesigning, sight condition
– Curve treatments, road widening	– Interchanges (instead of crossroad)
– Curve treatments, transition curves	– Passing lanes (one side)
– Ordinary resurfacing of roads	– Road alignment, general improvement
– Improving the evenness of the surface	– Sight conditions, removing obstacles
– Winter maintenance of tracks, more	– Yield signs at intersections
– Speed-reducing, raised intersections	– Stop signs at intersections
– Wide edge line	
– Shoulder rumble line	
– Delineator posts with reflectors	
– Ordinary pedestrian crossing	
– Pedestrian crossings, mixed phases, intersection	
– One-way streets	
– Cycle equipment, spokes reflectors	

TØI report 1009/2009

7 Lack of knowledge

Besides the previous classification of road safety measures in different categories with different effect on objective and subjective safety, the objective of this project is also identifying road safety measures where the effect on subjective safety has not been studied, knowledge about the measure in other ways are insufficient, or the classification in other ways raises some interesting questions.

7.1 Unknown effect on subjective safety

Among the 54 included measures the effect on subjective safety has been only studied for 14 measures corresponding to 26 % of the measures. As described before, several of the 54 measures consist of several submeasures. The fact that subjective safety has been studied for 14 measures means that it has been studied for one or maybe more submeasures under the 14 “main measures”. In other words, the percentage of studied measures is less than 26 %.

Table 7.1 summarises the number of measures studied for seven categories of safety measures. Half of the 14 measures are traffic control measures.

Table 7.1. Number of measures where the effect on subjective safety among vulnerable road users directly or indirectly have been studied. () indicate percentage for each group of road safety measures.

Category	Measures	Directly	Directly or indirectly
1. Design and road furniture	17	3 (18)	4 (24)
2. Road maintenance	5	2 (40)	5 (100)
3. Traffic control	17	7 (41)	11 (64)
4. Vehicle design and protective devices	8	2 (25)	5 (63)
5. Driver training and regulation	1	0 (0)	0 (0)
6. Public education and information	2	0 (0)	0 (0)
7. Police enforcement and sanctions	4	0 (0)	3 (75)
Total	54	14 (26)	28 (52)

TØI report 1009/2009

Table 7.2 summarises for which measures the effects on subjective safety of vulnerable road users have been studied. Most of the measures directly dealing with cycling and walking have been evaluated. The only exceptions are:

- Bicycle safety equipment (brakes, handlebars, wheel, bells, distance marker, child seats and bicycle wagons)
- Safety standards for transporting school children
- Education of pre-school children
- Education in schools.

Table 7.2. Measures where the effect on subjective safety among vulnerable road users directly or indirectly have been studied. The number refers to the numbers for categories of road safety measures described in table 7.1. The effect of bicycle safety equipment has only been studied for some of the submeasures, and therefore the measure is included in a bracket.

Directly studied	Indirectly studied
– Tracks for walking and cycling (1)	– Road lighting (1)
– Arterial roads in and around cities (1)	– Ordinary resurfacing of roads (2)
– Roundabouts (1)	– Better evenness of road surface (2)
– Winter maintenance of roads (2)	– Improving road surface friction (2)
– Winter maintenance of tracks (2)	– Urban play streets (3)
– Area-wide traffic calming (3)	– Access control (3)
– Environmental streets (3)	– Road markings (3)
– Pedestrian streets (3)	– Bus lanes and bus stop design (3)
– Signal-controlled pedestrian crossings (3)	– Reflective materials and protective clothing (4)
– Speed limits (3)	– Regulating vehicle mass (4)
– Speed-reducing devices (3)	– Safety equipment on trucks (4)
– Traffic control for pedestrians and cyclists (3)	– Stationary speed enforcement (7)
– (Bicycle safety equipment) (4)	– Patrolling (7)
– Cycle helmets (4)	– Automatic speed enforcement (7)

TØI report 1009/2009

As described, the effect on subjective safety has been studied for 14 measures. However, for several measures it was only possible to find one or maybe few studies dealing with this issue. The quality of these studies has not been examined, but some of the studies are based on very few respondents. In other words, the assessments may in worst case scenario be based on one bad study with few respondents. However, the supplementary qualitative considerations may minimise this problem. It should be also noted that several of the studies are very systematic and comprehensive.

For those measures which indirectly studied the issue, the results have been interpreted in order to estimate the effects on subjective safety. Maybe theses studies have been "over- interpreted".

To overcome the problem with few measures which were addressed in the literature, the literature study has been supplemented with theoretical and qualitative considerations about factors having impact on subjective safety. In this way, we have succeeded to estimate for several of the unstudied measures whether they have positive or negative effect on subjective safety. In fact, it is only the assessment of six out of 125 measures that failed. However, there are several reservations:

- Some assumptions about correlations have not been verified. For example, it is difficult to say if safety equipment on bicycles or education actually improves subjective safety.
- It is difficult to assess an effect when factors having impact on subjective safety are affected by the measure in different and opposite directions. This is the case for many of the measures.

7.2 Magnitude of effect, exposure and road users

The objective of this project was to make a qualitative and not quantitative assessment regarding the effects on subjective safety. The theoretical and qualitative considerations cannot directly be used for a quantitative assessment. Thus, the assessed effects have just been grouped into two categories; “effect” and “small effect”. The result is that measures with possible large difference in magnitude of the effects are classified in a same category. For example tracks for cycling and ordinary resurfacing of roads both assessed to have “the same” positive effect on subjective safety of cyclists, even though the effect probably is much larger for cycle tracks than ordinary resurfacing of roads.

Another problem with the assessment is that exposure of cyclists and pedestrians are not included. A measure may have positive effect on subjective safety, but if there is no vulnerable road users the effect may not be so important. For example you may ask what is most important; small positive effect for many vulnerable road users or large positive for few vulnerable road users? One simple division to be made could be to divide the measures into urban area measures and measures for rural areas. The idea of this division is that normally there are more vulnerable road users in urban areas than in rural areas. For some of the measures this clarification has been made.

In the assessment of subjective safety among vulnerable road users no systematic division of vulnerable road users for cyclists and pedestrians have been made. Often the effect is assessed and described for the most relevant groups of road users. For example, the effect of bicycle safety equipment is assessed for cyclists, and signal controlled pedestrian crossings are assessed for pedestrians. However, this distinction is not explicitly described for the measures. Additionally, the assessment should be done for both groups of road users for all measures. Table 7.3 illustrates nine possible categories of road safety measures regarding their effect on subjective safety of pedestrians and cyclists. For example, a measure may have a positive effect for both groups (1a), positive effect for one group and negative effect for the other group (2a, 1b), negative effect for both groups (2b) or maybe positive effect for one group and no effect for the other group (3a, 1c).

Table 7.3. Nine possible groups of road safety measures regarding their effect on subjective safety for pedestrians and cyclists.

		Pedestrians		
		Positive	**Negative**	**None or unknown**
Cyclists	**Positive**	1a	1b	1c
	Negative	2a	2b	2c
	None or unknown	3a	3b	3c

TØI report 1009/2009

The literature does not usually make this distinction because it is only the most relevant groups of vulnerable road users which are normally studied. However, this distinction may be done as part of the theoretical and qualitative considerations of the effects on subjective safety.

7.3 Unknown effect on objective safety

For some measures the described effect on objective safety in "The Handbook of Road Safety Measures" (Elvik and Vaa 2004, Elvik, Erke and Vaa 2008) used for classification in this project should be used with caution.

Firstly, some of the chapters in the handbook is despite its continuous updating are about 10 years old, and therefore do not include new study results regarding the effects that could have affected the assessment and classification of this report. For example a new study by Robinson (2006, 2007) questions if the effect of mandatory wearing of bicycle helmets has a positive effect on objective safety among vulnerable road users as described in the handbook. Another example is the effect of cycle tracks. Two new large Danish studies indicate that the negative effect for cyclists is probably larger than that indicated in the handbook (Agerholm, Caspersen and Lahrmann 2008, Jensen 2006b).

Secondly, the effect on objective safety for cyclists and pedestrians has been only evaluated for under 20 % of the sub-measures. For the remaining 80 % of the measures the effects for vulnerable road users are unknown or non existing. For these measures the general effect for all road users are used in the classification. Thus, it is assumed that the effect for vulnerable road user has the same sign as the effect for all road users, but this may not always be the case. For such measures there is a risk for misleading classification.

7.4 Classification

Choice of method for classification induces a dilemma between choosing a simple, clear and maybe incomplete classification or a complete but more confusing one.

In this project the first method has been selected, and the measures are only been divided into nine different groups. In addition, this division has been discussed regarding the different categories of safety measures used by "The Handbook of Road Safety Measures".

However, a more detailed model may contribute to further information. Parameters that may be clarified or included in the classification are:

1. Dividing of vulnerable road users into cyclists and pedestrians
2. Dividing the last category into measures with none, a ambiguous or a unknown effect on objective and subjective safety
3. Dividing of measures into measures with different magnitude of effect on objective and subjective safety
4. Dividing of measures into measures for urban and rural areas
5. Dividing of measures into measures that reduce the risk of accidents and measures that reduce the consequence
6. Dividing of the measures with agreement or disagreement among professionals and maybe among professionals and public about the effect on subjective and maybe objective safety.

The first four points have already been discussed.

The argument for the fifth point is that different studies have concluded that measures which reduce the risk of accidents are associated with larger risk compensation than measures reducing the consequence of an accident (Amundsen and Bjørnskau 2003, Bjørnskau 1994). This has an influence on subjective safety and thereby what category the measures should be associated with.

The argument for including the last point is that disagreement among professionals about effects on subjective safety is a reason for further investigation in the RiskDisk project regarding what effect the measure have on subjective safety.

7.5 Recommendation for further research

This project reveals 12 different problems with estimating the effect of road safety measures on subjective safety. Table 7.4 lists the problems.

Table 7.4. Problems with estimating the effect of road safety measures on subjective safety among vulnerable road users and possible solutions.

Problems		Solution
1	**Few studies:** The effect on subjective safety among vulnerable road users has been studied directly for only about on fourth of the included measures	Effect studies of measures not studies before
2	**Amount of studies:** For the measure studied it is only possible to find one or maybe a few studies dealing with the question	Effect studies of measures studied or not studies before
3	**Quality of studies:** The quality of the studies has not been examined, but some of the studies are based on very few respondents	Assessment of quality and weighting of results
4	**Over-interpretation:** The effect on subjective safety among vulnerable road users has been studied indirectly for about another fourth of the measures included. The result of these studies may have been over-interpreted	Effect studies for measures where the effect have been interpreted
5	**Considerations not verified:** Assumptions about correlations have not been verified satisfactorily	Studies that quantify the correlation between influencing factors and subjective safety
6	**Difficult to sum up considerations:** It is difficult to assess the effect when factors having an impact on subjective safety have opposite directions. This is the case for several of the measures	Studies that verify the consideration.
7	**Unambiguous or unknown results:** Ambiguous or unknown results about the effect on subjective safety for several measures	Effect studies for these measures
8	**Magnitude of effect:** The magnitude of the effect on subjective safety is often unknown	Effect studies that quantify the magnitude
9	**Number:** Number of vulnerable road users is not taken account for in the classification	Dividing of measures in measures for urban and rural areas (simple solution)
10	**Division of vulnerable road users:** Vulnerable road users are not divided systematically between cyclists and pedestrians. This may only been done in the qualitative considerations	Divide the group into cyclists and pedestrians
11	**Old studies:** Some new relevant studies about objective safety have not yet been included in "The Handbook of Road Safety Measures"	More frequency updating of the handbook
12	**Few studies about objective safety:** The effects on objective safety among vulnerable road users have only been evaluated for under 20 % of the included submeasures.	Effect studies hat include the effect on accident with vulnerable road users

TØI report 1009/2009

Table 7.4 indicates also some possible solutions on the problems. The general problem is little knowledge about the effect of varying measures and about correlation between influencing factors and subjective safety. More studies are recommended.

Table 7.5. Classification of the 125 submeasures.

Group	Characteristic	Number
1a	Positive effect on objective and subjective safety	78
2b	Negative effect on objective and subjective safety	2
3a, 3b, 3c, 1c, 2c	Neutral, ambiguous, unknown effect on objective and subjective safety	20
1b	Positive effect on objective safety, negative effect on subjective safety	9
2a	Negative effect on objective safety, positive effect on subjective safety	16

TØI report 1009/2009

The 125 measures are classified as summarized in table 7.5. Among these submeasures further studies are most relevant for the last three groups. The measures in these groups are described in table 6.13 and table 6.14. For five of the 80 submeasures in group 1a and 2b the described effects are supplemented with a question mark. See table 6.8 and table 6.10. Further investigation is also relevant for these measures.

However, it is very ambitious to recommend further studies for 50 varying measures. Thus, about one fourth of the measures have been selected as measures where further studies are most relevant.

Besides ambiguous, unknown and/or opposite effect on objective and/or subjective safety the selection criteria is that the measures to some extent should target on vulnerable road users and have or should be expected to have a significant effect on objective and/or subjective safety for this group of road users. In addition special attention should be on measures where professionals disagree about the effect or where the public do not “understand” the found effects. Finally, measures dominating the current debate among professionals and in the media should also be selected.

Based on these selection criteria 13 submeasures are assessed as the most relevant measures for further investigation. These are listed in table 7.6.

The measures could be divided into four groups:

1. *Infrastructure for vulnerable road users:* Track for cycling, winter maintenance of tracks and pedestrian crossings
2. *Cross sections improvements:* lane width and shoulder width
3. *Equipment for cycle and cyclist:* Helmet, brake blocks, spokes reflectors, and retro-reflective materials
4. *Regulations of heavy vehicles:* Weight, ban on trailers, speed and rails.

The reason for recommendation of more studies about the measures in group 1 is primarily disagreement among professionals and missing understanding from the public. A lot of studies have been performed, but publication of new study results still cause a lot of discussion among professionals and in the media even though the result verify old studies. Securing of good conditions for cyclists and pedestrians in an attempt to promote more cycling and walking is also a prevailing trend. This includes better conditions for cycling in the winter.

Table 7.6. Recommended measures for further study and the reason for selection. The measures are ranked after category and not priority for further study. Category refers to categories of measures and group refer their effect on objective and subjective safety.

Measure	Category	Group	Reason for selection
Tracks for cycling	1	2a	– Cycle measure – Disagreement among professionals – Missing understanding from the public – Dominating the current debate
Cross section, lane width	1	3c	– Ambiguous effect on both objective and subjective safety
Cross section, shoulder width	1	3a	
Winter maintenance of tracks	2	2a	– Cycle measure – Dominating the current debate
Pedestrian crossing	3	2a	– Pedestrian measure – Missing understanding from the public – Dominating the current debate
Cycle helmets	4	1a (?)	– Ambiguous effect on objective safety – Disagreement among professionals
Cycle equipment, brake blocks	4	3a	– No/few studies – Unknown effect – Cycle measure
Cycle equipment, spokes reflectors	4	2a	
Retro-reflective materials for cycles	4	1a (?)	
Weight limits for lorries/trailers	4	3a	– Dominating the current debate – Unknown effect on subjective safety
Ban on driving with trailers	4	3a	
Special speed limits for lorries	4	3a	
Under-run guard rails on lorries	4	1c	

TØI report 1009/2009

Cross sections improvements are recommended for further investigation due to the ambiguous effect on both objective and subjective safety.

Group 3; Equipment for cycle and cyclist, is selected of several reasons. Even through these measures can be described as cycle measures only very few evaluations of the effect on objective and subjective safety for cyclist have been preformed. Only the effect of cycle helmet has been studied in several projects. However, the results of these studies are not unambiguous and therefore there is no agreement among professionals about the effect of cycle helmets (Robinson 2006, 2007).

Regulations of heavy vehicles are included as measures relevant for further investigation because several cities have or want to implement varying regulations to reduce the environmental impact, improve life in the cities and improve conditions especially for cyclists. However, no evaluation of the effect on objective and subjective safety for cyclists exist (Sørensen 2008a, 2009a).

7.6 Summary

This project reveals lack of knowledge for several road safety measures regarding their effect on subjective safety among vulnerable road users. Among 54 selected measures assumed to have some effect on subjective safety, the effects have been studied directly only for 14 measures and indirectly for another 14 measures. In other words, no studies have been preformed for half of the measures. In addition, the effect on objective safety for cyclists and pedestrians has only been evaluated for under 20 % of the sub-measures.

More evaluation studies are recommended. Among 50 varying submeasures 13 measures have been selected as the most relevant measures to evaluate. Those are:

- Three types of infrastructure measures for vulnerable road users
- Two types of cross sections improvements
- Four types of equipment for cycle and cyclist
- Four types of regulations for heavy vehicles.

8 Conclusion

8.1 Objective and method

The objective of this project consists of the following four parts:

1. *Effect on subjective safety:* Collecting all available knowledge and studies regarding the effects of varying road safety measures on subjective safety among vulnerable road users in order to make an overall overview of all the measures.
2. *Classification:* Classification of road safety measures in different categories regarding their effect on objective and subjective safety in order to try to study the relationship between road safety measures with confirmed positive effect on road safety and perceived risk for accidents.
3. *Lack of knowledge:* Identifying of road safety measures where the effect on subjective safety has not been studied, knowledge about the measure in other ways are insufficient or the classification in other ways raises some interesting questions.
4. *Further research:* Selection of road safety measures most relevant for further studies about the effect on subjective safety or the relationship between subjective and objective safety.

54 road safety measures among the 111 described measures in "The Handbook of Road Safety Measures" have been included in the study. These measures have been divided into 125 varying submeasures. The measures are selected as measures that have or are expected to have some direct or indirect effect on objective safety, subjective safety or mobility and accessibility for cyclists and/or pedestrians.

A comprehensive literature study regarding each of the selected measures is conducted. Over 200 studies or references have been included in study. However, for many of the selected road safety measures no evaluation studies have been found. Thus, theoretical and qualitative considerations about factors having impact on subjective safety are made in this report for each measure to assess if the measures may have a positive or a negative effect on subjective safety.

The classification of road safety measures is based on results from the literature study and the qualitative considerations. Regarding the effect on objective safety the effects described in "The Handbook of Road Safety Measures" are used.

8.2 Effect on subjective safety

Based on the results from the earlier studies and the qualitative considerations, it is assessed that 39 out of 54 studied measures and 78 out of 125 submeasures to a larger or smaller extent have positive effect on subjective safety of cyclists, pedestrians or both of them. This corresponds to 70-83 % of the measures.

Only a minority of six measures or 13 submeasures are assessed to have definite negative effects on subjective safety. The remaining nine measures have none, unknown or ambiguous effect.

This result - that a majority of the measures probably have a positive effect - may be considered as a surprising result due to all the debate among professionals and non-professionals about road safety measures having a negative effect on subjective safety among vulnerable road users. However, this study shows that the problem most likely is smaller than the debate immediate indicates. The reason probably is that the debate is dominated by few "problematic" measures for example having opposite effect on subjective and objective safety.

8.3 Classification

The classification is done for the 125 submeasures.

74 % of the submeasures have positive effect on objective safety, 15 % have negative effect and 10 % have neutral, ambiguous or unknown effect.

83 % of the submeasures have positive effect on subjective safety, 10 % have negative effect, and 6 % have neutral, ambiguous or unknown effect.

62 % of the submeasures have positive effect on both objective and subjective safety. These are "good" measures, which more or less can be used without "problems" when tying to improve safety in general and safety among vulnerable road users.

38 % of the submeasures are "problem" measures. They have unknown, unclear or opposite effect on objective and/or subjective safety.

16 % are submeasures with unknown or unclear effect on objective or subjective safety. These measures are listed in table 6.13.

20 % are submeasures with opposite effect on objective and subjective safety. 13 % have positive effects on subjective safety and negative effect on objective safety, while 7 % have positive effect on objective safety and negative effect on subjective safety. Table 6.14 list the measures with opposite effect. These measures should be used with caution and as minimum an assessment of the effect should be made considering the specific case.

2 % are submeasures with negative effect on both objective and subjective safety. These measures should not be used if the aim is improving objective and subjective safety. However, they have positive effects on other parameters.

8.4 Lack of knowledge

This project reveals lack of knowledge for several road safety measures regarding their effect on subjective safety among vulnerable road users. Among the 54 measures, the effects have been studied directly for only 14 measures and indirectly for another 14 measures.

Among these 28 measures several of the assessments of the effect on subjective safety are only based on few, old, small or poor studies.

No studies have been performed for half of the measures. Thus, the classification of several of the measures is only based on theoretical and qualitative considerations about the effect, and no studies exist to verify the assessment.

8.5 Further research

Due to the quality and the quantity of the evaluation studies preformed further evaluation is both recommended for measures already studied and measures not studied before.

50 measures are identified for further investigation. However, it is very ambitious to recommend further studies for 50 varying measures. Thus, 13 (one fourth) of the measures have been selected as measures where further studies are most relevant.

The measures are selected as measures with ambiguous, unknown, significant and/or opposite effect on objective and/or subjective safety among vulnerable road users, measures where professionals and/or public "disagree" about the effect and measures dominating the current debate among professionals and in the media.

The 13 measures divided into four groups are:

1. *Infrastructure for vulnerable road users:* Track for cycling, winter maintenance of tracks and pedestrian crossings
2. *Cross sections improvements:* lane width and shoulder width
3. *Equipment for cycle and cyclist:* Helmet, brake blocks, spokes reflectors, and retro-reflective materials
4. *Regulations of heavy vehicles:* Weight, ban on trailers, speed and rails.

9 References

Agerholm, N., Caspersen, S. and Lahrmann, H. (2008). *Traffic safety on bicycle paths – result from a new large scale Danish study*, International cooperation on theories and concepts in traffic safety (ICTCT), Extra workshop, Melbourne.

Agerlin , M. and Jensen, N. (2008). *Cykling mod ensretningen I København*, Vejforum, Nyborg.

Alm, C. and Lindberg, E. (2000). *Perceived risk, feelings of safety and worry associated with different travel modes: pilot study 2000:7*. Kommunikationsforskningsberedningen, Stockholm.

Alm, C. and Lindberg, E. (2002). *Upplevd trygghet vid resor med kollektiva transportmedel,* VTI meddelande 919. Väg- och transportforskningsinstitutet (VTI), Linköping, Sweden.

Alm, C. and Lindberg, E. (2004). *Betydelsen av upplevda risker och känslor av otrygghet vid resor med kollektivtrafikk*, Väg- och transportforskningsinstitutet (VTI), Linköping, Sweden.

Amundsen, A. (1999). *Gjennomgang av tidligere undersøkelser som tar for seg utrygghet i trafikken*, Working paper 1050/1999, Institute of Transport Economics, Oslo.

Amundsen, A. H. and Bjørnskau, T. (2003). *Utrygghet og risikokompensasjon i transportsystemet. En kunnskapsoversikt for RISIT-programmet*, report 622. Institute of Transport Economics, Oslo.

Amundsen, A. and Kolbenstvedt, M. (2008). *Miljøhåndboken*, online available on http://miljo.toi.no/ (cited September 2008 – February 2009).

Amundsen, A., Elvik, R. and Sælesminde, K. (2000). *Fartsgrenser i tettbygd strøk – trgghet, samfunnsøkonomisk analyse og kriterier for fastetting av fartsgrenser*, report 471, Institute of Transport Economics, Oslo.

Andersen, T. (2002). *Driftens betydning for cykeltrafikken*, Vejfoum, Nyborg.

Andersen, T., Lahrmann, H. and Madsen, J. C. O. (2006). *Kørelys på cykel – en effektundersøgelse*, Odense Kommune, project Cykelby and Trffic research group at Aalborg University, online available on http://www.vejsektoren.dk/imageblob/image.asp?objno=151334.pdf.

Angenendt, W. and C Hausen. (1989). *Zur Sicherheitswirkung von Fahrradkellen,* Forschungsberichte der Bundesanstalt für Strassenwesen 197, Bundesanstalt für Strassenwesen (BASt), Bergisch Gladbach.

Anund, A. (1992). *Vägytans inverkan på fordonshastigheter*. VTI-meddelande 680. Väg- och transportforskningsinstitutet, Linköping.

ARTISTS, Arterial Streets Towards Sustainability (2005). Appendix 2, Street element 7.4, *T-junction*, online available on http://www.tft.lth.se/artists/dokument/Appendix_2_Street_element_7_4.pdf.

Association of British Drivers (2002). *Bus Lanes,* Updated on 18.10. 2008, online available on http://www.abd.org.uk/buslanes.htm.

Assum T., Bjørnskau, T., Fosser, S. and Sagberg, F. (1999). *Risk compensation—the case of road lighting*, Accident Analysis & Prevention, 31, 545-553.

AASHTO (1999). *Guide for the planning, Design, and Operation of Pedestrian Facilities,* American Association of State Highway and Transport Officials (AASHTO).

Bach-Jacobsen, A. M. and Kure, R. (2004). *Taastrup bymidter – Fra gennemfart til sivegade*. Dansk vejtidsskrift, 4, 46-48, online available on http://asp.vejtid.dk/Artikler/2004/04/3967.pdf.

Backer-Grøndahl, A., Amundsen, A. H., Fyhri, A., & Ulleberg, P. (2007). *Trygt eller truende? Opplevelse av risiko på reisen*, report 913. Institute of Transport Economics, Oslo.

Backer-Grøndahl, A., Fyhri, A., and Ulleberg, P. (2008). *Accidents and Incidents: Worry in transport and prediction of travel behaviour*. Unpublished article.

Berggrein, B. and Ágústsson, L. (1999). Mer sikker på cykel i Randers – Evaluering af et Trafikpuljeprojekt, Rapport 173, Vejdirektoratet, København.

Bergström, A. (1999). *Effects on cycling of road maintenance and operation*, Swedish Road and Transport Research Institute, Linköping.

Bergström, A. (2002). *Winter Maintenace and cycleways*, Ph.d.-thesis, Royal Institute of Technology, Division of Highway Engineering, Stockholm

Bergström, A. and Magnusson, R. (2003). *Potential of transferring car trips to bicycle during winter*, Transportation Research Part A, 37, 649-666.

Bettum, O. (1998). *Oslo - Byens liv - gaten som social arena*, Statens vegvesen,, Oslo commune, Oslo Sporveier, Oslo Handelsstads forening, Oslo.

Bjørnskau, T. (1994). *Hypotheses on risk compensation*, Road safety in Europe and strategic highway research program (SHRP), VTI konferense 2A part 4: 84-89, Swedish Road and Transport Research Institute, Linköping.

Bjørnskau, T. (2004). *Trygghet i transport. Oppfatninger av trygghet ved bruk av ulike transportmidler*, report 702. Institute of Transport Economics, Oslo.

Bjørnskau, T. (2005). *Sykkelulykker – ulykkestyper, skadeskonsekvenser og risikofaktorer*, report 793, Institute of Transport Economics, Oslo.

Bjørnskau, T. (2008). *Risiko I trafikken 2005-2007*, report 986. Institute of Transport Economics, Oslo.

Bjørnstig, U. (1987). *Fordonulyckor med personskador i Umeå*, Rapport nr 1:1987, Regionsjukhuset i Umeå.

Borger, A. and Frøysadal, E. (1993). *Sykkelundersøkelsen 1992*, report 217, Institute of Transport Economics, Oslo.

Bouyer, M., Bagdassarian, S., Chaabanne, S. and Mullet, E. (2001). *Personality correlates of risk perception*. Risk Analysis, 21, 457-465.

Bretherton Jr, W. Martin (1999). *Multi-way Stops - The Research Shows the MUTCD is Correct!,* Transportation Frontiers for the Next Millennium: 69th Annual Meeting of the Institute of Transportation Engineers, online available on http://www.ite.org/traffic/documents/AHA99B49.pdf.

Carlsson, A., Brüde, U. and Bergh, T. (2001).*Utvärdering av alternativ 13 m väg. Halvårsrapport 2001:1*, VTI notat 69-2001, Väg- och Transportforskningsinstitutet, Linköping.

Catinét (2008). *Evaluering af Trafikforsøg på Nørrebrogade*, online available on http://www.kk.dk/Nyheder/2008/December/~/media/0A691EE49743432FA678F97915E81076.ashx.

Chang-Hee, A. (2001). *Influences of Constructive Traffic Safety Education on the Coping Ability and the Perception for Safety of Preschool Children*.

Cleveland, D. E. (1987). *Effects of Resurfacing on Highway Safety*. In: Relationship Between Safety and Key Highway Features, A Synthesis of Prior Research, 78-95. State of the Art Report 6, Transportation Research Board, Washington DC.

Cooper, D. R. C., Jordan, P. G. and Young, J. C. (1980). *The effect on traffic speeds of resurfacing a road*. TRRL Supplementary Report 571. Transport and Road Research Laboratory, Berkshire.

Cottage Grove (2005). *Public Works Traffic Sign Details*, online available on http://www.cottage-grove.org/docs/public_works_traffic_sign_details.pdf.

Courtesy of WCRC and DLZ Michigan, Inc. (2009). *Common Modern Roundabout Myths,* online available on http://www.livingstonroads.org/pdf_docs/RAB_Myths.pdf. (cited January 2009).

Crook, T. (2006). *Drive the Debate on Bikes in Bus Lanes with Industry Campaigns*, online available on http://londonbikers.com/news/3709/drive-the-debate-on-bikes-in-bus-lanes-with-industry-campaigns.

Crossette, J. G. and Allen, G. L. (1969). *Traffic Control Measures Improve Safety*. Traffic Engineering, 39, 18-21.

Cuuneen, Michael and O'Toole Randal (2005). *One-Way Streets Are Better Than Two-Way*, Independent Institute, issue paper 2-2005, online available on http://www.i2i.org/articles/2-2005.pdf.

Daley, J. (2009). *Facts suggest that letting bikers sidle up alongside cyclists in bus lanes is a recipe for disaster*, The Independent 14 February 2009, online available on http://www.independent.co.uk/environment/green-living/james-daley-facts-suggest-that-letting-bikers-sidle-up-alongside-cyclists-in-bus-lanes-is-a-recipe-for-disaster-1606977.html.

DeRobertis, M. M. and Rae, R. (2001). *Buses and bicycles: Design alternatives for sharing the road,* Institute of Transportation Engineers. ITE Journal, 71, 5, May 2001.

Drottz-Sjöberg, B. M. (1991). *Perception of risk – Studies of risk attitudes, perceptions and definitions*, Centre for Risk Research, Stockholm.

Elvik, R. (1997). *Problemnotat: Gang- og sykkeltrafikk - ulykker, miljø og framkommelighet*, Working paper TST/0820/97, Institute of Transport Economics, Oslo.

Elvik, R. (2000). *Which are the relevant costs and benefits of road safety measures designed for pedestrians and cyclists?* Accident Analysis and Prevention, 32, 37-45.

Elvik, R. and Bjørnskau, T. (2005). *How accurately does the public perceive differences in transport risks? An exploratory analysis of scales representing perceived risk.* Accident Analysis and Prevention, 37, 1005-1011.

Elvik, R. and Sælensminde, K. (2000). *Prioriteringsverktøy for gang- og sykkeltiltak - premisser og veiledning*, report 479. Institute of Transport Economics, Oslo.

Elvik, R. and Vaa, T. (2004). *The Handbook of Road Safety Measures*, Elsevier.

Elvik, R., Amundsen, F. H. and Hofset, F. (2001). *Road safety Effect of bypasses*, Transportation Research Record, 1758, 13-20.

Elvik, R., Kolbenstvedt, M. and Strangeby I. (1999). *Gå eller sykle? – fakta om omfang, sikkerhet og miljø*, report 432. Institute of Transport Economics, Oslo.

Elvik, R, Amundsen, A. and Christensen, P. (2004). *Speed and Road accidents – an evaluation of the power model*, report 740. Institute of Transport Economics, Oslo.

Elvik, R, Erke, A. and Vaa, T (2008). *Trafikksikkerhetshåndboken*, online available on http://tsh.toi.no/ (cited September 2008-February 2009).

Erke, A. (2007). *Revisjon av Trafikksikkerhetshåndboken: 1.18 Vegbelysning*, Working paper SM/1915/2007, Institute of Transport Economics, Oslo.

Erke, A. (2008). Making Vision Zero real: *Prevention of accident and injuries among elderly pedestrian*, report 972, Institute of Transport Economics, Oslo.

Erke, A. and Elvik, R. (2006). *Effektkatalog for trafiksikkerhetstiltak*, report 851, Institute of Transport Economics, Oslo.

Erke, A. and Elvik, R. (2007). *Making Vision Zero real: Preventing pedestrian accidents and making them less severe*, report 889, Institute of Transport Economics, Oslo.

Erke, A. and Sørensen, M (2008). *Veger med intrukken kantlinje utenfor tettbygd strøk: Tiltak for syklsiter og gående?*, report 961, Institute of Transport Economics, Oslo.

FHWA (2004). *Intersection Safety: Myth Versus Reality*. US Department of Transportation, Institute of Transportation Engineers, online available on http://safety.fhwa.dot.gov/intersections/interbriefing/10myth.htm.

FHWA (2007). *Traffic Signals*, US Department of Transportation, Institute of Transportation Engineers, online available on http://www.ite.org/safety/issuebriefs/Traffic%20Signals%20Issue%20Brief.pdf.

FHWA (2009). *Pedestrian Safety Improvements, Chapter 13: Street Conversions*, online available on: http://safety.fhwa.dot.gov/saferjourney/Library/countermeasures/13.htm.

Forskningsrådet (2008). *Research programme - Risk and safety in transport*, online available on http://www.forskningsradet.no/servlet/Satellite?pagename=risit/Page/HovedSide&c=Page&cid=1088801916081 (cited September 2008).

Fosser, S. (1991). *Sykkelhjelm – Holdinger til og bruk av hjelm blandt syklister*, note 0946, Institute of Transport Economics, Oslo.

Fowler, M. (2005). The *effects of the pages Road Cycle lane on Cyclist Safety and Traffic Flow Operations*, ENCI 495 project Report, Bachelor prosjekt, University of Canterbury, Christchurch, New Zealand.

Frøysadal, E. (1998). *Syklistenes transportarbeid og risiko*, Working paper 0883/1988, Institute of Transport Economics, Oslo.

Fyhri, A. (2001). *Evaluering av riksveg gjennom tettsteder - Resultater fra undersøkelse om folks opplevelse av miljøgater*, Working paper SM/1360/2001, Institute of Transport Economics, Oslo.

Fyhri, A. (2002). *Barns reiser til skolen – En spørreundersøkelse om reisevaner og trafikksikkerhet på skoleveien*, report 616. Institute of Transport Economics, Oslo.

Fyhri, A. (2004). *Vegpakke Drammen. Mellomundersøkelse av bomiljøet 1998 til 2003*, report 757. Institute of Transport Economics, Oslo.

Fyhri, A. (2005). *Bruker barn beina? Evaluering av prosjektet Aktive Skolebarn (2002-2005)*, report 814. Institute of Transport Economics, Oslo.

Fyhri, A. and Hjorthol, R. (2006). *Barns fysiske bomiljø, aktiviteter og daglige reiser*, report 869. Institute of Transport Economics, Oslo.

Gibbard, A., Reid, S., Mitchell, J., Lawton, B., Brown, E. and Harper, H. (2004). *The effect of road narrowings on cyclists*, TRL report TRL621, Transport Research Laboratory, Wokingham.

Gjerstad, S. (2002). *Trafiksäkerhet – Kunskap, attityd och beteende – En sammanställning av resultat från undersökningar genomförda av Vägverket*, Publikation 2002:108, Vägverket, Borlänge.

Goebel Frahm C. (2009). *Considering Risk Homeostasis Theory,* American Driver & Traffic Safety Education Association, Indiana University of Pennsylvania, online available on http://adtsea.iup.edu/adtsea/articles/Article.aspx?ArticleID=ecec7741-281e-4862-8897-8aa4a78f4c25.

Grile Cameron (2002). *Stop Vs. Yield Signs*, Oregon Department of Transportation, Traffic Management Section, online available on http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/Stop_Yield_Report.pdf.

Gårder P., Leden, L. and Thedeen, T. (1994). *Safety implications of bicycle paths at signalized intersections*, Accident Analysis and Prevention, 4, 429-439.

Haddon, W. (1970). *A Logical Framework for Categorizing Highway Phenomena and Activity*, Tenth International Study Week in Traffic and Safety Engineering, World Touring and Automobile Organisation/Permanent International Association of Road Congresses, Rotterdam.

Huserbråten, K. (2002). *Fotgjengere – sin egen ulykkes smed?*, Samferdsel, 2, 10-12.

Hvoslef, H. (1980). *Risikoanalyse av trafikksystemet i Haugesund 1970-76. En analyse av trafikkulykker og trafikkrisiko*, Working paper 30.9, Institute of Transport Economics, Oslo.

Hvoslef, H. (1993). *Syklistulykker i Norge. Hva er problemet?*, course in cycle planning, Sanders.

HVU (2006). *Ulykker mellem højresvingende lastbiler og ligeudkørende cyklister*, Rapport 4, Havarikommissionen for vejtrafikulykker, online available on http://www.hvu.dk/pdf/HVUrapp04.pdf.

Iowa Access Management Awareness Project (2007). *Answers to frequently asked questions: Access Management and Pedestrian Safety,* online available on http://www.ctre.iastate.edu/Research/access/toolkit/10.pdf.

Jacqemart and P.E. (1998). *Synthesis of Highway Practice 264, Modern Roundabout Practice in the United States*. Transportation Research Board National Research Council, Washington, D.C. online available on http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_syn_264.pdf. (cited January 2009).

Jensen, S. U. (2006). *Cyklisters oplevede tryghed og tilfredshed – Forskelle i tryghed og tilfredshed afhængig af strækningers og kryds` udformning*, Trafitec, online available on http://www.trafitec.dk.

Jensen, S. U. (2006a). *Svendborg sikker cykelby – evaluering af trafiksikkerhed, tryghed og cykeltrafik*, Trafitec, online available on http://www.trafitec.dk/pub/SvendborgSikkerCykelbyrapport.pdf.

Jensen, S. U. (2006b). *Effekter af cykelstier og cykelbaner. Før-og-efter evaluering af trafiksikkerhed og trafikmængde ved anlæg af ensrettede cykelstier og cykelbaner i Københavns Kommune*, Trafitec, online available on http://www.trafitec.dk/pub/Effekter%20af%20cykelstier%20og%20cykelbaner.pdf.

Jensen, N., Jensen, S. U. (2006). Tryghed for cyklister i København – samt konsekvenser af en undersøgelse af sikkerhed og tryghed for fremtidig designpraksis, Vejforum.

Jølsgard, E. J. (2005). *Sykkelhåndboka – Håndbokas oppbygging og bruk – Generelt om planlegging for sykkeltrafikk*, Sykkelbynettverket sykkelkurs, Trondheim, 11.12. mars 2005.

Karan, M. A., Haas, R. and Kher, R. (1976). *Effects of Pavement Roughness on Vehicle Speeds*. Transportation Research Record, 602, 122-127.

Kim H. J. (2003). *Performance of Bus Lanes in Seoul – Some impacts and Suggestions* –, IATSS Research, vol. 27, no. 2, 2003.

Kjærgaard, E. and Lahrmann, H. (1981). *Skolepatruljeblink - en undersøkelse af skolepatruljeblinks effekt på bilernes hastighed*, Dansk Vejtidsskrift, 4, Næstved.

Kolbenstvedt, M. (1986). *Vegtrafikkens risiko- og barrievirkninger*. report 781. Institute of Transport Economics, Oslo.

Kolbenstvedt, M. (1998). *Miljøkonsekvenser av hovedvegomlegging Oslo Øst – Oppsummering av studier 1987-1996*, report 405. Institute of Transport Economics, Oslo.

Kolbenstvedt, M. and Fyhri, A. (2004). *Veger til bedre bymiljø. Miljøundersøkelser Oslo Øst 1987-2002*, report 743, Institute of Transport Economics, Oslo.

Kutz Myer (2004). *Handbook of Transportation Engineering*, MCGraw-Hill Handbooks.

Københavns Kommune (2009). *Evaluering og videreførelse af trafikforsøget på Nørrebrogade i 2009*, København, online available on http://www.kk.dk/eDoc/Teknik-%20og%20Milj%C3%B8udvalget/17-12-2008%2015.00.00/Referat/19-12-2008%2009.37.48/4247947.PDF (cited January 2009).

Køltzow, K. (1986). *Omsorgsangst. Et begreb som gjør livsverdier synlige*, Oslo University, Institute of education, Oslo.

Lahrmann, H and Leleur, S. (1994). *Vejtrafik – Trafikteknik & trafikplanlægning*, Polyteknisk Forlag, Lyndby.

Landis Bruce W. and Vattikuti Venkat R. and Ottenberg Russel M. and Petritsch Theodore A. (2003). *Intersection Level of Service: The bicycle Through Movement*, Transportation research record, issue 1828, 101-106.

Larsen, L. B. (1991). *Eneuheld på sykkel*. UlykkesAnalyseGruppen, Odense sykehus.

Leite, T. and Fyhri, A. (2006). *Tøyengate som miljøgate – Evaluering av trivsel, parkeringsforhold og varelevering*, report 846. Institute of Transport Economics, Oslo.

Levinson Herbert S. and Gluck Jerry S (1997). *Safety Benefits of Access Spacing.* Dearborn, Michigan, online available on http://ntl.bts.gov/lib/7000/7400/7485/789781.pdf.

Levinson Herbert S. (2007). *Driveway Design Practices, Issues and Needs*, 3rd Urban Street Symposium, Seattle, Washington.

Linderoth, B. and Gregersen, N. P. (1998). Skolepatruller *i Sverige – en studie om dess förekomst och utformning, barnens arbetssituation, deras egen syn på verksamheten samt dess inverkan på bilisters hastighetvall*, VIT rapport 436, Väg- och transportforskningsinstitutet (VTI), Linköping.

Lodden, U. B. (2002). *Sykkelpotensialet i norske byer og tettsteder*, report 561, Institute of Transport Economics, Oslo.

Mahalel D. and Craus J. and Polus A. (1986) *Evaluation of Staggered and Cross Intersections*, Journal of Transportation Engineering, 112, 5, 495-506.

Maryland State Highway Administration (2007). *Maryland SHA Bicycle and Pedestrian Design Guidelines*, *Chapter 7: Pedestrian and Bicycle Access at Interchanges and Bridges*. online available on http://www.sha.state.md.us/exploremd/bicyclists/oots/pdf/Chapter%207%20-%20Interchanges_Bridges.pdf.

Maslen G. (2008). *Smashing results*, online available on http://www.theage.com.au/news/education-news/smashingresults/2008/05/10/1210131279887.html?page=fullpage.

Massachusetts Highway Department, (2006). *Project Development and Design Guide*, chapter 6, online available on http://www.mhd.state.ma.us/downloads/designGuide/CH_6_a.pdf.

Mathew T. and Krishna Rao K V. (2007). *Introduction to Transportation Engineering*, Chapter 39, online available on http://www.cdeep.iitb.ac.in/nptel/Civil%20Engineering/Transportation%20Engg%20I/39-Ltexhtml/nptel_ceTEI_L39.pdf.

McKnight Claire E., Mouskos K., Kamga C., Hardej C., Ahmed A. (2007). *Pedestrian Safety in the NYMTC Region,* CUNY Institute for Transportation Systems, online available on http://www.nymtc.org/project/sawg/Pedestrian%20Safety%20Study.pdf.

Miljøministeriet (1992). *Miljø og trafik I kommuneplanlægningen*, miljøministeriet, Planstyrelsen, København.

Monsere C. (2001). *Safety Comparison of 4-Way Cross and Offset T Intersections*, Oregon Department of Transportation.

Muskaug, R. (1983). *Virkning av gatetun i Oslo og Sandefjord*, TØI report, Institute of Transport Economics, Oslo.

Muskaug, R. (1983a). *Gateturn på Sofienberg. Analyse av før- og etterundersøkelsene i gatetunene på sofienberg i Oslo*, Working paper, Institute of Transport Economics, Oslo.

Myrberg, G., Winjgarden, K. V., Børrud, E. og Stenersen, L. (2008). *Shared space – erfaringer med "Shared space" ved kryssutforming*, Rambøll, Tønsberg, online available on http://img.custompublish.com/getfile.php/734480.466.wddtfxppvw/Rapport+-+Shared+Space.pdf?return=www.bytransport.no.

Møller M. (2006). *Oplevet risiko i rundkørsler*, Dansk Vejtidsskrift, 11, 22-24.

Møller, M. and Hels, T. (2007). *Cyklistsikkerhed i rundkørsler*, Rapport 4, Danmarks Transportforskning, Kgs. Lyngby.

Møller, M. and Hels, T. (2008). *Cyclists' Perception of Risk in Roundabouts*, Accident Analysis and Prevention, 40, 1055-1062.

Nielsen M. L., Nielsen O. V. and Andreasen, G. (2005). *Tryghed på cykelstier*, Vejforum, Nyborg.

Nielsen. P. H. and Lahrmann, H. (2008). *Forskønnede centrale bygader - Den sikkerhedsmæssige effekt*, Trafikdage, Aalborg Universitet, online available on http://www.trafikdage.dk/papers_2008/peter_hvid_nielsen_174.pdf.

Nielsen, T. F., Thesberg, M., Jensen, N. M. and Sørensen, M. (2007). *Secure Routes to School – A new process for working with secure routes to scholl*, Selected papers from the annual transport conference at Aalborg University, www.trafikdage.dk.

Nilsson, A. (2001). *Re-allocating road space for motor vehicles to bicycles: effects on cyclist's opinion and motor vehicle speed*, The AET European Transport Conference, Cambrigde.

Nilsson, A. (2003). *Utvärdering av cykelfälts effekter på cyklisters säkerhet och cykelns konkurrenskraft mot bil*, Ph.d.-thesis, Bulletin 217, Lunds University, Lund Institute of Tehnology, Department of Techology and Society, traffic Engineering, Lund.

Nilsson, G. K., Rigefalk, S. and Koronna-Vilhelmsson, I. (1992). *Hastighetsuppföljning på landsväg. Mätresultat 1991*, VTI-meddelande 690, Statens väg- och trafikinstitut, Linköping.

NJDOT (2001). "*Roadway Design Manual*," Section 7, New Jersey Department of Transportation, online available on http://www.nj.gov/transportation/eng/documents/RDME/sect7E2001.shtm.

Nolén, S. and Lindqvist, K. (2003). *Effekter av åtgärder för ökad cykelhjälmsanvädning – En litteratutstudie*, VTI rapport 487, Väg och transpoprtforkningsinstitutet, (VTI), Linköping.

NTF (2002). *Cykelbanor och cykelfâlt i Stockholms innerstad*, Nationalföreningen för trafiksäkerhetens främjand (NTF).

Nygårdhs, S. (2006). *Vägbelysning – En litteraturstudie*, VTI rapport 535, Swedisk national Road and Transport Research Institute, Linköping.

Ogden, K.W. (1996). *Safer Roads: A Guide to Road Safety Engineering*. Aldershot, Hants, England ; Brookfield, Vt. : Avebury Technical.

Opfer Scott (2001). *Stop & Yield Signs Assign Right of Way*, City of Lincoln, Public Works and Utilities Deparment Engineering Services Division, online available on http://lancaster.ne.gov/City/pworks/engine/traffic/sign/stopyld.htm.

Oranen, L. (1975). *Investigations into light traffic I*, Reports from Liikenneturva 16. Liikenneturva, Central Organization for Traffic Safety, Helsinki.

O'Toole, Randal (2001). *The Vanishing Automobile and Other Urban Myths: How Smart Growth Will Harm American Cities*, update # 30, Thoreau Institute, online available on http://www.ti.org/vaupdate30.html.

Papayannoulis V. and Gluck J. S. and Fenney K. Levinson H. S. (1999). *Access Spacing and Traffic Safety,* Dallas, Texas, 1999.

Parkin J., Wardman, M. and Page M. (2007). *Models of perceived cycling risk and route acceptability*, Accident Analysis and Prevention, 39, 364-371.

Pierce County (2007). *When are STOP and YIELD signs used?*, online available on http://www.co.pierce.wa.us/PC/abtus/ourorg/pwu/traffic/stopyield.htm.

Phillips, R. and Fyhri, A. (2008). *Trafikantenes kunnskaper om og holdninger til trafikksikkerhet – 2008*, Working paper SM/2010/2008, Institute of Transport Economics, Oslo.

Portland Community and School Traffic Safety Partnership (2009). *What Is The Purpose of A STOP Sign?* online available on http://www.portlandonline.com/transportation/index.cfm?c=45258&a=166034.

Queensland transport (2006). *Bicycles and Bus Lanes*, online available on http://www.transport.qld.gov.au/resources/file/ebe6020dbc387a4/Pdf_b9_bicycles_and_bus_lanes.pdf.

Ragnøy, A. (1985). *Gangtrafikk på vinterføre I Oslo. Kan vegvedlikeholdet hjelpe?* Institute of Transport Economics, Oslo.

Ragnøy, A. (2002). *Automatisk traffikkontroll (ATK) – Effekt på kjørefart*, report 573, Institute of Transport Economics, Oslo.

Ragnøy, A. (2005). *Speed limit changes. Effects on speed and accidents*, report 784, Institute of Transport Economics, Oslo.

Robinson D. L. (2006). *Do enforced bicycle helmet laws improve public health? No clear evidence from countries that have enforced the wearing of helmets*, British Medical Journal, 332, 722-725.

Robinson D. L. (2007). *Bicycle helmet legislation: Can we reach a consensus?*, Accident Analysis & Prevention, 39, 86-93.

Rodegerdts Lee A. (August 2004). *Signalized Intersections: Informational Guide*, US Department of Transportation, Federal Highway Administration, online available on http://www.tfhrc.gov/safety/pubs/04091/04091.pdf.

RUTGERS (2008). *Bicycle and Pedestrian Safety Needs at Grade-Separated Interchanges*, The New Jersey Bicycle and Pedestrian Resource Centre, New Jersey Department of Transportation.

Ryan P. et al. (2006). *Cycle Network and Route Planning Guide*, Land Transport NZ, online available on http://www.ltsa.govt.nz/road-user-safety/walking-and-cycling/cycle-network/docs/cycle-network.pdf.

Sagberg, F. (2007). *Virkning av utvidet midtoppmerkning på kjørefart og sideplassering*, report 884, Institute of Transport Economics, Oslo.

Sakshaug, K. (1986). *Fartsgrenseundersøkelsen -85. Detaljerte resultater fra fartsdelen og ulykkesdelen*, Notat 535/86 and 536/86. SINTEF, Trondheim.

Schioldborg, P. (1979). *Fotgjenger og bilfører - to forskjellige verdener?*, Oslo University, Department of Psychology, Oslo.

Shared space (2008). *Shared Space – Final Evaluation and Results – It takes Shared Space to Create shared understanding*, online available on http://www.shared-space.org/files/11276/Def.Final_Evaation31_okt.pdf.

Simon, M., and H. Rutz S, (October 1998) *Sicherheit von Verkehrskreiseln Innerorts*, Emch + Berger AG, Aarau, Switzerland.

Sjöberg, L. (1993). *Uro och riskuppfatning,* Contributions to FRN/Riaskkollegiets symposium, Stockholm.

Skarra, N. and Gabestad, K .O. (1993). *Kjørekostnadshåndboken*, Institute of Transport Economics and Norwegian Public Roads Administration, Oslo.

Stangeby, I. (1997). *Attitudes Towards Walking and Cycling instead of Using a Car*, report 370, Institute of Transport Economics, Oslo.

Statens vegvesen (1996). *Miljøgate – Stedet og vegen – hovedrapport fra miljøgateprosjektet*, Vegdirektoratet, Oslo.

Statens vegvesen (1996a). *Miljøgate – Stedet og vegen – Sammendragsrapport fra miljøgateprosjektet*, Vegdirektoratet, Oslo.

Statens vegvesen (1996b). *Miljøgate – Stedet og vegen – hovedresultater fra før- og etterundersøkelser i fem prøvesteder*, Vegdirektoratet, Oslo.

Statens vegvesen (2003). *Sykkelhåndboka – Utforming av sykkelanlegg*, Veiledning, Handbook 233, Oslo, online available on http://www.vegvesen.no/binary?id=34600.

Staten vegvesen (2003a). *Nasjonal transportplan 2006-2015 – Nasjonal sykkelstrategi – trygt og attraktivt å sykle*, online available on http://www.vegvesen.no/Fag/Fokusomrader/Miljovennlig+transport/Sykkel/Publikasjoner.

Staten vegvesen (2003b). *Standard for drift og vedlikehold*, Handbook 111, online available on http://www.vegvesen.no/binary?id=14137.

Statens vegvesen (2003c). *Fra riksveg til gate - erfaringer fra 16 miljøgater*, Staten vegvesen, Vegdirektoratet, Utbyggingsavdelingen, Oslo, online available on http://www.sykkelby.no/Publikasjoner/1371/Liten_pdf_Fra_veg_til_2Web.pdf.

Statens vegvesen (2003d). *Sammendrag og anbefalinger fra rapporten Fra riksveg til gate - erfaringer fra 16 miljøgater*, Staten vegvesen, Vegdirektoratet, Utbyggingsavdelingen, Oslo.

Statens Vegvesen (2004). *Cycle Path Inspections - Road safety - Accessibility - Experience of travel*, Handbook 249, online available on http://www.vegvesen.no/binary?id=13274.

Statens Vegvesen (2007). *Nasjonal transportplan 2010-2019 – Nasjonal sykkelstrategi – attraktivt å sykle for alle – Grunnlagsdokument for NTP 2010-2019 vegdirektoratet*, online available on http://www.sykkelby.no/Publikasjoner/3220/Nasjonal_sykkelstrategi_09-2007.pdf.

Statens vegvesen (2008). *Teknisk planlegging av veg- og gatebelysning*, Handbook 264, online available on http://www.vegvesen.no/binary?id=14206.

Statistisk sentralbyrå (2008). *Statistikkbanken – Personer drept eller skadd I veitrafikkulykker etter kjønn, skadesgrad og trafikantgruppe*, Online database available on http://statbank.ssb.no/statistikkbanken (cited October 2008).

Steinman Norm and Hines Keith (2003). *A Methodology to Access Design Features for Pedestrian and Bicyclist Crossing at Signalized Intersections*, 2nd Urban Street Symposium, Anaheim, California.

Svenska Kommunförbundet (2000). *Lugna gatan! En planeringsprocess för säkrara, miljövänligare, trivsammare och vackrare tätortsgator*, Third edition, Stockholm.

Sælensminde, K. (2002). *Gang- og sykkelvegnett i norske byer – Nytte-kostnadesanalyse inkluderet helseeffekter og eksterne kostnader av motorisert vejtrafikk*, report 567, Institute of Transport Economics, Oslo.

Sørensen, M. (2006). *Grå strækninger I det åbne land – udvikling, anvendelse og vurdering af alvorlighedsbaseret metode til udpegning, analyse og udbedring af grå strækninger*, PHD thesis, Aalborg University, Aalborg.

Sørensen, M. (2007). *Best Practice Guidelines on Black Spot Management and safety Analysis of Road Networks*, report 898, Institute of Transport Economics, Oslo.

Sørensen, M. (2008). *Revisjon av Trafikksikkerhetshåndboken: 1:10 Utbedring av spesielt ulykkebelastede steder*, Working paper SM/1955/2008, Institute of Transport Economics, Oslo.

Sørensen, M. (2008a). *18 tons forbudszone i København – Erfaringer fra udlandet om den sikkerheds- og tryghedsmæssige virkning*, Working paper SM/1976/2008, Institute of Transport Economics, Oslo.

Sørensen, M. (2009). *Kryssløsninger i by – Internasjonale anbefalinger for å sikre miljøvennlig bytransport*, report 1004. Institute of Transport Economics, Oslo.

Sørensen, M. (2009a). *Regulering af tung trafik i bymidter – eksempler på forskellige foranstaltninger i europæiske byer*, Working paper SM/2015/2009, Institute of Transport Economics, Oslo.

Sørensen, M. and Elvik, R. (2007). *Black Spot Management and Safety Analysis of Road Networks – Best Practice Guidelines and Implementation Steps*, report 919. Institute of Transport Economics, Oslo.

Sørensen, M., Madsen, J. C. O., Lahrmann, H., Madsen, J. R. and Bech, V. (2005), *Midteradskillelse på landevej 447, Vestbjerg-Hjørring*, Trafikdage, Aalborg Universitet, online available on http://www.trafikdage.dk/td/papers/papers05/Trafikdage-2005-415.pdf.

Toole Jennifer L. and Zimny Bettina (1999). *Chapter 16: Bicycle and Pedestrian Facilities.* in Transportation Planning Handbook. Edwards, John D., Jr. ed. Institute of Transportation Engineers, Washington, DC, 599-641. online available on http://safety.fhwa.dot.gov/ped_bike/docs/tph.pdf.

Towliat, M. (2001). Effects of Safety Measures for Pedestrians and cyclists at crossing Facilities on Arterial Roads, Ph.d.-thesis, Bulletin 195, Lunds University, Lund Institute of Tehnology, Department of Techology and Society, traffic Engineering, Lund.

Transportation Research Board. (1989). *Improving School Bus Safety. Special* Report 222. National Research Council, Washington DC.

Transport- og Energiministreriet (2007). *Flere cykler på sikker vej i staten – Transport- og energiministeriets cykelstrategi*, København, online available on http://www.trm.dk/graphics/Synkron-Library/trafikministeriet/Publikationer/2007/Cykelstrategi.pdf.

Trygg Trafikk (2009). *Usikker skolevei? - Hva kjennetegner en utrygg skolevei, og hva kan gjøres for å bedre den?*, online available on http://www.tryggtrafikk.no/?module=Articles;action=Article.publicShow;ID=916 (cited February 2009).

TTM Consulting Pty. Ltd. (2003). *Proposed Development Strategy Traffic Management Report*, online available on http://www.greaterdandenong.com/Resources/SiteDocuments/sid1_attachment%20g%20traffic%20report.pdf.

US Department of Transportation, Federal Highway Administration, (May 2006). *BIKESAFE: Bicycle Countermeasure Selection System*, Chapter 6, online available on http://www.bicyclinginfo.org/bikesafe/downloads/bikesafe_ch5.PDF.

Tyrens (2007). *Trafiksäkerhet vid shared space*, Tyrens for Vägverket, online available on http://www.vv.se/filer/210/slutrapport_06_4665.pdf.

Vaa, T. (1991). *Effekt av siktforbedrende tiltak på strekninger*, Rapport STF63 A91014, SINTEF Samferdselsteknikk, Trondheim.

Vaa, T. (1991a). *Vurdering av sammenheng mellom opplevd utrygghet og ulykkesrisiko. Bilføreres opplevde utrygghet: Vurdering av måleproblemer,* Working paper TST/0264//91, Institute of Transport Economics, Oslo.

Vaa, T. (1993). *Politiets trafikkontrollvirksomhet: Virkning på atferd og ulykker. En litteraturstudie*, report 204, Institute of Transport Economics, Oslo.

Vaa, T. (2006). *Intelligente transportsystemer (ITS): En oversikt over effekter på atferd og ulykker*, report 845, Institute of Transport Economics, Oslo.

Vaa, T., Christensen, P. and Ragnøy, A. (1995). *Politiets fartskontroller: virkning på fart og subjective oppdragelsesrisiko ved ulike overvågingsnivåer*, report 301, Institute of Transport Economics, Oslo.

Vaa, T., Glad, A., Sagberg, F., Bjørnskau, T. and Berge, G. (2002). *Faktorer som påvirker kjørefart – Litteaturstudier og hypoteser – SIP føreratferdsmodeller: rapport 2*, report 601, Institute of Transport Economics, Oslo.

Várhely, A., Hydén, C., Hjälmdahl, M., Almqvist, S., Risser, R., Draskóczy, M. (2002). *Effekterna av aktiv gaspedal i tätort. Sammenfattende rapport*, Lunds Tekniske Hogskola, Institution för Teknikk och samhälle, Avdelning Trafikteknik, Lund.

Vejdirektoratet (1987). *Effektvurdering af miljøprioriteret gennemfart i Vinderup*, Rapport 52, Vejdatalaboratoriet, Herlev.

Vejdirektoratet (1988). *Effektvurdering af miljøprioriteret gennemfart i Skærbæk*, Rapport 63, Vejdatalaboratoriet, Herlev.

Vejdirektoratet (1988a). *Effektvurdering af miljøprioriteret gennemfart i Ugerløse*, Rapport 63, Vejdatalaboratoriet, Herlev.

Vejdirektoratet (2000). *Idékatalog for cykeltrafik*, Vejdirektoratet, København, online available on http://www.vejdirektoratet.dk/pdf/idekatalog/katalog.pdf.

Vejdirekroratet (2004). *21 miljøprioriterede bygennemfarter - Den trafiksikkerhedsmæssige effekt*, Rapport nr. 281, online available on http://www.vejdirektoratet.dk/publikationer/VDrap281/pdf/Bog21byer.pdf.

Vejdirektoratet (2009). *Model for cykelstiprioritering på statsvejnettet – Den oplevede utryghed*, online available on http://www.vejsektoren.dk/wimpdoc.asp?page=document&objno=219633 (cited January 2009).

Vermont Agency of Transportation (2002). *Pedestrian and Bicycle Facilities Planning and Design Manual*, online available on http://www.aot.state.vt.us/progdev/Documents/LTF/FinalPedestrianAndBicycleFacility/PedestrianandBicycleFacilityDesignManual.pdf.

VG (2009). *Norsk undersøkelse: Sjåfører mest irritert på syklister*, VG nett, bil og motor, online available on http://www.vg.no/bil-og-motor/artikkel.php?artid=193095 (cited January 2009).

Værø, H. (1992). *Byens Trafikmiljø – Lokal kortlægning av miljøkonsekevnser*, Ph.D. thesis, report 71, Institut for veje, trafik og byplan, Danmarks Tekniske Højskole, Lyngby.

Walker, I. (2006). *Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender*, Accident Analysis & Prevention, 39, 417-425.

Walkinfo (2008). *Do curb extensions reduce speeds?*, Walkinfo, online available on på www.walkinginfo.org (cited February 2009).

Wanvik, P. O. (2008). *Road light and traffic Safety*, PHD thesis (draft), Norwegian University of Science and Technology (NTNU), Trondheim.

Washington State (1997). *Pedestrian Facilities Guidebook*, Washington State, Department of transportation, online available on http://www.psrc.org/publications/pubs/pedfacilitiesguidebook.pdf.

Watts, G. R. (1984). *Evaluation of pedal cycle spacers*, TRRL Supplementary Report 820, Transport and Road Research Laboratory, Crowthorne, Berkshire.

Weitemeyer, B. (2006). *Cyklister i gågader*, Trafikdage, Aalborg Universitet, Aalborg.

Wennike, F. (1994). *Fartdæmping ved hjælp af afmærkning*, Dansk Vejtidsskrift, 6/7, 36.

1 Appendix. The effects on subjective safety

This appendix clarifies the effects of the 54 selected road safety measures on subjective safety among vulnerable road users summarised in chapter 5 of the main report.

The appendix address readers who want to read more about specific road safety measures. The appendix includes a lot of references to relevant studies about each measure and can therefore also be used to find more information about the measures and their effect on subjective safety.

The assessment of subjective safety is based on the following two parts:

1. Literature study of existing studies and evaluations
2. Theoretical, qualitative considerations.

For many of the selected road safety measures, none of the available literature has studied their effects on the subjective safety of vulnerable road users. Thus, the literature study has been supplemented with theoretical considerations about factors having an impact on subjective safety.

For each of the measures it is assessed which impact it probably has on 16 parameters identified in chapter 2.4 of the main report which all have potential influence on subjective safety. The 16 parameters are:

– Traffic volume
– Heavy vehicle volume
– Vulnerable road users volume
– Speed
– Distance
– Crossing distance
– Paths
– Separation & integration
– Intersections design
– Crossings, number
– Road conditions.
– Sight
– Light
– Thoughtfulness
– Skills
– Personally protection.

The following symbols are used in the assessment, individually or in a combination:

↑: Positive effect on subjective safety of cyclists and pedestrians
↓: Negative effect on subjective safety of cyclists and pedestrians
↕: Both positive and negative effects on subjective safety of cyclists and pedestrians is possible
(): Maybe a small or very small effect
- : Probably no effect on subjective safety of cyclists and pedestrians
?: Unknown effect on subjective safety of cyclists and pedestrians.

The assessment for each parameter is made qualitatively. The total effect on subjective safety is made as a qualitative assessment which is a summation of the effects on the 16 included parameters. Note that it is not possible to sum up the total effect by a simple summation because the parameters have different importance and should therefore be assigned with different weights.

1.1 Road Design and Road Furniture

This chapter of the appendix describes the effects of the 17 measures under the category of road design and furniture on subjective safety.

1.1.1 Tracks for walking and cycling

The effect of tracks for walking and cycling on subjective safety for pedestrians and cyclists has been evaluated directly or indirectly in several projects.

In 2006, 1079 bicyclists in Copenhagen were interviewed about their perceived safety associated with different road designs. Three different designs of road sections including cycle tracks, cycle lanes and mixed traffic were studied. The conclusion was that bicyclists feel most safe on cycle tracks and less safe on sections where bicycles and cars are integrated. 45 % feel very safe on cycle tracks, 32 % feel very safe on cycle lanes and only 11 % feel very safe on sections with mixed traffic. In mixed traffic 48 % feel unsafe while the values for cycle tracks and lanes were only 13 % and 21 % respectively (Jensen 2006, Jensen and Jensen 2006).

Jensen (2006a) has also made an evaluation of a project trying to improve the condition for bicyclists in Svendborg in Denmark. The main project was a new 4 km long cycle route between Thurø and Svendborg city centre. This project consists of building of new cycle tracks and cycle lanes and new pavement on existing tracks. The evaluation shows that the number of cyclists feeling unsafe has been reduced in 22 intersections and eight sections in Svendborg, and the number increased just in six intersections and two sections.

Nilsson (2001, 2003) has evaluated the effect of cycle lanes on subjective safety for cyclists. The evaluation includes six streets in Sweden where some of the road space has been re-allocated to bicycles. Questionnaires were answered by about 600 cyclists before the changing and about 600 cyclists after the changing. More than half of the cyclists thought the street had improved due to the cycle lane. This improvement includes feeling of safety, accessibility and road surface. However, driver behaviour towards cyclists is still regarded as a problem after introduction of the bicycle lane.

Another Swedish study finds that the opinion of cyclists is that the risk is reduced by about 20 % when a cycle track is installed. In other words they are feeling more safe on cycle tracks (Gårder, Leden and Thedeen 1994).

An evaluation of cycle lane on Flemingsgatan in Stockholm found that subjective safety has been improved with 18 % (NTF 2002).

An evaluation of an installation of an on-road cycle lane in Christchurch in New Zealand found that the percentage of cyclists feeling safe increased from about 33 % to about 44 %. However, the percentage feeling unsafe was not reduced in the same degree (Fowler 2005).

According to cycle handbooks from Norway (Statens vegvesen 2003) and Denmark (Vejdirektoratet 2000) cyclists tend to perceive tracks most safe and sections with mixed traffic most unsafe.

Parkin, Wardman, and Page (2007) have developed models for perceived cycling risk and route acceptability. The models are based on responses from a sample of

144 commuters to video clips of routes and junctions. Facilities for bicycle traffic along streets and at junctions are shown to have little effect on perceived risk among cyclists. This result is not consistent with results from the other described evaluations and recommendations.

Mixing of cycle traffic and moped traffic on cycle tracks may cause that several cyclists feel unsafe. The reason for that is high speed among mopeds and that mopeds overtake with small distance to the cyclists. This is especially a problem for “weak” cyclists as children and elderly (Nielsen, Nielsen and Andreasen 2005).

Several designs of cycle tracks and lanes in intersections exist. Sørensen (2009) has made a review of recommendations in design guidelines and cycle handbook from Denmark, Sweden, The Netherlands, Belgium, Germany, United Kingdom, USA, Canada and Australia about how cycle tracks and lanes should be designed at intersections and the impact on different designs on passability, safety and subjective safety. 12 designs or measures were reviewed. Table 1.1 shows the impacts on subjective safety for these designs according to the cycle handbooks. Some of the designs have a positive effect, some have a negative effect and for some of the designs the effect is unknown.

An example of a study about the effect of varying designs of cycle lane in intersection is Jensen (2006). He concludes that coloured cycle lanes through the intersection gives the best feeling of safety compared with other kind of design as shortened cycled track and a narrow cycle lane.

Another study finds that nine out of 10 cyclists feel more safe after alternative marking of cycle lanes have been introduced in a non signal controlled intersection in Randers in Denmark (Berggrein and Ágústsson 1999).

Table 1.1. Impacts of varying designs of cycle tracks and lanes at intersections on subjective safety of cyclists (Sørensen 2009).

Design/measure	Impact	Design/measure	Impact
Shortened cycle track	↓	Moved stop line for vehicle	(↑)
Central approach cycle lane	↓	Coloured/alternative cycle lane	↑
Cycle lane for right turn at intersection	?	Cycle lane bended out	?
Cycle lane for right turn outside intersection	↑	Cycle track bended in	↓
Cycle lane for small left turn	↑	Mixing of traffic in roundabout	↓
Expanded cycle stacking lane	↕	Cycle track in roundabout	↑

Table 1.2 summarizes the results of the theoretical and qualitative assessments. It estimates that tracks for walking and cycling have a positive impact on subjective safety.

Tracks give vulnerable road users their own traffic area and separate them from cars and heavy vehicles. Also separate tracks often increase the distance between vulnerable road users and vehicles.

Tracks are normally described as an improvement for vulnerable road user. Thus, they can lead to more people cycling and walking in stead of driving.

Tracks beside roads in some cases narrows the width of the roads. This can have a speed reducing effect.

Finally, tracks are often badly maintained because of small budgets for road maintenance. This results in potholes etc. in the surface of the track, which especially for bicycles can reduce the feeling of safety.

Table 1.2. Possible effects of tracks for walking and cycling on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
(↑) ?	-	↑ ?	↑ ?	↑	-	↑	↑	-	-	(↓) ?	-	-	-	-	-	↑

TØI report 1009/2009

Both the literature study and the theoretical, qualitative assessments show that tracks for walking and cycling increase the subjective safety of vulnerable road users.

1.1.2 Motorways

No studies about possible effects of motorways on subjective safety of vulnerable road users have been found. This was expected because building of motorways has no direct impact on the subjective safety of vulnerable road users as this group of road users are not allowed to use motorways.

However, building of motorways may indirectly have some effects. This is summarized in table 1.3. Motorways change to a larger or lesser extent the traffic pattern and traffic volume on the roads of the surrounding area. This means that the volume of private cars and in particular heavy vehicles may be reduced on the other roads. This can improve the condition for vulnerable road users on these roads. On the other hand, buildings of motorways sometimes results in higher speed level at adjacent roads.

Based on these considerations, it is estimated that motorways may have a small positive impact on the subjective safety.

Table 1.3. Possible effects of motorways on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
(↑) ?	↑ ?	-	(↓) ?	-	-	-	-	-	-	-	-	-	-	-	-	(↑) ?

TØI report 1009/2009

1.1.3 Bypasses

The aims of designing bypasses are both to improve traffic flow for through traffic and thus the quality of life in the city as well as to reduce traffic related problems including subjective unsafety. Several evaluations of bypasses have been preformed. But, even though one of the objectives of designing bypasses is to improve the conditions for vulnerable road users in the city, none of the available studies are regarding this theme.

Table 1.4 summarizes the qualitative assessment of the impacts on subjective safety. The impacts are summarized for vulnerable road users at the original "old" roads through the cities, because these road users are normally not allowed or recommended to use the new way. The most important effect is decreased volume of traffic which has no destination in the city. A study by Elvik, Amundsen and Hofset (2001) shows that traffic volume has been reduced by 5-94 % in 20 Norwegian cities. Traffic volume on the original main road though the city was increased by 20 % in one city. The improvement may encourage people particularly school children to bike or walk in the city.

While traffic volume is reduced, the speed level might increase on the city's roads due to lesser congestion. This will have a negative effect on the subjective safety.

A last very important impact of bypasses is an improved opportunity for introduction of environmental measures in the city since the needs for long distance travel should no longer be taken into account. This opens up new possibilities as tracks for walking and cycling, speed humps, raised pedestrian crossings, alternative narrowing of the way and planting and furnishing of pavements and traffic islands. Accordingly, speed rise is possibly prevented or even speeds are reduced. In addition, this will probably move even move through traffic to the new roads. This contributes to even a better condition for vulnerable road users.

Thus, bypasses should be and are normally combined with implementation of environmental streets in the "old" main road in the city. Environmental streets are described in chapter 1.3.2.

The conclusion of the considerations is that bypasses alone or in combination with environmental streets have positive effects on subjective safety of vulnerable road users at the original main road through the city. Vulnerable road users are not expected to use the new road unless it is designed for cycling and walking.

Table 1.4. Possible effects of bypasses on subjective safety on the road in the city.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	↑	(↑)	(↓)	-	-	-	(↑)	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

1.1.4 Arterial roads in and around cities

Elvik and Vaa (2004) describes the measure as building new arterial roads, increasing the capacity of existing arterial roads and minor improvement of existing arterial roads. This chapter focuses on building of new roads and the effects on the old roads which are unloaded for traffic.

In Oslo East the highway authorities have conducted a comprehensive development and rerouting of the traffic system from 1987 to 1999. The project includes building of three tunnels, closing of streets for through traffic and redesigning streets as environmental streets. The project has been continuously under evaluation including several surveys. The surveys show that the percentage of pedestrians in the area feeling unsafe has decreased from 43 % in 1987 to 25 % in 1994, 21 % in 1996, 22 % in 1998 and 16 % in 2002 (Kolbenstvedt 1998, Kolbenstvedt and Fyhri 2004).

Families with young children in particular are concerned with the safety issues. In 1987, 52 % of the parents in Oslo East were feeling unsafe for their children on the school way. In 1996 and 2002 the percentage was reduced to respectively 40 % and 27 % (Kolbenstvedt and Fyhri 2004).

In Drammen a similar project as in Oslo East has been carried out. The objective was to improve the traffic environment and alleviate the situation for the city’s inhabitants. The most important elements of the package were two tunnels rerouting traffic to a new ring road system around the centre.

Contrary to Oslo East a survey shows that there has been no improvement in the parents’ experience of safety regarding their children as a result of the traffic rerouting in Drammen. After the project about 75 % of the parents were feeling unsafe for their children. However, among the cyclists, 63 % are feeling safe when cycling in the centre of the city. In general, Drammen is considered as a safe and comfortable town for cycling (Fyhri 2004).

Table 1.5 summarizes the qualitative assessment of the impacts on subjective safety. The table is very similar to table 1.4 for bypasses. The volume of traffic and heavy vehicles on the old ways in the local area is reduced and speed is probably reduced because building of new arterial roads is often supplemented with speed reducing measures at the local roads.

Both the literature study and the qualitative considerations show that arterial roads in and around cities normally increase the subjective safety of vulnerable road users at old local roads.

Table 1.5. Possible effects of arterial roads in and around cities on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	↑	(↑)	↑	-	-	-	(↑)	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

1.1.5 Channelisation of junctions

Channelisation of junctions is carried out by physical measures to segregate different systems of traffic at intersections. Channelisation can be performed using traffic islands or pavement markings (Elvik and Vaa 2004). Unfortunately, no literature which studied possible effects of channelised intersections on subjective safety among vulnerable road users have been found.

Channelisation of intersections reduces areas of conflict both between vehicles and bicycles and between vehicles and pedestrians by separating or regulating traffic movements into definite paths of travel. Thus, it has positive effects on subjective safety of vulnerable road users considering the “paths”, “separation and integration”, and “intersection design” factors.

Moreover, channelisation islands effectively reduce the crosswalk distance in which pedestrians are exposed to moving motor vehicles (Massachusetts Highway Department 2006). In case of channelisation by means of traffic islands, channelising island also serves as a refuge for pedestrians and makes pedestrian crossing safer. This has a positive effect on subjective safety of vulnerable road users considering the “crossing distance” factor.

As vehicles are separated by medians in different paths or channels of travel based on their driving direction, pedestrians cross one direction of traffic at a time when crossing each part. In other words, although the total amount of traffic volume is not reduced by channelisation, vulnerable road users crossing the intersection encounter lower amount of vehicles in each path, and thus their perceived traffic volume is less than the total, actual traffic volume in the intersection. This gives the sense of safety to vulnerable road users when crossing the intersections especially when the channelisation is performed by means of traffic islands. From this point of view, channelisation of intersections has positive effect on subjective safety of vulnerable road users considering the “traffic volume” factors.

In addition, the presence of traffic islands, markings etc. narrowing the street forces drivers to reduce the speed and become more cautious while manoeuvring the intersections. If no channelising is provided, the drivers will have less tendency to reduce the speed while entering the intersections from the carriageway (Mathew 2007). Thus, channelisation of intersection has a positive effect on subjective safety of vulnerable road users considering the “speed” factor. On the other hand the narrowing may reduce the distance between cyclists cycling along the road and motor vehicles.

Table 1.6 Possible effects of channelisation of junctions on subjective.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	↑	-	↑	↓	↑	↑	↑	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

The mentioned results of the qualitative assessment are summarised in table 1.6.

Considering a general evaluation, the effect of channelisation of junctions on subjective safety of vulnerable road users is positive.

1.1.6 Roundabouts

According to Jacqemart (1998) pedestrian safety at roundabouts is an issue of perceived versus real risks. While pedestrian safety at roundabouts seems to be high according to international experience and limited U.S. experience, many pedestrians do not perceive roundabouts to be safe.

According to Courtesy of WCRC and DLZ Michigan Inc. (2009) pedestrians, in general, have a higher perception of safety at stop sign and traffic signal locations because they assume traffic will stop for them. Experience has shown that pedestrians accept a false sense of security from traffic signals and stop signs when crossing a roadway. At modern roundabout intersections, some pedestrians feel that the crossing manoeuvre is not as safe as at conventional intersection locations. However, experience indicates that this environment generally increases the pedestrian's level of awareness prior to crossing the roadway, thereby increasing their level of real safety.

According to Jacqemart (1998) in a study related to pedestrian, light motorcycle and bicycle safety at roundabouts, 250 bicyclists and light motorcycle users were interviewed. The results indicated that 74 % of the interviewed bike/moped users felt safe in roundabout, whereas 26 % did not feel safe.

According to a model for perceived cycling risk and route acceptability developed by Parkin, Wardman, and Page (2007) roundabouts add more perceived risk than traffic signal controlled junctions. The model is based on responses from a sample of 144 commuters to video clips of routes and junctions.

In a study carried out in Denmark (Møller 2006, Møller and Hels 2007, 2008) 1019 cyclists aged 18-85 interviewed regarding their perception of risk in five Danish roundabouts. Among the five roundabouts, just two of them had a cycle facility both along the roundabout and the sidewalks. The aim of the study was primarily to describe cyclists' perception of risk in different situations of a roundabout, as well as to identify factors influencing the perception of risk with a particular focus on the influence of cycle facility. According to the final results, in all the roundabouts one situation was perceived as particularly dangerous measured as perception of accident risk as well as perception of danger. This particular situation was the situation in which a cyclist is circulating in the roundabout and a car is exiting the roundabout. 82 % of all interviewed cyclists perceived this situation as "very much" or "to a large extend" dangerous. 65 % of all the interviewed cyclists perceived the accident risk in this situation as "very high" to "high". Moreover, the level of perceived risk in specific situations as well as perception of general level of risk was significantly higher in roundabouts without a cycle facility than in roundabouts with a cycle facility.

The results are summarized in figure 1.1 and figure 1.2.

As it is seen in the figures, the cyclists perceived the situations involving a circulating bicycle and an exiting or entering car as those in which they perceive the highest level of risk. This indicates an accordance between the perceived and actual risk as the majority of the Danish police recorded car-bicycle collisions in those two situations.

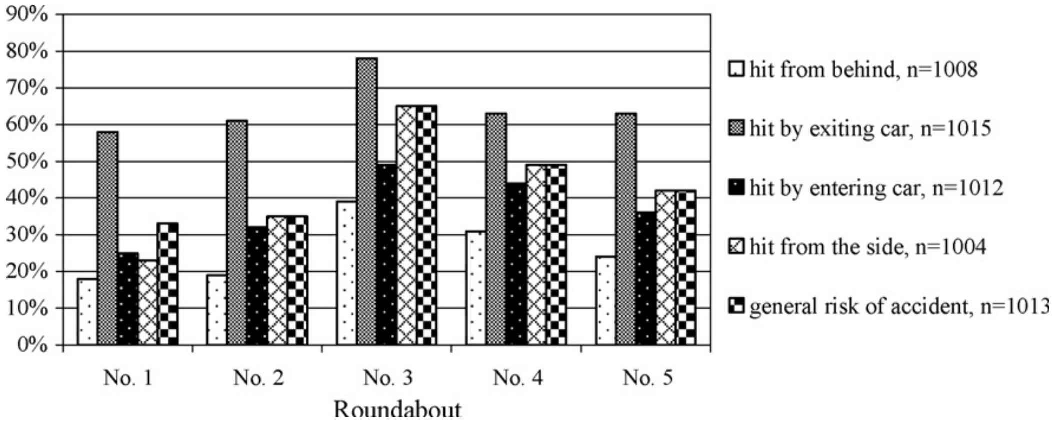

Figure 1.1.Percentage of cyclists in each roundabout, who has answered that the risk of being involved in a bicycle accident is 'large' or 'very large' in each situation. The cyclist is assumed to circulate in the roundabout in all situations. Roundabout no. 1 and 2 have a cycle facility. Roundabout no. 3, 4 and 5 do not have a cycle facility (Møller and Hels 2008).

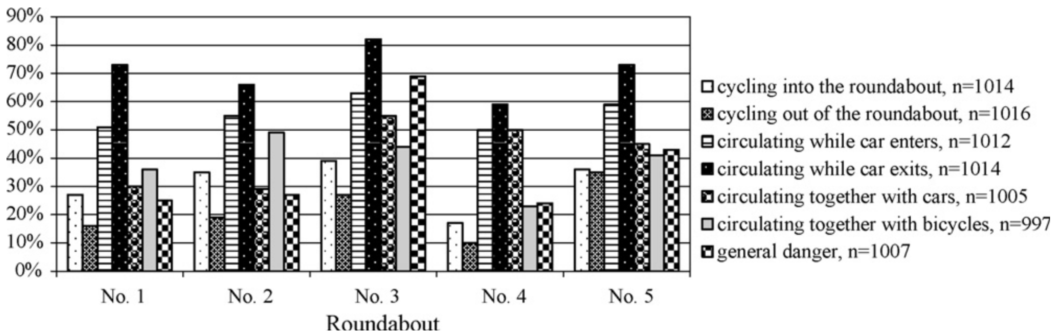

Figure 1.2. Percentage of cyclists in each roundabout, who has answered that each situation 'very much' or 'to a large extent' is dangerous. Roundabout no. 1 and 2 are with a cycle facility and no. 3, 4 and 5 are without a cycle facility (Møller and Hels 2008).

Table 1.7 summarizes the results of theoretical and qualitative assessment of subjective safety at roundabouts in four different scenarios. In this table the scenarios are:

- *Scenario 1:* Roundabouts without any bicycle facility and the evaluation results are just for cyclists
- *Scenario 2:* Roundabouts with bicycle facility in the roundabout and the evaluation results are just for bicyclists
- *Scenario 3:* Roundabouts with bicycle facility outside the roundabout and the evaluation results are just for bicyclists
- *Scenario 4:* As the factors influencing cyclists' perception of safety in roundabouts are very different from those for pedestrians, evaluation of pedestrians' subjective safety in roundabouts is presented separately here.

In all four scenarios it is assumed that the roundabouts are not signalized.

One of the main approved benefits of roundabouts over signalized or stop sign intersections is that the deflection of entry approaches at roundabouts makes drivers reduce their speeds when entering the intersections. Moreover, drivers cannot drive a straight path through roundabouts as they have to drive round a traffic island located in the middle of the junction (Elvik and Vaa 2004). This reduces their speed also inside roundabouts. This characteristic of roundabouts has a positive effect on perceived safety of both pedestrians and cyclists.

Not all roundabouts have bicycle facilities. In such cases, bicycles do not have their own traffic area and thus are not separated from vehicles inside the roundabouts. This may make the bicyclists feel unsafe. On the other hand, at roundabouts in which bicycles have their own facility, which means that they have their own path along or outside the roundabouts, they are more or less well-separated from vehicles. This avoids risky integration of bicycles with vehicles and thus increases the perceived safety of bicyclists. However, bicycle facilities have no significant effect on the subjective safety of pedestrians.

The other dilemma for bicyclists at roundabouts without bicycle facility is when they are circulating in a roundabout and a vehicle driving behind them going to exit the roundabout. According to the Danish study bicyclists feel highly unsafe in such situations. This is mainly due to the fact that bicyclists do not have a good sight over the vehicles which are driving behind them. They do not also have a good sight over vehicles entering roundabouts.

Table 1.7. Possible effects of roundabouts on subjective safety. The three scenarios are described in the text.

Scenario	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
1	-	-	-	↑	-	-	↓	↓	-	-	-	↓	-	-	-	-	↓
2	-	-	-	↑	-	-	(↑)	(↑)	-	-	-	(↑)	-	-	-	-	↑
3	-	-	-	↑	-	-	↑	↑	-	-	-	↑	-	-	-	-	↑
4	-	-	-	↑	-	-	-	-	↕	-	-	-	-	-	-	-	↑ ?

TØI report 1009/2009

Comparing roundabouts with signalized intersections, pedestrians feel more unsafe when crossing them. This is because of the fact that at signalized intersections pedestrians feel sure that vehicles are stopped by red light, and they can confidently pass the zebra lines. As it is mentioned in Courtesy of WCRC and DLZ Michigan Inc. (2009), pedestrians feel anxious when crossing roundabouts since they are not assured by the intersection design (intersection's control system) that vehicles will stop for them. Some roundabouts are signalized to promote pedestrian accessibility. In those situations, the perceived safety of pedestrians is greatly improved.

Summarizing the qualitative assessments, the overall effect of roundabouts on subjective safety of cyclists is negative when there is no bicycle facility and more or less positive when roundabout has bicycle facility. However, it is difficult to conclude whether the total effect of roundabout design on subjective safety of pedestrians is positive or negative.

1.1.7 Redesigning junctions

According to Elvik and Vaa (2004), older intersections which were built in difficult terrain may have a substandard geometric layout. Redesigning of junctions is intended to improve sight conditions at intersections, simplify turning manoeuvres and make the intersection more visible to the road users who are approaching it.

Redesigning junctions includes:

- Changes to the angle between roads
- Changes to the gradients of roads approaching the intersection
- Measures to improve sight conditions at intersections.

These measures are often implemented in conjunction with channelisation of intersections or other measures (Elvik and Vaa 2004).

Unfortunately, no literature which studied possible effects of redesigning junctions on subjective safety among vulnerable road users has been found.

According to McKnight (2007), design of roadways or their environment may unintentionally encourage drivers to speed up on certain sections, for example where a curve makes a higher speed more enjoyable or a wider shoulder suggests there are no conflicts. These sections are not consistent with use by non-motorized traffic. Moreover, according to US Department of Transportation (2006), motor vehicles turning at a high rate of speed pose problems for bicyclists as well as pedestrians. This is a common problem when motorists travelling on an arterial street turn onto a residential street. A typical bicycle-motor vehicle crash type, sometimes called a "right hook," occurs when a motor vehicle passes a bicycle going straight ahead and then turns right shortly after making the passing manoeuvre. Reducing the radii of curbs at these high speed right turns provides a remedy. Creating 90-degree intersection corners or corners with tight curb radii tend to slow motorists.

According to Rodegerdts (2004), in areas of high pedestrian and bike use, smaller radii are desirable to reduce turning speeds and decrease the distance for pedestrians and bikes to cross the street. However, according to US Department of Transportation (2006), it should be noticed that bicyclists which bike in the intersecting approaches need to see the movements of motor vehicles, and vice versa at intersections. At skewed intersections, cross streets with greater or less than 90 degrees, it is difficult for bicyclists/vehicles to see other vehicles. In this situation the exposure of bicyclists or pedestrians crossing the street is also increased. So the angles should be selected in a way that not only the speed of motorists in the intersection is controlled, but also the sight distance for vulnerable road users is not deteriorated.

Considering the above-mentioned arguments, redesigning intersection's gradient for the purpose of facilitating turning manoeuvres of vehicles, as stated by Elvik and Vaa (2004), might increase their speed, and thus have negative effect on the subjective safety of vulnerable road users considering the "speed" factor.

However, if redesigning of intersection is carried out so that vehicles speed decrease by changing the curve designs and slopes, the effects on the subjective safety of vulnerable road users will be positive considering the "speed" factor.

A similar evaluation is also applicable for redesigning the angles of an intersection. If angles are changed to simplify the vehicles' turns and thus increase their speed, the effect will be negative on the subjective safety of vulnerable road users considering the "speed" factor. On the other hand, if the radii are decreased in order to reduce the turning speeds, the effect will be positive on the subjective safety of vulnerable road users considering the "speed" factor. The same argument is applicable for the "sight" factor.

However, according to Goebel (2009) redesigning of roads may "solve" initial crash problems at a particular location, but afterwards other types of crashes may increase exactly as a result of that solution. It seems when drivers are aware of a dangerous or risky road, they tend to drive with a certain amount of caution and complain to authorities to "fix" the road. Often when roads are redesigned, reducing severity of curves and/or ditches are re-sloped to be more "forgiving", drivers perceive roads to be safer, so they decide to drive faster, thus increasing their risk of severity of crash due to higher rates of speed on the re-designed "safer" road.

Considering this theory, redesigning of old intersections for the purpose of improving safety, can unexpectedly have negative safety effects. When drivers perceive roads to be safer, so they decide to drive faster, it may not only have negative effects on the subjective safety of vulnerable road users considering the "speed" factor, but it also may have negative effects considering the "thoughtfulness" factor. In other words, the drivers' sense of safety due to the intersection redesign may persuades them to not thoughtful driving manner, and thus decrease the perception of safety among vulnerable road users.

The results of the qualitative assessment are summarised in table 1.8.

Table 1.8 Possible effects of redesigning junctions on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↕	-	-	-	-	-	-	-	↕	-	↓	-	-	↓ ?

TØI report 1009/2009

Considering a general evaluation, the effect of redesigning junctions on subjective safety of vulnerable road users is not easy to judge as the effects on speed and sight are dependent on different scenarios. However, in case of negative effects on speed or sight, the general effect will be also negative.

1.1.8 Staggered junctions

Converting a cross intersection into two adjacent T-intersections results in a design called staggered junction (Mahalel 1986). According to Elvik and Vaa (2004), staggered junctions reduce the number of conflict points at intersections and thus make the task of crossing the intersection simple for road users. The number of conflict points at a standard cross intersection is 32 which are reduced to 22 at two offset T-intersections. Some international studies presented in Ogden (1996) report that paired T-intersections are 1.5 to 2.0 times as safe as cross intersections for the same traffic flow and that the injury consequence is 1.5 times greater at cross intersections (Monsere 2001). However, no literature has been found studying the effects of staggered junctions on the subjective safety of vulnerable road users.

Converting a cross intersection to a staggered T-intersection forces drivers on the side road to slow down on approach to the intersection (Maslen 2008). According to TTM Consulting Pty (2003), staggered intersection is another effective means of providing an intersection speed control because it breaks the continuity provided by a cross intersection. In Maslen (2008) it is stated that staggered intersection does have disadvantages, which are expressed in interferences to traffic on the main road. Several types of interferences may be distinguished, such as an addition of slow-moving vehicles and a lessening of the overtaking ability. These disadvantages for vehicles on the main road, on the other hand, can be considered as advantages not only for pedestrians and cyclists crossing the main stream, but also cyclists which are cycling along the main stream by giving them the sense of safety. From this point of view, staggered junctions have positive effect on the subjective safety of vulnerable road users considering the “speed” factor.

Moreover, by converting one crossroad to two adjacent T-intersections, vehicles are dispersed in two separate areas. Thus, vulnerable road users encounter with less amount of traffic volume in each T-junction. Also, as a result of the dispersion of road users in two separate junctions instead of one crossroad the distance between them is also decreased. Therefore, staggered junctions have positive effects on the subjective safety of vulnerable road users considering the “traffic volume” and “distance” factors.

ARTISTS (2005) has recommended to avoid T-junctions with very acute angles in order to maximise the ability of pedestrians and cyclists and approaching motor vehicles to see one another at the junctions. It implies that T-junctions with very acute angles make sight problems for vulnerable road users crossing the intersections. Thus, staggered junctions, if designed with sharp angles, have negative effect on the subjective safety of vulnerable road users considering the “sight” factor.

The results of the qualitative assessment are summarised in table 1.9.

Summarizing the qualitative assessments, the overall effect of staggered junctions on subjective safety of vulnerable road users is positive.

Table 1.9 Possible effects of staggered junctions on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	-	-	↑	↑	-	-	-	-	-	-	(↓)	-	-	-	-	↑

TØI report 1009/2009

1.1.9 Interchanges

An interchange is an intersection where the primary traffic streams are segregated from each other by being placed on separate levels. Interchanges are built in order to improve traffic flow and reduce the chances of conflict between different traffic streams (Elvik and Vaa 2004).

If interchanges are built as intersections between motorways the measure have no influence on vulnerable road users. However, if interchanges are implemented as intersections between motorways and smaller roads or between two smaller roads where cyclists and pedestrians are allowed the measure may affect subjective safety.

According to NJDOT (2001) crossing conflicts are eliminated at interchanges by grade separations. Turning conflicts are either eliminated or minimized depending upon the type of interchange design.

However, according to Maryland State Highway Administration (2007) interchanges and other locations with on-ramps and off-ramps can be among the most difficult locations for pedestrians and bicyclists to navigate. The combination of high speed merging traffic and crossings by pedestrians and bicyclists creates inherent conflicts and can be very uncomfortable for non-motorized users.

Like in channelised intersections, vulnerable road users cross one direction of traffic at a time at interchanges. When crossing each ramp of interchanges they encounter with less traffic volume comparing with a crossroad intersection. From this point of view, interchanges have positive effect on subjective safety of vulnerable road users considering the “traffic volume” factors.

According to RUTGERS (2008), at grade-separated interchanges sidewalks on approach roads may not continue through the interchange, leaving pedestrians without safe facilities or confused about the path to take. Pedestrians walking along the roadway edge face risks from passing motor vehicles. Moreover, when bike lanes or shoulders terminate before an interchange, cyclists face similar challenges. Reduced road space and merging motor vehicle traffic create a challenging cycling environment. Thus, interchanges can have negative effect on the subjective safety of vulnerable road users considering the “paths” factor.

Another problem of vulnerable road users at interchanges, according to RUTGERS (2008), is due to free flowing entry and exit ramps. Where entry and exit ramps make a free flowing transition between the highway and secondary road, it can be difficult for pedestrians and bicyclists to cross due to motor vehicle speeds and insufficient breaks in traffic. Moreover, merging drivers are focused on observing oncoming motor vehicle traffic, particularly at sharply angled intersections, and therefore are less observant of pedestrian and bicyclists. These factors contribute to poor pedestrian and bicyclist visibility and poor driver yielding behaviour. Thus, interchanges have negative effects on the subjective safety of vulnerable road users considering the “speed” and “paths” factors.

On curved free-flowing ramps, poor sight distance can be a pedestrian safety issue. Other factors that contribute to site distance issues include the placement of guardrails, poles, and signal boxes (RUTGERS 2008). Hence, interchanges have negative effect on the subjective safety of vulnerable road users considering the “sight” factor.

In addition, ramp terminals at interchanges often have large turning radii to accommodate truck traffic. This can create long crossing distances for pedestrians, and pedestrians may not have enough time to safely cross in the presence of motor vehicle traffic. Seniors, children, and others who have lower walking speeds may find crossing particularly difficult (RUTGERS 2008). Thus, interchanges have negative effect on the subjective safety of vulnerable road users considering the “crossing distance” factor.

The results of the qualitative assessment are summarised in table 1.10.

Table 1.10 Possible effects of interchanges on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	-	-	↓	-	↓	↓	-	-	-	-	↓	-	-	-	-	↓

TØI report 1009/2009

Summarizing the qualitative assessments, the overall effect of interchanges on subjective safety of vulnerable road users is negative.

1.1.10 Black spot treatment

The definition, identification, analysis and treatment of black spots and hazardous road sections are solely based on the number and types of registered and expected road accidents, and not subjective safety.

The interview by Sørensen (2006) with 18 traffic safety employees of the Danish Road Directory and all the Danish counties verifies that subjective safety should not be included in the definition and identification of hazardous road locations. However, according to Sørensen (2006, 2007) and Sørensen and Elvik (2007), the prior assessment of proportion for treatment as well as a socio-economic assessment about saved accidents as a minimum, should include a qualitative consideration of whether the measures have a positive, neutral or negative effect on subjective safety. But whether this is done in practice has not been studied yet.

Several evaluations of black spot management have been performed worldwide. Sørensen (2008) has made a review over 14 of these evaluations from 1997 to 2008. None of these evaluations has evaluated the effect on subjective safety.

It is very difficult to conclude with a general assessment regarding the effect of black spot management on subjective safety since black spot management consists of a wide range of road safety measures with very different characteristics. Actually, black sport management includes most of the road safety measures described in chapter 1.1, 1.3 and partly 1.4. Depending on the measures, black spot management can both have positive, neutral and negative effect on subjective safety. Subjective safety effects of the specific road safety measures which are mostly included in black spot management are clarified in the other chapters.

Table 1.11 summarizes the qualitative assessment of the impacts on subjective safety. As described and illustrated in the table, both positive and negative effects are possible. However, in the majority of cases the effect is probably positive. There are several reasons for that:

– The main objective of black spot management is typically to reduce speed. Reduced speed improves subjective safety.
– Another objective of black spot management is mostly to reduce the numbers of crossings, improve road conditions, and improve sight and road light. This will has a positive effect on subjective safety.
– When safety measures are chosen and implemented, the effect on subjective safety should be considered. Measures that possibly reduce subjective safety should be reconsidered, and that will properly reduce the number of situations where black spot treatment reduces subjective safety. Sometimes it is necessary to choose a measure having a negative effect on subjective safety even though the negative effect is known.

Table 1.11. Possible effects of black spot management and network safety management on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing Distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↑	↕	↕	↕	↕	↕	↑	↑	↑	↑	-	-	-	↕ / ↑

TØI report 1009/2009

Regarding distance, paths, separation/integration and design of intersections the effect of black spot management will be both positive, neutral and negative.

The main idea of black spot management is to change the detailed road design and not the general design. Thus, the effect on traffic volume, heavy vehicle, cycle traffic and pedestrians is usually minimal. In situations where black spot management reduces traffic volume the effect on subjective safety is probably positive.

Based on these considerations, it is classified that black spot treatment can have positive, neutral and negative effects on subjective safety, but in the most common situations it has a positive, small positive or neutral impact on subjective safety.

1.1.11 Cross section improvements

According to Elvik and Vaa (2004) cross sections improvement consists of the following nine measures:

1. Increasing the number of traffic lanes
2. Increasing the width of the road
3. Increasing shoulder width
4. Constructing passing lanes (on one or both sides)
5. Constructing hard shoulders
6. Increasing the width of the hard shoulder
7. Simultaneously altering lane width and shoulder width
8. Kerbstones in central reservations and increasing the width of the central reservation
9. Increasing the width of bridges.

No studies which evaluate the effects of the above-mentioned measures on subjective safety of vulnerable road users have been found.

However, several of the measures are different kinds of improvement of the shoulders. This is in many ways similar to implementing cycle lanes. One of the primary differences is that cycle lanes is a measure for urban roads and improved shoulders is a measure for rural rods. In chapter 1.1.1 it is concluded that cycle lanes improve subjective safety compared with mixed traffic. This is probably also the case for wide and hard shoulders on road in rural areas.

An alternative to constructing of hard shoulders and increasing the width of the hard shoulders is to make so called 2-minus-1-roads, which are the roads where the number of driving lanes is reduced from two to one, the centre line is removed and the shoulders are widened. Several countries such as Denmark, Sweden and the Netherlands have made demonstration projects with this measure.

Effects on subjective safety among cyclists have been evaluated in Denmark and Sweden. The results are ambiguous and large proportions of cyclists were not feeling safe neither before nor after the roads were converted to 2-minus-1-roads. No evaluations of the effect for pedestrians are made (Erke and Sørensen 2008).

Table 1.12 summarises the qualitative assessment of the impacts on subjective safety for each of the nine measures.

Measure 1, increasing the number of traffic lanes, gives a major improvement on road capacity. In many cases, such an improvement leads to more traffic. More lanes also improve the possibility to overtake, and thus the average speed will increase most probably. However, the increase will be in the overtaking lane and the distance between vulnerable road users and fast cars will increase. Increasing the number of lanes will in some situations make it necessary to reduce the number of crossings. In addition, road conditions will in general be improved when the road is reconstructed. Finally, more lanes can make intersections more complicated and increase the crossing distance for vulnerable road users.

The effects of measure 4, constructing passing lanes, is almost the same as the effects of measure 1 with the exception that it probably does not lead to more traffic because it is just a minor road capacity improvement.

Measures 2 and 9 which are widening of a road or a bridge increase the speed level because speed normally is higher at wide roads than narrow roads (Nilsson et al. 1992, Sakshaug 1986, Vaa et al. 2002). The distance between cyclists along the road and vehicles driving on the road will increase as a result of measures 2 and 9, which consequently improve subjective safety. On the other hand, increasing the width of the road will increase the crossing distance and therefore be a minus for vulnerable road users crossing the road. Road conditions and sight will probably be improved as a result of the reconstruction. Widening a bridge is very expensive, so it is only done when there is a real need for it. Thus, widening a bridge probably leads to more traffic.

Measures 3, 5, 6 and 7 have the same characteristics. The widening of the road increases the average speed (Vaa et al. 2002), but at the same time the distance between vulnerable road users along the road and vehicles also increase. The increased width and better pavement of the shoulders resemble construction of a path for cycling and walking. Road conditions and sight are improved in general as a result of the reconstruction.

Measure 8, kerbstones in central reservations and increasing the width of the central reservation, probably reduces speed because the width of the road is narrowed. On the one hand, the crossing distance for vulnerable road users is improved because they can make a stop on the central reservation. But the moving distance along the road for vulnerable road users and vehicles decrease. Road conditions in general are improved, and the number of crossings probably reduced. Sight can both be improved and reduced.

The conclusion of the qualitative considerations is that the nine measures can be divided into three groups with different effects on subjective safety. The three groups are:

- Increasing the number of lanes: Measures 1 and 4
- Reconstructing shoulders and central reservations: Measure 3, 5, 6, 7 and 8
- Increasing the width of road: Measure 2 and 9.

The first group has likely a negative effect on subjective safety of vulnerable road users. The first measure; increasing the number of traffic lanes will have the greatest effect.

The second group of measures probably has a positive effect on subjective safety of vulnerable road users.

The third group of measures can both have positive and negative effects on subjective safety depending on specific designs and situations.

Table 1.12. Possible effects of cross section improvements on subjective safety. The number of measures refers to the numbers in the previous text.

Measure	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
1	↓	↓	-	↕	(↑)	(↓)	-	-	(↓) ?	(↑)	(↑)	-	-	-	-	-	↓
2	-	-	-	↓	(↑)	(↓)	-	-	-	-	(↑)	(↑)	-	-	-	-	↕
3	-	-	-	↓	↑	-	↑	↑	-	-	(↑)	(↑)	-	-	-	-	↑
4	-	-	-	↓	(↑)	-	-	-	-	-	(↑)	(↑)	-	-	-	-	(↓)
5	-	-	-	↓	↑	-	↑	↑	-	-	↑	-	-	-	-	-	↑
6	-	-	-	↓	↑	-	↑	↑	-	-	↑	(↑)	-	-	-	-	↑
7	-	-	-	↓	↑	(↓)	↑	↑	-	-	(↑)	(↑)	-	-	-	-	↑
8	-	-	-	↑	↕	↑	-	-	-	(↑)	(↑)	(↕)	-	-	-	-	(↑)
9	(↓)	(↓)	-	↓	(↑)	(↓)	-	-	-	-	(↑)	(↑)	-	-	-	-	↕

TØI report 1009/2009

1.1.12 Roadside safety treatment

Roadside safety treatment includes flattening side slopes, increasing distance between the edge of the road and fixed obstacles and removal of such obstacles. No studies regarding the effects on subjective safety have been found.

Table 1.13 summarizes possible effects of roadside safety treatment. On one hand, speed may increase due to more "open" roads (Vaa et al. 2002). On the other hand, the sight is probably improved and it is possible that the distance between vulnerable road users along the road and vehicles driving on the road increase. Thus, the total effect on subjective safety is not clear, but the effect is probably not very significant.

Table 1.13. Possible effects of roadside safety treatment on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↓	(↑)	-	-	-	-	-	-	↑	-	-	-	-	(↕) ?

TØI report 1009/2009

1.1.13 Improving road alignment and sight conditions

Improvement of road alignment and sight conditions consists of over 10 different measures as for example increasing the radii of horizontal curves, constructing of transition curves and reducing gradients (Elvik and Vaa 2004).

No studies about the possible effects of the measures on safety among vulnerable road users have been found.

However, improving road alignment and sight conditions could have small negative effects on subjective safety. This is summarized in table 1.14.

Road alignment affects the mean speed of traffic and the speed profile of vehicles over a given distance. The effect on speed is greater for heavy vehicles than for light vehicles (Skarra and Gabestad 1983).

Vaa (1991) has found that average speed is 7-8 km/h lower on uphill stretches and 1-4 km/h higher on downhill stretches than on flat roads with an average speed of 70-76 km/h.

The radius of horizontal curves also affects the speed level. The larger the curve is, the higher is the speed level.

Reducing gradients and increasing the radii of horizontal curves probably increase speed level and thus reduce the subjective safety. Improved sight has an opposite effect.

Table 1.14. Possible effects of improving road alignment and sight conditions on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↓	-	-	-	-	-	-	(↑)	↑	-	-	-	-	(↓)

TØI report 1009/2009

1.1.14 Rehabilitation, reconstruction and resurfacing of roads

The measure consists of altering the existing roads to provide them with current design standards as well as other improvements that include both road cross section and road alignment. When these changes are made, usually it is the case that road surface and road equipment are also replaced.

No studies that evaluate the effect of the measure on subjective safety of vulnerable road users have been found.

Table 1.15 summarizes some of the possible effects. Like the previous measures, the measures increase the speed level if nothing else changes. Road conditions and sight are improved. Depending on different cases, the measures can have both positive, neutral and negative effect on the subjective safety.

Table 1.15. Possible effects of rehabilitation, reconstruction and resurfacing of roads on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↓	-	-	-	-	-	-	↑	↑	-	-	-	-	(↕)

TØI report 1009/2009

1.1.15 Guardrails and crash cushions

No studies have been found which indicate the effects of different types of guardrails and crash cushions on subjective safety.

Table 1.16 summarizes some of the possible effects.

Guardrails narrow the roads. Normally, this reduces the speed level for the benefit of subjective safety. However, this possible effect has hardly been evaluated. The few available studies are old and mostly refer to guardrails in medians of divided highways (Elvik and Vaa 2004), which are not relevant to this case. These studies found no significant changes or increase of subjective safety. Carlsson et al. (2001) found an increase of about 2 km/h for mean speed on undivided highways in Sweden after implementing guardrails.

Guardrails between foot and cycle paths and the roads can increase subjective safety of pedestrians and cyclists using the foot and cycle paths.

A guardrail can increase the barrier effect of a road, i.e. make it more difficult for vulnerable road users to cross the road. This does not directly affect subjective safety, but reduces the general service level for vulnerable road users.

Table 1.16. Possible effects of guardrails and crash cushions on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	(↕)	(↑)	-	-	↑	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

Based on these considerations it is assessed that guardrails most likely have a positive effect on subjective safety of vulnerable road users

1.1.16 Horizontal curve treatments

The treatment includes warning measures and optical lines of sight which prepare road users for curves and indicate the path of curves. These include:

- Danger warning signs before curves
- Recommended speed in curves
- Background or directional marking in curves
- Painting the guardrails in curves
- Widening the roads in curves
- Minor changes of alignment.

The effects of the above-mentioned measures on subjective safety of vulnerable road users have not been studied in any known project. The reason is probably that the objective of the treatment is not normally to improve the conditions for vulnerable road users as the measures are mostly related to rural roads where considerations for vulnerable road users are normally less than in urban roads.

However, it is still possible that different curve treatments have some effects on the subjective safety of vulnerable road users. The treatments can reduce speed as a result of danger warning, recommended speeds or maybe speed limits. This will have a positive effect. On the other hand, it is possible that the speed increases in some situations if the alignment or width of the road is changed.

Widening of roads at curves can increase the distance between vulnerable road users and vehicles while widening of roads and changes of alignments improve sight conditions. Finally, implementation of different curve treatment probably improves road conditions in general.

Table 1.17. Possible effects of horizontal curve treatment on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↕	↑	-	-	-	-	-	(↑)	↑	-	-	-	-	(↑)

TØI report 1009/2009

Based on the considerations summarized in table 1.17, it is concluded that horizontal curve treatment probably has a small positive impact on subjective safety of vulnerable road users. This effect is however not so important because the treatment is mostly carried out in rural areas where the number of bicyclists and pedestrians is small.

1.1.17 Road lighting

According to Wanvik (2008) and Statens vegvesen (2008), one of the benefits of road lighting is improving the comfort and sense of safety for all road users during dark hours. Statens vegvesen (2003) also describes that road lighting should be implemented on cycle tracks in open space where feeling of safety is important.

A literature review by Nygårdhs (2006) of over 20 references about road light and security for vulnerable road users concludes that road lighting on road and track improves the feeling of safety.

Subjective unsafety is influenced by the possible outcome of road accidents as well as fear for crimes. As described in chapter 1.3 of the main report this report only focuses on subjective safety regarding road accidents. However, it should be noted that several studies have found reduced crime after road lighting installation (Erke 2007, Nygårdhs 2006). This may influence the feeling of safety.

Supplementary considerations about the effects on subjective safety is summarised in table 1.18. It is assessed that road lighting in total has a positive effect. However, a study by Assum et al. (1999) shows that the average speed during dark hours increases by 5 % on straight road sections and 0.7 % on the curved parts of the roads as a result of road lighting. This may reduce the positive effect on subjective safety.

Table 1.18. Possible effects of road lightning on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	(↓)	-	-	-	-	-	-	-	-	↑	-	-	-	↑

TØI report 1009/2009

Both the literature study and the qualitative considerations indicate that road lighting increases the subjective safety of vulnerable road users. However, the question has not been studied directly in any known projects.

1.2 Road maintenance

This chapter of the appendix describes subjective safety effects of five measures under the category of road maintenance.

1.2.1 Ordinary resurfacing of roads

Ordinary resurfacing denotes the normal replacement of existing road surface with new surface, for example in the form of re-asphalting. Elvik and Vaa (2004) do not clarify if resurfacing of tracks for walking and cycling is included under the measures. It is included in this report.

No studies are available which directly have evaluated the effects of resurfacing of roads and tracks on subjective safety. However, different handbooks, cycle strategies and reports describe indirectly the possible effects especially regarding what happens to subjective safety if resurfacing is not carried out. This is summarized in table 1.19.

According to Karan et al. (1976), Cooper et al. (1980), Cleveland (1987) and Anund (1992), re-asphalting of roads affects driving speed, especially where the evenness of the road surface is improved. In this respect, an increase of speed up to 10 km/h has been detected, but more typical values are 2-5 km/h.

Compared to car drivers, cyclists are more sensitive to evenness, holes and cracks on road surface (Andersen 2002). In this respect, cyclists with slim wheels are especially more sensitive (Staten vegvesen 2003a). Thus, Staten vegvesen (2003b) has some supplementary standards for operation and maintenance of tracks for walking and cycling. In addition, guidelines for cycle path inspections have been developed to record flaws or shortcomings that would then form a basis for immediate measures to the road network (Statens Vegvesen 2004).

Nevertheless, surveys among the road users show that cyclists and pedestrians are displeased with the operation and maintenance of tracks for walking and cycling both in summer and winter. A question about the quality of the road surface is included in the summer survey (Staten vegvesen 2007).

Bad maintenance of the road surface results in several problems regarding subjective safety. Firstly, it increases the fear of accidents as a result of holes in the road surface. Erke and Elvik (2007) describes that holes in the asphalt, slippery roads, high curbs etc. contribute to accidents of pedestrians and cyclists. A questionnaire to 590 Norwegian cyclists involved in accidents showed for example that 4.5 % of the 375 single accidents were caused by holes in the road surface (Bjørnskau 2005). According to earlier studies from Norway, Denmark and Sweden the percentage of cycle single accidents caused by bad design, operation and maintenance is 30-50 % (Bjørnstig 1987, Borger and Frøysadal 1993, Frøysadal 1988, Hvoslef 1993, Larsen 1991).

Secondly, the result may be that cyclists are forced to use roads instead of cycle tracks. This will integrate motor vehicles and vulnerable road users with an increased feeling of unsafety (Amundsen and Kolbenstvedt 2008, Staten vegvesen 2003a).

Thirdly, cyclists and motor vehicles will probably try to steer around evenness, holes and cracks in the road surface, which in some situations will give conflicts and reduce the distance between vehicles and cycles.

Fourthly, evenness, holes and cracks on road surface may distract cyclists and make it more difficult to cycle. This can have a negative effect on the feeling of safety (Transport- og Energiministeriet 2007). In other words ordinary resurfacing may reduce the required task of cycling. In table 1.19 this is indicated by improved skills.

Finally, the service level for vulnerable road users is reduced in general if the ordinary resurfacing of roads and tracks is not carried out regularly.

Table 1.19. Possible effects of ordinary resurfacing of roads on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↓	↑	-	-	↑	-	-	↑	-		-	(↑)	-	↑ ?

TØI report 1009/2009

Based on these considerations, it is concluded that bad road surface maintenance probably reduces subjective safety. In other words, ordinary regular resurfacing of roads and tracks can particularly contribute to improved subjective safety of bicyclists.

1.2.2 Improving the evenness of road surface

Improving the evenness of road surface involves filling potholes on the road surface, sealing large cracks, repairing damage following frost heave and other measures in areas where the road surface is abnormally uneven. The difference between this measure and the previous measure is that this measure deals with spots or short sections where a particular unevenness has occurred on the road surface (Elvik and Vaa 2004).

Table 1.20. Possible effects of improving the evenness on subjective safety

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↓	↑	-	-	↑	-	-	↑	-		-	(↑)	-	↑ ?

TØI report 1009/2009

Like ordinary resurfacing of roads no studies regarding the effects of repairing the road surface on subjective safety have been made.

Ordinary regular improvement and repairing of road surface are very similar measures, and therefore the effects on subjective safety are quite identical. The effects are summarized in table 1.20 and were clarified in chapter 1.2.1:

– *Speed:* Speed increases.
– *Distance:* Distance may decrease because it is not longer necessary that vehicle drivers and cyclists try to steer clear of evenness, holes and cracks in the road surface.
– *Separation:* Separation will in some situations be improved because cyclists no longer are forced to use the road instead of cycle tracks.
– *Road condition:* Road conditions are improved which will reduce the fear for single accident as result of holes in the road surface.
– *Skills:* The required task of cycling will be reduced which can improve subjective safety.

It is concluded that improving the evenness of road surfaces may contribute to improved subjective safety of vulnerable road users especially cyclists.

1.2.3 Improving road surface friction

No studies about possible effects of improving road surface friction on subjective safety of vulnerable road users have been found.

Table 1.21. Possible effects of improving friction on the subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↓	↑	-	-	↑	-	-	↑	-		-	(↑)	-	↑ ?

TØI report 1009/2009

If improving of road surface friction is carried out as a part of an ordinary regular resurfacing or as a part of improving the evenness of road surfaces, which is normally the case, the measure will have the same effects on subjective safety as these two measures. This is summarized in table 1.21. Changing from normal road surface to road surface with extra good friction solely does not influence subjective safety in any significant degree.

Provided that the measure also improves the evenness of the road surface, it is concluded that subjective safety is improved especially for cyclists.

1.2.4 Winter maintenance of roads

The most important winter maintenance measures are snow clearance, sanding and salting (Elvik and Vaa 2004). This chapter focuses on roads without separate tracks for cycling and walking while the next chapter deals with winter maintenance of pavements and foot and cycle paths.

A review of 21 Norwegian studies from 1979 to 1998 which deal with subjective safety in different ways shows that slippery and icy road conditions increase the percentage of road users feeling unsafe (Amundsen 1999, Amundsen et al. 2000). In other words, winter maintenance of roads contributes to improved subjective safety. For example Ragnøy (1985) has studied drop of accidents among 514 old pedestrians in Oslo. 71 % stated that they went out as pedestrian less frequently in winters than in summers. 50 % of them stated slippery pavements as the reason.

Erke (2008) concludes in a study about accidents among elderly pedestrians that winter maintenance improves the feeling of safety while walking among elderly pedestrians.

Some possible effects of good winter road maintenance are discussed in the following and summarized in table 1.22.

Good mobility is the main objective of the majority of winter maintenance measures. Thus, a number of studies have evaluated how different winter maintenance measures affect speed. These studies indicate that winter maintenance measures increase the average speed of traffic up to 7 km/h. The increase in speed depends on how large improvements in friction the car drivers think the measures giver. During snowy weather, speed is reduced greatly by 10-15 km/h (Elvik and Vaa 2004).

The distance between vulnerable road users along/on the road and motor vehicles are reduced by bad winter maintenance. The reason is that snow and ice at the road shoulder forces cyclists in particular to cycle more to the left on the road and more close to the motor vehicles (Erke and Sørensen 2008). In addition to the reduced distance, it also leads to more conflicts and disputes between vehicle drives and cyclists if the road is so narrow that motor vehicles cannot pass the cyclists. For example a survey by Trygg Vesta shows that cyclists on the road irritate over 70 % of the interviewed vehicle drivers (VG 2009).

Table 1.22. Possible effects of winter maintenance of roads on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	(↑)	↓	↑	-	-	-	-	-	↑	-		-	(↑)	-	↑

TØI report 1009/2009

Like maintenance and improvement of the surface, good winter maintenance improves road conditions which consequently reduce the fear of accidents due to icy and slippery roads.

Improved road conditions also reduce the required tasks for cycling, which may improve subjective safety. In table 1.22 this is illustrated by improved skills.

Finally, improved road conditions that make cycling possible in winter and improve subjective safety consequently encourage more people to cycle in winter

(Bergström and Magnusson 2003), which itself improve subjective safety because more volume of cyclists increases the vehicle drivers' attention.

Both the literature study and the qualitative considerations show that winter maintenance of roads increases subjective safety of vulnerable road users.

1.2.5 Winter maintenance of pavements and foot and cycle paths

Winter maintenance of pavements, foot and cycle paths and other public areas includes the same measures as winter maintenance of roads, i.e. snow clearance, sanding and salting (Elvik and Vaa 2004).

As described in the previous chapter, different studies conclude that icy and slippery road conditions in general are associated with increased feeling of unsafety. Pedestrians and cyclists are more sensitive to "difficult" road conditions, so this correlation should be also considered for foot and cycle paths.

A study about winter maintenance of cycle paths in Sweden concludes that temperature, precipitation, and road condition are the most important factors for those who choose to cycle to work in summer but not in winter. By improving winter maintenance service levels on cycle tracks, it might be possible to increase the number of bicycle trips during winter by 18 %, representing a corresponding decrease in the number of car trips by 6 %. They have also found that snow clearance is the most important maintenance measure. Less motor vehicle traffic and more cycle traffic improve subjective safety of vulnerable road users (Bergström 1999, 2002, Bergström and Magnusson 2003).

No or bad winter maintenance of tracks for walking and cycling force vulnerable road users to use roads instead of tracks. This integration of motor vehicle and vulnerable road users reduces the feeling of safety.

Table 1.23. Possible effects of winter maintenance of pavements, foot and cycle paths and other public areas on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
(↑)	-	↑	-	-	-	-	↑	-	-	↑	-		-	(↑)	-	↑

TØI report 1009/2009

Good winter maintenance of tracks for walking and cycling improves road conditions which consequently simplifies the task of walking and cycling, and therefore reduces the fear for accidents due to icy and slippery roads.

The qualitative considerations are summarized in table 1.23. Both the literature study and qualitative considerations show that winter maintenance of pavements, foot and cycle paths as well as other public areas increases subjective safety of vulnerable road users.

1.3 Traffic control

This chapter of the appendix describes the subjective safety effects of 17 measures under the category of traffic control.

1.3.1 Area-wide traffic calming

Area-wide traffic calming is the coordinated use of traffic control measures in a large, defined area in order to improve traffic safety and environmental conditions. Different measures such as ban on through traffic in residential streets, speed-reducing devices in residential streets and improving main roads may be applied as part of area-wide traffic calming (Elvik and Vaa 2004).

As described in chapter 1.1.4 Oslo East has undergone a comprehensive area-wide traffic calming from 1987 to 1999 including building of three tunnels, closing of streets for through traffic and redesigning of streets to environmental streets. Surveys show that the percentage of pedestrians in the area feeling unsafe has decreased from 43 % in 1987 to 25 % in 1994, 21 % in 1996, 22 % in 1998 and 16 % in 2002. The percentage of parents feeling unsafe for their children on school way has decreased from 52 % in 1987 to 40 % in 1996 and 27 % in 2002 (Kolbenstvedt 1998, Kolbenstvedt and Fyhri 2004).

Drammen has undergone similar changes. After the changes, 63 % of the cyclists were feeling safe when cycling in the city centre and the city was in general seen as a safe and comfortable town for cycling. However, 75 % of the parents were still feeling unsafe for their children (Fyhri 2004).

As a part of an overall plan, Nørrebrogade in Copenhagen was closed in 2008 for through traffic. According to a survey among about 900 residents, 100 cyclists and 100 pedestrians, about half of the interviewed people stated that the safety among vulnerable road users improved, while only 22 % declared that the level of safety was reduced due to this change. About 70 % of the vulnerable road users supported the project to become permanent (Catinét 2008).

According to Svenska Kommunförbundet (2000), area-wide traffic calming improves subjective safety of vulnerable road users due to lower speed levels and improved crossings for cyclists and pedestrians.

Table 1.24. Possible effects of area-wide traffic calming on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	↑	↑	↑	-	-	-	(↑)	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

Table 1.24 summarizes the qualitative assessment of the impacts on subjective safety. As described earlier, speed-reducing devices in residential streets are often applied as part of the area-wide traffic calming operation. In these streets the mean speed is normally reduced 5-10 km/h compared to the initial mean speed, when the speed reducing measures were not implemented (Elvik and Vaa 2004).

Traffic volume on residential streets is also reduced. In Oslo East traffic volume was reduced by 90 % on some streets (Kolbenstvedt and Fyhri 2004). On Nørrebrogade in Copenhagen the traffic volume has been reduced by 30-80 % (Københavns Kommune 2009).

While motor traffic volume decreases, cycle volume may increase. On Nørrebrogade the cycle volume has increased 15 % (Københavns Kommune 2009).

In other words the effect of area-wide traffic calming is partly separation of different traffic groups; motor vehicles on main roads and vulnerable road users on residential streets.

Both the literature study and qualitative considerations show that area-wide traffic calming increases subjective safety of vulnerable road users in residential streets.

1.3.2 Environmental streets

Elvik and Vaa (2004) describes environmental street as a road where through traffic is permitted, but where the road is built in such a way that it leads to low speed and high degree of alertness and consideration with regard to local traffic. Different elements as for example tracks for walking and cycling, speed humps, raised pedestrian crossings, widening the pavement at intersections, alternate narrowing of the street and refuges may be included in the construction.

Most of the measures that could be part of environmental streets are described separately elsewhere in this report. Most of these measures are assessed to have a positive effect on subjective safety. Thus, the combination of different measures probably has a positive effect as well.

In addition, Vejdirektoratet (2004) explicitly formulate improved subjective safety among vulnerable road users as one of the main objective of environmental streets.

As described in the previous chapter, different studies conclude that area-wide traffic calming has a positive effect on subjective safety in residential streets. In several cases these streets are environmental streets.

Different evaluations regarding environmental streets itself have also been made. But these studies do not usually focus on subjective safety. However, the aspect is often to a limited extent or indirectly included.

According to a survey for evaluation of 16 environmental streets in Norway, 75 % of the pedestrians believed that the conditions for pedestrians have been improved. The percentage varies between 38 and 96 % for each city. Among the cyclists about 56 % answered that conditions have been improved. The percentage varies between 13 and 85 % for each city (Fyhri 2001, Statens vegvesen 2003c, 2003d). Although the survey does not directly deal with subjective safety, it is assumed that subjective safety was also considered by vulnerable road users when evaluating their general conditions on the roads.

Leite and Fyhri (2006) have made an evaluation of Tøyengata in Oslo as an environmental street. According to the results of the study, 74 % of the cyclists and 70 % of pedestrians believe that conditions for vulnerable road users have been improved in the street. It is assumed that subjective safety is included in this assessment.

A Danish evaluation of three environmental streets shows hat the percentage of pedestrians feeling unsafe in every street has declined respectively from 63 to 25 %, from 43 to 14 % and from 73 to 45 %. The percentage of cyclists feeling unsafe has declined from 70 to 30 %, from 56 to 17 % and from 73 to 45 % in the streets (Vejdirektoratet 1987, 1988, 1988a).

Table 1.25 summarizes the qualitative assessment of the effects on subjective safety among vulnerable road users.

Table 1.25. Possible effects of environmental streets on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
(↕)	(↑)	↑	↑	(↕)	↑	↑	(↑)	↑	-	(↑)	-	(↑)	-	-	-	↑

TØI report 1009/2009

Mean speed normally decreases in environmental streets. The Norwegian study of 16 environment streets show that the speed decreased by over 20 % for most of the streets. The speed level typically decreased from 40-50 km/h to 30-40 km/h (Statens vegvesen 2003c, 2003d).

An earlier study regarding the effects of five environmental streets shows a speed reduction from 37-50 km/h to 29-41 km/h which is about 10-20 % speed change. Speed variation and maximum speed also decreased (Statens vegvesen 1996, 1996a, 1996b).

A Danish study regarding 21 environmental streets shows speed reductions as a result of the environmental street design. According to this study, the speed level was reduced in average from 50 km/h to 50 km/h on the streets. A later study also shows that the speed reductions are permanent (Vejdirektoratet 2004).

An earlier study of environmental streets in three Danish cities shows that the mean speeds in each city reduced respectively from 49 to 44 km/h, from 57 to 50 km/h and from 52 to 44 km/h. Especially, mean speeds for heavy vehicles and high speed levels decreased (Vejdirektoratet 1987, 1988, 1988a).

Statens vegvesen (1996) shows that traffic volume has decreased 3-12 % on three of the five streets reformed as environmental streets in Norway. Motor traffic volume has increased 3-17 % on the remaining streets. The study also concludes that pedestrian volume has increased while no definite trend has been found for cycle volume.

The studies by Vejdirektoratet (1987, 1988, 1988a) show that traffic volume has decreased with 10 % in one of the three cities and increased with 3-30 % in the other two cities. In two cities the volume of vulnerable road users has increased by 5-38 % while there has been a reduction of 60 % in one city. However, this reduction is explained by new parallel cycle tracks and changed public transport service.

An evaluation of an environmental street in Taastrup in Denmark shows that traffic volume has decreased from 13,000 to 6,000 vehicles per day (Bach-Jacobsen and Kure 2004).

Narrowing the streets and implementing chicanes can reduce the distance between vulnerable road users, along/on the road, and motor vehicles if there is no cycle track (Nielsen and Lahrmann 2008). Other measures such as construction of tracks for walking and cycling or widening the pavement at intersections, however, increase the distance between motor vehicles and vulnerable road users.

Moreover, narrowing the streets and construction of refuges on pedestrian crossings on the other hand reduce the crossing distance, and thereby improve subjective safety.

As part of the reconstruction, road conditions may probably be improved. In some cases road lighting may be implemented. Both changes have positive effects on subjective safety.

Both the literature study and the qualitative considerations show that environmental streets most likely increase the subjective safety among vulnerable road users at the reconstructed streets.

1.3.3 Pedestrian streets

A pedestrian street is a street where motor vehicles are not permitted to enter, apart from delivering goods at given times of the day. In Norway cyclists are allowed to use the pedestrian streets, but they should pay for this by cycling with walking speed and giving way to the pedestrians on these streets. In Denmark cycling in pedestrian streets is only allowed in some cases.

A study by Bettum (1998) found that only 8 % of pedestrians feel unsafe regarding road accidents on pedestrian streets in Oslo. 10-20 % feels unsafe regarding crimes and other unpleasant incidents. This is primarily a problem at night.

One possible problem on pedestrian streets is conflicts between pedestrians and cyclists (Statens vegvesen 2003). According to Jølsgard (2005) cycling in pedestrian streets contributes to pedestrians' feel of unsafety. However, a review of five pedestrian streets in Denmark where cyclists are allowed at certain times of day concludes that the mixing of pedestrians and cyclists has not given significant problems (Weitemeyer 2006).

If cycling in pedestrian streets is not allowed the changing of a street to pedestrian street will force cyclists to cycle on the main roads, where they might feel more unsafe (Weitemeyer 2006).

An alternative for traditional pedestrian streets is the so called shared space. Shared space is an alternative method for designing road sections, intersections and squares where they are planned and designed with limited or no regulation regarding separation of vehicles, bicycles and pedestrians in time and space.

Different studies have examined and summarized foreign experiences concerning effects of shared space. The conclusion is that shared space at first has negative effect on subjective safety of vulnerable road users, but after getting used to the design, the initial decrease in subjective safety is neutralised (Myrberg et al. 2008, Shared space 2008, Sørensen 2009, Tyrens 2007).

Motor vehicles are not permitted on pedestrian streets. Thus, the volume of motorized traffic and speed decrease while the volume of vulnerable road users increases. In other words, motor vehicles and vulnerable road users are separated in these streets. At the same time cyclists and pedestrians are integrated, which may result in more conflicts among these two groups. The required tasks for walking and cycling may be reduced. This is indicated as improved skills in table 1.26. Finally, road lighting may also be implemented as part of the reconstruction. This has a positive effect on subjective safety.

Concluding the literature survey, traditional pedestrian streets have positive effect on subjective safety of vulnerable road users, but shared spaces have negative effect in the beginning while the effect becomes neutral after some time. The conclusion of the qualitative considerations is also that pedestrian streets have positive effect on subjective safety of vulnerable road users. This is summarized in table 1.26.

Table 1.26. Possible effects of pedestrian streets on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	↑	↑	↑	-	-	-	↕	-	-	-	-	(↑)	-	(↑)	-	↑

TØI report 1009/2009

1.3.4 Urban play streets

Urban play streets permit mixed traffic at walking speed. Like environmental streets the measure may be one of the several measures used in area-wide traffic calming for a specific area.

As described in chapter 1.3.1 area-wide traffic calming has positive effect on subjective safety on residential streets. Residential streets are normally the streets which are rebuilt as urban play streets.

Urban play streets have a lot in common with pedestrian streets and much more with shared spaces, which respectively have positive and negative or neutral effect on subjective safety.

As a result of urban play streets speed is reduced. A study by Muskaug (1983, 1983a) shows that mean speed is reduced by 15-25 km/h on these streets. Traffic volume and especially the volume of heavy vehicles declined as well. This is the case in particular if arterial roads are improved or constructed.

Motor vehicles and vulnerable road users are to a greater or lesser extent separated between residential streets and arterial roads. Cyclists and pedestrian are integrated on the residential streets. Integration of different kinds of vulnerable road users may cause more conflict between them.

Road lighting may be implemented as part of the reconstruction.

It is concluded that urban play streets improve subjective safety of vulnerable road users in these streets.

Table 1.27. Possible effects of urban play streets on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	↑	↑	↑	-	-	-	↕	-	-	-	-	(↑)	-	(↑)	-	↑

TØI report 1009/2009

1.3.5 Access control

Access points are the main source of accidents and congestion. Their location and spacing affects the safety and functional integrity of streets and highways. Too many closely-spaced street and driveway intersections increase accident potential and delays, while too few inhibit access and over-concentrate traffic (Levinson 1997).

According to Papayannoulis (1999), vehicles entering and leaving the main roadway often slow the through traffic. The differences in speeds between through and turning vehicles increase accident potential. Increasing the spacing between access points improves arterial traffic flow and safety by (a) reducing the number of conflicts per km, (b) providing greater distance to anticipate and recover from turning manoeuvres, and (c) providing opportunities for improved design of turning lanes.

Access control includes minimizing direct frontage access onto major roads and avoiding access at dangerous locations such as bends or hill crests as well as also near existing intersections.

According to Elvik and Vaa (2004), access control is intended to reduce number of private access roads along public roads, to make each access point as safe as possible and to distribute traffic between private access roads in such a way that the total accident rate is minimized. A private access road (driveway in US parlance) is any road connecting private property to a public road. According to Levinson (2007), driveways are ubiquitous. They are found in urban, rural, and suburban areas. They are located along highways (i.e. non-access controlled), suburban roadways, city streets and alleys.

According to Elvik and Vaa (2004), there are different measures for access control as following:

- Constructing roads without access to private properties along the road
- Removing access points on existing roads
- Merging access points on existing roads
- Improving the design of each access point.

It is not always possible to construct roads without private access points or remove all private access points from the existing main roads to the extent desired. As long as a business needs access to the road, the issue is whether the access should be designed in the form of a separate point to each property or a communal access road, possibly a public intersection, which serves traffic to several properties. When traffic from a number of small access roads is merged, the result is fewer private access roads, each with more traffic (Elvik and Vaa 2004).

According to Iowa Access Management Awareness Project (2007), every sidewalk or path that crosses a private access road represents at least four potential pedestrian/vehicle conflict points. Reducing the number of driveways per block reduces the number of conflict points proportionally. Greater separation of driveways promotes pedestrian safety by reducing the number of conflict points as a result of reducing the "number of crossings". Reducing the number of crossings also means that vulnerable road users cross a shorter distance while moving by the main road. Thus, access control by means of merging private access roads has positive effect on subjective safety of vulnerable road users considering the "crossing distance" factor.

However, as mentioned in Elvik and Vaa (2004), as a result of merging private access roads the traffic volume passing through them increase. Thus, access control by means of merging private access roads has negative effect on subjective safety of vulnerable road users considering the "traffic volume" factor.

Table 1.28 Possible effects of access control on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↓	-	-	(↓)	-	↑	-	-	-	↑	-	↑		-	-	-	↑

TØI report 1009/2009

The last access control measure, improving the design of each access point, includes increasing sight distances on private access roads and the curve radius on the main road. Although this has a positive effect on the subjective safety of vulnerable road users considering the "sight" factor, studies stated in Elvik and Vaa 2004 show that increasing the sight distance along the main road did not reduce the number of accidents at private access roads.

The results of the qualitative assessment are summarised in table 1.28.

Summarizing the qualitative assessments, the overall effect of access control on subjective safety of vulnerable road users is possibly positive.

1.3.6 Priority control

At intersections between a road with heavy traffic and a road with light traffic, the right hand priority rule functions poorly. Consistent application of the right road priority rule at intersections along main roads in town and cities leads to delays for through traffic. Priority control is signposting main roads in towns and cities as priority roads and requiring minor road traffic to yield to major road traffic. By this, the intersection between road users is simplified and the capacity of main roads is increased (Elvik and Vaa 2004).

No literature which studied possible effects of priority control on subjective or objective safety among vulnerable road users have been found.

In fact, priority control has probably no significant effect on any of the factors influencing subjective safety of vulnerable road users as shown in table 1.29. It is not indicated in the table, but priority control may lead to a small increase in speed level on the main road, but no studies verifying this possible effect have been found.

Table 1.29 Possible effects of priority control on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TØI report 1009/2009

1.3.7 Yield signs at intersections

According to Elvik and Vaa (2004), yield rules at intersections are introduced by putting yield signs on the approach or approaches where traffic is required to give way. Vehicles controlled by a yield sign need to slow down or stop when necessary to avoid interfering with conflicting traffic.

One main purpose of introducing yield signs is to simplify road user decision-making and thus increase safety. However, yield signs at intersections do not appear to have any statistically significant effect on the number of accidents. The explanation may be that speed increases at intersections with yield signs (Elvik and Vaa 2004).

According to studies comparing yield signs versus stop signs and no control intersection in the City of Cottage Grove in United States, accident rate for intersections with yield signs was six times higher than intersections with stop sign control. Intersections with yield signs had an accident rate twice as high as intersections with no control at all. The reason for the high accident rate at yield controlled intersections might be in part that drivers generally react to a stop sign with their foot on or near the brake pedal preparing to stop. Their reaction to a yield sign seems to be to have their foot on or near the gas pedal preparing to accelerate (Cottage grove 2005).

However, no literature which studied possible effects of priority control on subjective safety among vulnerable road users has been found.

Although a yield sign indicates that drivers must reduce speed or stop if necessary when approaching an intersection, national standards dictate that stop and yield signs should not be installed as an attempt to reduce speeding problems. Research also has revealed that motorists often increase their driving speeds between intersections in an attempt to make up for lost time (Pierce County 2007).

Moreover, stop and yield signs create “through” streets, which are unimpeded by cross traffic. Accordingly, speeds tend to increase on the through streets and driver attentiveness tends to decrease (Scott 2001). This implies that not only speed increases as a result of yield signs but also drivers’ thoughtfulness decreases.

Thus, yield signs have possibly negative effect on subjective safety of vulnerable road users considering the “speed” and “thoughtfulness” factors.

The results of the qualitative assessment are summarised in table 1.30.

Summarizing the qualitative assessments, the overall effect of yield signs at intersections on subjective safety of vulnerable road users is possibly negative.

Table 1.30 Possible effects of yield signs at intersections on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↓	-	-	-	-	-	-	-	-	-	↓	-	-	↓

TØI report 1009/2009

1.3.8 Stop signs at intersections

According to Elvik and Vaa (2004), by putting stop signs, road users are obliged to come to a complete halt before passing the junction. This ought to give better time to observe traffic. The use of stop signs in junctions comes in two various: Two-way stop and all-way stop. Two way stop means that stop signs are put up on the minor road only. All-way stop means that stop signs are put up on all roads entering a junction. If a junction is controlled by all-way stop, whoever arrives first goes first. If there is a two-way stop, vehicles from the minor road have to wait until there is a sufficient gap in traffic on the major road to enter it.

Stop signs may often seem like a good solution to neighbourhood speeding, but similar to what was explained in chapter 1.3.7 for yield signs, traffic studies and experience show that using stop signs to control speeding doesn't necessarily work. When stop signs are installed to slow down speeders, drivers may actually increase their speed between signs to compensate for the time they lost by stopping. Some drivers tend to accelerate rapidly after a stop, possibly creating an even more dangerous situation. In fact, most drivers reach their top speed within 100 feet of a stop sign (Portland Community and School Traffic Safety Partnership 2009).

According to Bretherton (1999) who reviewed over 70 technical papers covering all-way stop signs, all-way stop signs do not control speed except under very limited conditions.

Thus, stop signs have possibly negative effect on subjective safety of vulnerable road users considering the "speed" and "thoughtfulness" factors

Moreover, all-way stop signs do not necessarily improve pedestrian or vehicle safety. In fact, pedestrians in stop sign-congested neighbourhoods often have a false sense of security about crossing local streets with four-way stop signs (FHWA 2004). This can be interpreted as although objective safety at intersections with four-way stop signs is not necessarily high, vulnerable road users have the feeling of safety there due to the "intersection design". However, this sense of safety is in fact a reason for decline of the objective safety. Stop signs have positive effect on subjective safety of vulnerable road users considering the "intersection design" factor.

Furthermore, stop signs that are not needed can create more problems than they solve. Stop signs create a false sense of security that reduces a person's awareness. This becomes a problem when motorists decide not to stop because they believe a particular stop sign to be pointless and at the same time pedestrians unwittingly cross into oncoming traffic because they believe that a stop sign makes it safe to cross the street. This is why it is usually better to allow drivers to enter an intersection cautiously without the perceived security of a stop sign, than to install a stop sign incorrectly as a cure-all problem solver.

The results of the qualitative assessment are summarised in table 1.31.

Table 1.31 Possible effects of stop signs at intersections on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↓	-	-	-	-	↑	-	-	-	-	↓	-	-	↓

TØI report 1009/2009

Summarizing the qualitative assessments, the overall effect of stop signs at intersections on subjective safety of vulnerable road users is possibly negative.

1.3.9 Traffic signal control at intersections

Traffic signal control separates different streams of traffic from each other, and can improve the flow of traffic at intersections. Traffic signals can be either time-controlled or vehicle-actuated. Traffic signals can be designed also with separate phases for each traffic stream at an intersection or by shared phases for some of the traffic steams. In Norway, it is normal for drivers who are turning right to share the same phase as pedestrians crossing the road, and for drivers who are turning left to share the same phase as oncoming traffic (Elvik and Vaa 2004).

Unfortunately, no literature studying possible effects of traffic signal control on subjective safety among vulnerable road users have been found.

One of the advantages of signals at intersections is to interrupt heavy traffic to permit other traffic, vehicular or pedestrian, to cross (FHWA 2007). In other words, signals stop (or reduce, in case of turning vehicles which share green phase with pedestrians) the traffic volume regularly, and let the vulnerable road users to cross the street more easily. In other words, traffic volume is decreased when vulnerable road users are crossing the street. From this point of view, signal control at intersections possibly has positive effect on subjective safety of vulnerable road users considering the “traffic volume” factor.

Moreover, signal lights basically separate different traffic streams based on their direction. From this point of view, signal control at intersections has positive effect on subjective safety of vulnerable road users considering the “integration/separation” factor.

The results of the qualitative assessment are summarised in table 1.32.

Table 1.32 Possible effects of traffic signal control at intersections on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	-	-	-	-	-	-	↑	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

Summarizing the qualitative assessments, the overall effect of traffic signal control at intersections on subjective safety of vulnerable road users is possibly positive.

1.3.10 Signal-controlled pedestrian crossings

A study by Schioldborg (1979) concludes that pedestrians feel safer crossing roads with signalised pedestrian crossings than other crossing points.

The qualitative assessment summarized in table 1.33 also indicates that the measure has positive effect on subjective safety of pedestrians. Speed decreases and pedestrian and motor vehicles are separated in time. Moreover, road lighting is sometimes implemented together with the signal-control.

Table 1.33. Possible effects of signal-controlled pedestrian crossing on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↑	-	-	-	↑	↑	-	-	-	(↑)	-	-	-	↑

TØI report 1009/2009

1.3.11 Speed limits

As described in chapter 2.4 of the main report several studies have shown that reduced speed improves subjective safety of vulnerable road users (Amundsen and Bjørnskau 2003, Elvik and Sælensminde 2000, Miljøministeriet 1992, Nielsen, Thesberg, Jensen and Sørensen 2007, Vejdirektoratet 2009).

According to Elvik et al. (2004) the relationship between changes in speed limit and changes in mean speed can be described by the following formula:

$$\text{Changes in mean speed} = (\text{speed limit}_{after} - \text{speed limit}_{before}) \cdot 0.253 - 1.220$$

On the average, a change in mean speed induced by a change in speed limit is around 25 % of the speed limit change. This means that if the speed limit is reduced by 10 km/h, one may expect the mean speed to go down by about 2.5 km/h (Elvik et al. 2004).

A Norwegian example is the lowering of the speed limit from 90 km/h to 80 km/h and from 80 km/h to 70 km/h in 2001 on hazardous road sections. It was found that mean speed was reduced by 1.6-2.8 km/h in the first case and 2.1-4.1 in the second case (Ragnøy 2005).

Table 1.34. Possible effects of speed limits on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↑	-	-	-	-	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

The conclusion is that speed limits reduce mean speeds in traffic and thus decrease the feeling of unsafety among cyclists and pedestrians. This is summarised in table 1.34.

1.3.12 Speed-reducing devices

Speed-reducing devices include the following measures (Elvik and Vaa 2004):

- Humps
- Raised pedestrian crossings
- Raised intersections
- Rumble strips
- Narrowing road width
- Speed zones: Use of a number of speed-reducing devices is co-ordinated.

Obviously, the objective is to reduce the mean speed of the traffic. If successful, it will have a positive effect on subjective safety. Humps on residential streets for example reduce the mean speed by 24 % in average (Erke and Elvik 2006).

Besides speed reduction, speed-reducing devices may also contribute to lower traffic volume, if alternative routes exist. Several studies show that traffic volume has decreased about 25 % on residential streets with humps (Erke and Elvik 2006).

Narrowing road width and implementing chicanes may reduce the distance between vulnerable road users along/on the road and motor vehicles if there are no cycle tracks. On the other hand, they reduce the crossing distance for vulnerable road users.

In a questionnaire survey in the United Kingdom among 393 cyclists 78 % stated that narrowing caused by traffic calming measures is a problem and makes them feeling more unsafe. Only 4 % of the respondents indicated that these narrowings help them. The larger the vehicles in a road narrowing, the higher proportion of cyclists that reported feeling intimidated or stressed. This suggests that the mechanism causing stress to cycling might be related the distance to the vehicles rather than speed differential (Gibbard et al. 2004).

Chicanes may increase the number of conflicts between cyclists and motor vehicles (Erke and Sørensen 2008).

Table 1.35. Possible effects of speed-reducing devises on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↑	↓	(↑)	-	-	-	-	-	-	-	-	-	-	↑ / ↕

TØI report 1009/2009

Speed-reducing devices normally have positive effect on subjective safety of vulnerable road users. But if the mean speed does not decrease significantly while the distance between vulnerable road users and motor vehicles decreases considerably, the effect may be negative.

1.3.13 Road markings

Road markings include the following measures (Elvik and Vaa 2004):

1. Longitudinal lines on the road surface
2. Shoulder rumble strips or edge lines
3. Two-way left turn lanes
4. Raised pavement markers
5. Delineator posts
6. Distance markings on motorways
7. Combinations of several types of road markings.

These measures except distance markings on motorways and maybe two-way left turn lanes probably have some effect on subjective safety of vulnerable road users. No studies that directly evaluate the effects of the five relevant measures on subjective safety have been found. However, the effect has been studied for the other road marking alternatives.

The effect of road markings of so called 2-minus-1-roads on subjective safety of cyclists has been studied in Denmark and Sweden. 2-minus-1-roads are roads where the number of driving lanes is reduced from two to one, the centre line is removed and the shoulders are widened. The results of the evaluations are ambiguous. Large proportions of cyclists were not feeling safe neither before nor after the roads were converted to 2-minus-1-roads. No evaluations regarding the effect for pedestrians are made (Erke and Sørensen 2008).

Another road marking alternative is coloured cycle lanes. A review of cycle handbooks from nine countries shows that coloured cycle lanes probably have a positive effect on the subjective safety of cyclists. The reason is that the visibility of cycle lanes and cyclists are improved in this case. The coloured road marking also helps the road user to use the road system in the right way (Sørensen 2009).

A similar review over pedestrian handbooks from six countries indicates that alternative marked or coloured pedestrian crossings probably have positive effect on the feeling of safety among pedestrians (Sørensen 2009).

Besides these studies, the effect on subjective safety has been studied indirectly in several projects. Table 1.36 summarises the results of the studies and as well as qualitative considerations.

Road marking may have different effects on average speed. According to several studies summarized by Elvik and Vaa (2004), “normal” road markings and delineator posts just have little effect on driving speeds. As a rule, speeds increase a little immediately after a road is marked, but this increase disappears gradually to some extend.

On the other hand, road markings can be used for widening or narrowing the width of a road. Narrowing of the width normally results in speed reduction (Nilsson et al. 1992, Sakshaug 1986, Vaa et al. 2002).

For example, Wennike (1994) found that 1 meter wide kerb lanes through a town, which were intended to reduce speed led to a 3 km/h decrease in the average speed.

Sagberg (2007) has evaluated the effects of two different types of wide painted medians at two-lane rural roads. He found that speed decreases by about 3 km/h.

A third example is Sørensen et. al (2005) who have evaluated a combination of different alternative road markings. The primarily measure was a very wide and coloured road marking in the middle of the road. In addition, the speed limit was reduced, intersection design changed and refuges implemented. This package of measures reduced the average speed by 10-15 km/h.

Distance may also be affected by road markings. Road marking can be used to increase the distance between motor vehicles and vulnerable road users along the road. But, on the other hand, distance may be reduced. Contrary to the intended effect, the evaluation of 2-minus-1-roads shows that the distance was reduced. The reason is that cyclists cycle closer to the middle of roads while the lateral placement of vehicles was mostly unchanged (Erke and Sørensen 2008). Wide painted medians may also reduce the distance (Sagberg 2007, Sørensen et. al 2005).

Road marking can be used to guide and help road users to use complicated intersections. This can have a positive effect on subjective safety. Road marking may also improve the attention of vehicle drives and possibly their thoughtfulness regarding vulnerable road users especially if it is alternative road marking as for example coloured road marking.

The conclusion of the literature study and the qualitative considerations is that road marking can both have positive and negative effects on subjective safety depending on the measure used. A positive effect is the most likely effect of road marking.

Table 1.36. Possible effects of road markings on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↕	↕	-	-	(↑)	(↑)	-	-	-	-	(↑)	-	-	↑ / ↕

TØI report 1009/2009

1.3.14 Traffic control for pedestrians and cyclists

Traffic control for pedestrians and cyclists includes the following nine measures (Elvik and Vaa 2004):

1. Pedestrian crossings on carriageways, normally combined with traffic signs
2. Traffic signal control of pedestrian crossings at intersections and on sections
3. Raised pedestrian crossings
4. Refuges (traffic islands on pedestrian crossings)
5. Pedestrian guard rails
6. School crossing patrols
7. Pavement widening at intersections
8. Cycle lanes on the carriageway
9. Advanced stop line for cyclists at intersections.

According to Elvik and Vaa (2004) Traffic control for pedestrians and cyclists is intended to:

- Separate pedestrians and cycle traffic in time and /or space from car traffic
- Direct pedestrians and cycle traffic to crossing points with good visibility conditions and unambiguous yield requirements
- Increase mobility for pedestrian and cycle traffic by reserving parts of the road for such traffic and by giving them priority when crossing the road.

As described in chapter 2.4 of the main report traffic control for pedestrians and cyclists is a factor which generally improves subjective safety among vulnerable road users. However, the effects of the above nine measures on subjective safety are discussed and clarified in the following.

Because the measures' objective is to improve the conditions for vulnerable road users, most of them have been also evaluated regarding their effects on this group of road users.

Pedestrian crossings described as the first three measures can reduce the feeling of unsafety when pedestrians crossing roads (Schioldborg 1979, Huserbråten 2002).

An evaluation of pedestrian crossings combined with different physical measures on arterial roads in Stockholm and Örebro in Sweden shows that 15 % of the pedestrians feel more safe after the reconstruction in Stockholm, while as much as 80 % feel more safe in Örebro after the reconstruction (Towliat 2001).

A review by Sørensen (2009) regarding design guidelines and pedestrian handbooks from six countries, Denmark, Sweden, United Kingdom, USA, Canada and Australia, shows that pedestrian crossings are described as a measure that improves the sense of safety among pedestrians. The review also shows that improving subjective safety for pedestrians is explicitly one of the objectives for implementing traffic islands on pedestrian crossings.

According to the Norwegian Trygg Trafikk (2009) school crossing patrols can be used for improving subjective safety on dangerous school routes.

Several American pedestrian handbooks describe that pavement widening at intersections improves the feeling of subjective safety among pedestrians. The reasons are that crossing distance is reduced, sight and visibility are improved and the waiting area for the pedestrians is enlarged. However, the design sometimes makes is difficult to have cycle lanes in the intersection and winter maintenance is complicated. This may reduce subjective safety for cyclists (AASHTO 1999, Vermont Agency of Transportation 2002, Washington State 1997).

As described in chapter 1.1.1. several studies and cycle handbooks describe that cyclists feel more safe on cycle lanes than sections with mixed traffic. However, cycle lanes do not have as much positive effect on subjective safety as cycle tracks do (Jensen 2006, 2006a, Statens vegvesen 2003, Vejdirektoratet 2000).

Sørensen (2009) has made a review over recommendations in design guidelines and cycle handbooks from nine countries about how cycle tracks and lanes should be designed in intersections and which effects different designs have on subjective safety. Table 1.1 showed the impacts on subjective safety for 12 different designs. Some of the designs have positive effect, some have negative effect and for some others the effect is unknown. For advanced stop line for cyclists at intersections, it is concluded that the design probably improves subjective safety for cyclists because they become more visible to motor vehicles.

Table 1.37 summarises the qualitative assessment of the impacts on subjective safety for each of the nine measures. It differs greatly how the different measures affect subjective safety, but on the whole the nine measures are assessed to have positive influence on subjective safety as intended.

The three first measures are different kind of pedestrian crossings. They all more or less reduce speed and separate crossing pedestrians and motor vehicles. Sometimes road light is implemented together with the pedestrian crossing.

The fourth measure, refuges, has positive effect because it reduces the crossing distance by making it possible to divide the crossings into two stages. Refuges also have a speed reducing effect. Like pedestrian crossing, refuges are sometimes implemented together with road light (Sørensen 2009).

Pedestrian guard rails separate motor vehicles and pedestrians and increase the distance between them which lead to an improved feeling of safety. Speed may also decrease due to narrowing the streets. Finally, streets are crossed at “safe” crossings.

A Danish study by Kjærgaard and Lahrmann (1981) concludes that school crossing patrols reduce car speed by 3 km/h compared with areas where school patrols do not operate. A Swedish study also concludes that school crossing patrols reduce car speed (Linderoth and Gregersen 1998). School patrols may contribute to more school children walking or cycling to school and less school children driven in cars by they parents. Patrols may also contribute to more thoughtfulness of car drives on the streets near schools. Finally, the patrols help the children. This is indicated as improved skills in table 1.37.

The seven measures, pavement widening at intersections, may reduce speed, but not in all cases (Walkinfo 2008). Most importantly it reduces crossing distance, improves visibility of the pedestrians and improves sight for the pedestrians (Sørensen 2009).

Cycle lanes partly give cyclists their own traffic area and separate them from cars and heavy vehicles. The distance between cyclists and motor vehicles may also increase. Improvement of the conditions for cyclists may contribute to more people cycling instead of driving. A cycle lane beside roads in some cases narrows the width of the roads. This can have speed reducing effects. If the cycle lane is constructed by making the street more wide, the measure may have an opposite effect. Finally, cycle lanes are often badly maintained. This results in unevenness, holes and cracks, which may reduce the feeling of safety.

The last measure is advanced stop line for cyclists at intersections. This makes the cyclists more visible for car drivers, and may therefore improve the feeling of safety among the cyclists.

The conclusion of the qualitative considerations is that the nine measures in general probably have positive effect on subjective safety. For most of the measures these assessments are verified in different studies.

Table 1.37. Possible effects of traffic control for pedestrians and cyclists on subjective safety. The number of measures refers to the numbers in the previous text.

Measure	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
1	-	-	-	(↑)	-	-	-	↑	-	-	-	-	(↑)	-	-	-	↑
2	-	-	-	↑	-	-	-	↑	↑	-	-	-	(↑)	-	-	-	↑
3	-	-	-	(↑)	-	-	-	↑	↑	-	-	-	(↑)	-	-	-	↑
4	-	-	-	(↑)	-	↑	-	-	-	-	-		(↑)	-	-	-	↑
5	-	-	-	(↑)	↑	-	↑	↑	-	↑	-	-	-	-	-	-	↑
6	(↑)	-	(↑)	(↑)	-	-	-	-	-	-	-	-	-	(↑)	(↑)	-	↑
7	-	-	-	(↑)	-	↑	-	-	-	-	-	(↑)	-	-	-	-	↑
8	(↑) ?	-	↑ ?	↕	↑	-	↑	↑	-	-	(↓) ?	-	-	-	-	-	↑
9	-	-	-	-	-	-	-	-	(↑)	-	-	(↑)	-	-	-	-	(↑)

TØI report 1009/2009

1.3.15 Parking regulations

Stopping and parking controls include measures as for example banning on-street parking, time-limited parking restrictions, zone regulation of stopping and parking, and parking charges (Elvik and Vaa 2004).

No studies regarding the effects of these measures on subjective safety have been published in the reviewed journals and reports. However, according to Vejdirektoratet (2000) parking illegally at cycle lanes and tracks may increase the feeling of unsafety among cyclists. One measure to solve this problem is using high kerbstones, but this also has negative effects for cyclists.

Table 1.38 summarises some of the possible effects on subjective safety. Parking regulations may reduce traffic volume in areas with parking regulations. This is normal in city centres where there are a great number of vulnerable road users. Subjective safety may be improved for these road users.

An old American study concludes on the other hand that speed level increases after banning on-street parking (Crossette and Allen 1969). The reason probably is that the street seems more wide when no cars park along the street.

Sight may be improved when no cars park along the street. This makes vulnerable road users more visible (Staten vegvesen 2003).

Based on these considerations, it is classified that parking regulations may have a small positive impact on subjective safety.

Table 1.38. Possible effects of parking regulations on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	-	-	(↓)	-	-	-	-	-	-	-	↑	-	-	-	-	(↑)

TØI report 1009/2009

1.3.16 One-way streets

According to O'Toole (2001), the evidence that two-way streets are more dangerous than one way is overwhelming. In many cases, two-way streets result in twice as many pedestrian accidents as one way. One review of two-way to one-way conversions found that two-way streets caused 163 % more pedestrian accidents in Sacramento, and 100 % more pedestrian accidents in Portland OR, Hollywood FL, and Raleigh NC. This study called one-way streets "the most effective urban counter-measure" to pedestrian accidents.

One-way streets have the obvious advantage that pedestrians and drivers need only look one way when watching for traffic (O'Toole 2001). In other words, crossing pedestrians face fewer directions of conflicting vehicular traffic. From this point of view, one-way streets possibly have positive effect on subjective safety of vulnerable road users considering the "intersection design" factor.

One-way streets however permit higher average speeds because signals on a one-way grid can be synchronized to allow drivers in all directions to proceed indefinitely at a fixed rate of speed. A semblance of synchronization can be approached on a two-way grid only if signals are more than a half-mile apart, and even then it is less than perfect (O'Toole 2001). Moreover, Traffic speeds may increase due to drivers' perception that there is no on-coming traffic. According to results of another study stated in Cuuneen (2005) converting two-way streets to one-way led to a 19 % increase in traffic at speeds that averaged 37 % faster. This wasn't because the maximum speed limit on the one-way streets was any greater than on two-way streets, but because drivers experienced 60 % fewer stops. In contrast, two-way streets tend to be slower due to "friction" especially on residential streets without a marked centre line (FHWA 2009). From this point of view, one-way streets have negative effect on subjective safety considering the “speed” factor.

Furthermore, when a two-way street is changed to a one-way street, there is much space for the vehicles. Thus, vulnerable road users may perceive less traffic volume in the street. From this point of view, one-way streets possibly have positive effect on subjective safety considering the “traffic volume” factor.

In some countries as Germany, Belgium and Denmark cycling against the normal direction of the traffic is allowed in some one-way streets. People cycling against the traffic may feel unsafe, but a study of one-way streets in Copenhagen finds that car drivers reduce the speed significantly when they meet oncoming cyclists on narrow one-way streets (Agerlin and Jensen 2008). Additionally, the permission of cyclists in the “wrong” direction may move some cyclists from the main roads, where they might feel more unsafe.

The results of the qualitative assessment are summarised in table 1.39. Summarizing the qualitative assessments, the overall effect of one-way streets on subjective safety of vulnerable road users is possibly positive.

Table 1.39 Possible effects of one-way streets on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	-	-	↓	-	-	-	-	↑	-	-	-	-	-	-	-	↑?

TØI report 1009/2009

1.3.17 Bus lanes and bus stop design

Constructing of bus lanes and protecting bus stops are intended to separate buses and trams from other traffic, and thus reduce the number of accidents.

Cyclists in London have been recently forced to share most of the city's major bus lanes with motorcyclists (Daley 2009). This is the same as what we have in Norway. Daley (2009) believes that allowing bikers into bus lanes has made the experience of cycling in London just that little bit more dangerous. Motorbikes are about 50 % more likely than cars to be involved in an accident which causes serious injury to a cyclist, and about 200 % more likely to be involved in an incident that results in a cyclist fatality.

According to Daley (2009), a recent study showed that when motorbikes are allowed to travel in bus lanes, their average speed increases with many travelling at speeds of more than 40 or even 50 mph in built-up areas. Moreover, according to Kim (2003), reserved bus lanes increase average travel speed of buses. From this point of view, bus lanes shared with bicycles, moped and motorcycles have negative effect on subjective safety considering the “speed” factor.

On the other hand, according to Crook (2006), an independent survey in 2005 found that 87 % of riders and just over half of the general public agree that allowing bikes in bus lanes has road safety benefits and 15 % of the public said they would ride to work if bikes or scooters are permitted in bus lanes. This implies that subjective safety of cyclists increases when they share a priority lane with buses.

According to the report by the Association of British Drivers (2002), bus lanes enthuse some bus drivers to drive aggressively by encouraging them to think they have more right to be on the road than anyone else. From this point of view, bus lanes have negative effect on subjective safety of vulnerable road users considering the "thoughtfulness" factor.

According to Queensland Transport (2006), shared use of a bus lane between bicycle riders and buses can create conflict where there is insufficient room for users to safely overtake each other within the same lane. On occasions buses fail to acknowledge the rider's right to be in a bus lane and bus drivers can 'squeeze' the rider between the gutter and the bus. Wind turbulence generated by buses can also be hazardous to cyclists.

According to Ryan et al. (2006), the LOS (level of service) is limited when bicycles and busses share a lane as buses obstruct cyclists by stopping regularly. Moreover, lane widths where drivers are unsure whether there is sufficient room to pass, create the greatest cyclist stress. From this point of view, bus lanes shared with bicyclists have negative effect on subjective safety of vulnerable road users considering the "paths" factor.

However, according to DeRobertis and Rae (2001), the strategy of sharing the same roadway space between bicyclists and buses can also provide some marginal benefits for bicyclists, depending on the type and frequency of bus service. When bus service is infrequent, the lane can be much more comfortable for bicycles than a regular traffic lane due to the lower traffic volumes. From this point of view, bus lanes shared with bicyclists have positive effect on subjective safety of vulnerable road users considering the "traffic volume" factor.

The results of the qualitative assessment are summarised in table 1.40. Summarizing the qualitative assessments, the overall effect of bus lanes on subjective safety of vulnerable road users is possibly negative.

Table 1.40. Possible effects of bus lanes on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
↑	-	-	↓	-	-	↓	-	-	-	-	-	-	↓	-	-	↓

TØI report 1009/2009

1.4 Vehicle design and protective devices

This chapter of the appendix describes the subjective safety effects of eight measures under the category of vehicle design and protective devices.

1.4.1 Reflective materials and protective clothing

According to Elvik and Vaa (2004) the measures include:

1. Pedestrian reflectors
2. Retro-reflective material on bicycles
3. Retro-reflective number plates and reflectors on the back of cars
4. Protective clothing for motorcyclists and others in traffic.

In this project only the two first measures are relevant.

No studies have been found which directly evaluates the effects of these two measures on subjective safety, but some studies indirectly indicate that they may have a positive influence.

Self-reported knowledge and opinions among 1,500 Norwegian road users show that around 90 % believe that use of pedestrian reflectors should be mandatory (Phillips and Fyhri 2008). The question does not directly deal with subjective safety, but it is assumed that people want reflectors to be mandatory because they perceive it as a tool that improves safety.

A Danish project concludes that cycle lamps improve the feeling of safety among cyclists (Andersen et al. 2006). See chapter 1.4.7 for further description of the project. The evaluated cycle lamps were lamps which made cyclists more visible, but not the lamps which help cyclists to see better at night. Thus, the difference between the lamps and the retro-reflective material on bicycles is not great. This indicates that retro-reflective material may have the same positive effect.

Table 1.41 summarizes the possible effects of reflectors and retro-reflective material. The measures improve visibility of vulnerable road users which may lead to more thoughtfulness of car users and thereby much feeling of safety among vulnerable road users. In the table, this is stated as improved sight, improved road light and improved thoughtfulness.

Table 1.41. Possible effects of reflective materials and protective clothing on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	-	-	-	-	-	-	-	-	(↑)	(↑)	(↑)	-	-	(↑)

TØI report 1009/2009

The conclusion of the literature study and qualitative considerations is that reflective material on bicycles and pedestrians may have a small positive effect on their subjective safety.

1.4.2 Cycle helmets

The effect of cycle helmets on subjective safety for cyclists has been evaluated directly or indirectly in several projects. Only a few results are presented in the following.

Fosser (1991) has made a study about attitudes and use of cycle helmets among Norwegian cyclists. Among 78 cyclists using helmet, 60 % stated that they use helmet because they feel safer with it.

A later study about opinions among 1,500 Norwegian road users show that around 80 % of them believed that use of cycle helmet should be mandatory (Phillips and Fyhri 2008). The question does not directly deal with subjective safety, but it is assumed that people answer that helmet should be mandatory because they think it has positive effect on safety of cyclists.

A similar Swedish study found that around 60-65 % think that more use of cycle helmets results in more safety for the cyclists (Gjerstad 2002).

Table 1.42 summarises some possible effects of helmet use that affect subjective safety for bicyclists.

One way to promote the use of cycle helmets is by law. The effect of cycle helmet rules on cycling is much debated. A review by Nolén and Lindqvist (2003) of different studies concludes that the results are ambiguous. However, several of the reviewed studies indicate that cycle helmet regulation may reduce cycling among young people and temporarily among younger children, while cycling by adults probably is not influenced. This leads to decrease of vulnerable road user volume and thus has a negative effect on subjective safety.

A naturalistic experiment by Walker (2006) found that wearing a bicycle helmet led to traffic getting significantly closer when overtaking. In other words, distance and thoughtfulness are reduced.

Table 1.42. Possible effects cycle helmets on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	(↓) ?	-	(↓)	-	-	-	-	-	-	-	-	(↓) ?	-	↑	(↑)

TØI report 1009/2009

Both the literature study and partly the theoretical, qualitative assessment show that cycle helmets increase the subjective safety for cyclists.

1.4.3 Regulating vehicle mass

The relationship between size of a car and the probability of injury can be described as (Elvik and Vaa 2004):

– The lighter the vehicle, the smaller the risk of injury for other road users

– The heavier the vehicle, the smaller the risk of injury for people in the car.

Thus, the objective of a possible regulation of car mass, as a traffic safety measure, is to influence the distribution of the car fleet according to mass, so that the total number of injured persons in traffic is as low as possible. Measures which could be used to regulate car mass include (Elvik and Vaa 2004):

– A ban on the use of cars under a given weight

– A ban on the use of cars above a given weight

– A tax regulation with a view to optimise the weight distribution.

According to the description in chapter 2.4 of the main report heavy vehicles have a negative effect on subjective safety (Lahrmann and Leleur 1994, Miljøministeriet 1992, Nielsen et. al 2007, Vejdirektoratet 2009, Værø 1992). In other words, a ban on the use of vehicles which are above a given weight may have a positive effect on subjective safety.

Among the above-mentioned measures, a ban or tax regulations on the use of vehicles above a given weight is in fact the most relevant one which can improve subjective safety.

Table 1.43 summarises the effect of this regulation on subjective safety. The measure probably gives less traffic by heavy vehicles. On the other hand, if the same amounts of goods have to be transported, the measure will also produce more traffic by light vehicles. One big heavy vehicles may be replaced by two or three small heavy vehicles. A review by Sørensen (2008a) of seven European environmental zones with weight regulations verifies this relation.

Less traffic by heavy vehicles may increase the speed level because heavy vehicles normally have lower speed than light vehicles. On the other hand, more traffic with light vehicles may cause a traffic queue. The first scenario is considered as more realistic. However, the actual effects on speed have not been studied.

Table 1.43. Possible effects of regulating vehicle mass on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
(↓) ?	(↑) ?	-	(↓) ?	-	-	-	-	-	-	-	-	-	-	-	-	(↕) ?

TØI report 1009/2009

The conclusion is that according to the literature study, regulating vehicle mass has a positive effect on subjective safety of vulnerable road users, but the qualitative considerations could not provide any clear conclusion in this respect.

1.4.4 Regulating automobile engine capacity and top speed

The measure includes regulation of motor power or top speed for heavy or light vehicles. Top speed is regulated either by a maximum speed governor, independent of the speed limit or by a more intelligent speed governor where the top speed depends on for example speed limit (Elvik and Vaa 2004).

No studies about the possible effects of these regulations on subjective safety among vulnerable road users have been found. However, the objective of the regulation is to reduce traffic speed. If successful, it will have a positive effect on subjective safety. This is summarised in table 1.44.

Vaa (2006) has made an overview over the effects of different Intelligent Transport Systems (ITS) on behaviour and accident. He summarizes that regulation of top speed for heavy vehicles reduces mean speed. A study in Sweden shows that more intelligent speed governor for private cars also reduced speed (Várhely et al. 2002).

Table 1.44. Possible effects of regulating automobile engine capacity and top speed on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↑	-	-	-	-	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

1.4.5 Under-run guardrails on trucks

Under-run or side under-run guardrails are rails or grates located on the back of a lorry or trailer or on the side of the vehicle between the wheel axles.

The objective of side under-run protection is to prevent pedestrians and people riding two-wheeled vehicles from being run over, by getting caught in the open space between the wheel axles on large vehicles.

Even though the measure addresses safety among vulnerable road users, no literature studying possible effects of the measure on subjective safety have been found.

Additionally, it is assessed that side under-run guardrails has no effect on any of the factors influencing subjective safety of vulnerable road users. This is illustrated in table 1.45.

Table 1.45. Possible effects of side under-run protection on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TØI report 1009/2009

1.4.6 Safety equipment in trucks

Safety equipment in heavy vehicles includes the following nine types of equipment and regulations (Elvik and Vaa 2004):

1. Total weight limit for heavy vehicles
2. Length limit for heavy vehicles
3. Extra mirrors and wide angle mirrors
4. Under-run guard rails and side under-run protection
5. Anti-lock brakes
6. Side marker lamps
7. Seat belts
8. Fire extinguishers
9. First aid equipment.

Only the first four measures may have an influence on subjective safety. The fourth measure is described in the previous chapter. Thus, this chapter deals with total weight limit for heavy vehicles, length limit for heavy vehicles as well as extra mirrors.

As described in chapter 2.4 of the main report and chapter 1.4.3 heavy vehicles have negative effect on subjective safety. Thus, weight limit or length limit may probably contribute to subjective safety improvement. A negative effect will however be if the limits significantly contribute to more traffic or faster traffic. Regarding weight limit, this will probably only has a positive effect if it contributes to smaller heavy vehicles. The reason is that vulnerable road users can only see the length, height and width of vehicles and not their weight.

Extra mirrors make cyclists more visible in some situations and improve the possibility for the cyclists to get eye contact with truck drivers (HVU 2006). This may improve the feeling of safety among the cyclists.

Table 1.46 summarizes the considerations about the possible effects of safety equipment in heavy vehicles on subjective safety. It is finally concluded that limits for total weight, length and extra mirrors might contribute to better subjective safety among vulnerable road users.

Table 1.46. Possible effects of safety equipment in heavy vehicles on subjective safety. The number of measures refers to the numbers in the previous text.

Measure	Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
1	-	(↑)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(↑)
2	-	(↑)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(↑)
3	-	-	-	-	-	-	-	-	-	-	-	(↑)	-	-	-	-	(↑)

TØI report 1009/2009

1.4.7 Bicycle safety equipment

Elvik and Vaa (2004) define bicycle safety equipment as:

1. Bicycle lamps and reflectors
2. Brakes
3. The height and design of handlebars
4. Wheel diameter and wheel distance
5. Gear construction
6. Bicycle bells
7. Distance marker
8. Spoke protection
9. Child seats and child bicycle wagons.

Among the nine mentioned categories of equipment, probably it is only the distance markers and bicycle lamps that directly affect the possible influencing factors on subjective safety of vulnerable road users which are listed in this report in tables such as table 1.47. However, reflectors, bells, brakes, wheel, handlebars and child seats and wagons may also have some small effects.

Although the objective of this equipment is to improve conditions for bicyclists, only one study that evaluates effects of the equipment on subjective safety for cyclists have been found.

Andersen et al. (2006) have studied the effects of daytime running light on bicycles. The study included 4,000 cyclists, where half of them got daytime running light on their bike. Overall 60 % of the cyclists with light were feeling more safe. At night, over 70 % were feeling safer and at twilight the percentage was about 90 %. About 50 % were feeling safer at daytime.

According to some old studies, distance markers in a horizontal position increase passing distances between bicycles and other vehicles 5-10 % (Oranen 1975, Watts 1984, Angenendt and Hauser 1989).

Lamps and reflectors and partly bells make bicyclists more visible. In table 1.47 this is indicated as improved sight, road light and thoughtfulness. Improved attentions from car drivers may improve the feeling of safety among cyclists.

Bicycles with high handlebars are more difficult to steer than bicycles with normal handlebars. This leads to more mistakes in manoeuvring on the road. The same applies to bicycles with small wheels compared with bicycles with standard wheels and bicycle with bad brakes compared with bicycles with good brakes (Elvik and Vaa 2004). In other words, normal handlebars and wheels facilitate the task of cycling. In table 1.47 this is listed as improved skills, which may have positive effect on subjective safety.

Child seats may increase thoughtfulness of car drivers, and bicycle wagons may increase the distance between cycles and passing cars. No studies verifying these assumptions have been found.

Table 1.47. Possible effects of bicycle safety equipment on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	-	↑	-	-	-	-	-	-	(↑)	(↑)	(↑)	(↑)	-	(↑)

TØI report 1009/2009

Based on one study and the qualitative considerations, the conclusion is that some of the bicycle safety equipment may have small positive effect on the feeling of safety among cyclists. But it does not affect pedestrians.

1.4.8 Safety standards for trailers and caravan

Possible safety measures for trailers and caravans include (Elvik and Vaa 2004):

1. A ban on driving with trailers, on whole or part of the road network
2. Total weight limits for trailers
3. Special speed limits for certain car and trailer combinations
4. Better stability, control and tracking for trailers
5. Regulating the types of trailers which can be used
6. Improved brakes for trailers
7. Better suspension and shock absorption for trailers.

No studies that evaluate effects of the seven listed measures on subjective safety among vulnerable road user have been found.

It is only the first three measures which partly have effect on subjective safety, as well as the fourth measure which may have some effects. Table 1.48 summarizes possible effects of these four measures.

A ban on driving with trailers and partly a total weight limit for trailers may reduce volume of the large heavy vehicles on the actual parts of a road network. This is typically in city centres with lots of vulnerable road users (Sørensen 2008a). Notice that the volume of small heavy vehicles may increase.

Speed limit may reduce the average speed as described in chapter 1.3.11.

Finally, better stability and control of trailers may reduce unintended swings of the trailer, which improve the distance between the trailer and vulnerable road users. Unintended swings may also give some unsafe situations.

Table 1.48. Possible effects of safety standards for trailers on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	(↑)	-	(↑)	(↑)	-	-	-	-	-	-	-	-	-	-	-	(↑)

TØI report 1009/2009

1.5 Driver training, education and enforcement

This chapter of the appendix describes the effects on subjective safety for seven measures under the three categories of:

- Driver training and regulation of professional drivers (1 measure)
- Public education and information (2 measures)
- Police enforcement and sanctions (4 measures).

1.5.1 Safety standards for transporting school children

Measures described as safety standard for transporting school children are (Elvik and Vaa 2004):

1. School transport with buses at different distances to school
2. Special safety standards for school buses
3. Improving bus stops
4. Training bus drivers
5. Training pupils.

Even though subjective safety is a very important issue for school children, no literature has been found studying the effects of safety standard for transporting school children on the subjective safety of vulnerable road users.

Table 1.49 indicates some possible effects of the first four measures. The fifth measure, training pupils is discussed in the next two chapters.

Table 1.49. Possible effects of safety standards for transporting school children on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	(↑) ?	-	-	-	(↑) ?	-	-	-	-	-	(↑) ?	-	-	(↑) ?

TØI report 1009/2009

The first measure does not directly influence subjective safety for children walking or cycling to school. However, it provides the possibility to use the bus instead of walking or cycling if the child or the parents are feeling unsafe.

Special safety standards for school buses include for example: Seat belts, higher seat backs, warning indicators at crossings, sensors for obstacles in front of the wheels, stop signal arm and exterior loudspeaker system (Transportation Research Board 1989). Warning indicators and stopping signal arms are installed on buses to make other road users aware of children crossing the road. This may improve thoughtfulness of other road users and thereby improve subjective safety of the children walking from the bus to the school.

According to the third measure, bus stops should be located so that the walking distance is as short as possible and so pedestrians can use footpaths or other areas which are separate from vehicle traffic. This separation improves subjective safety.

Training of bus drivers may lead to a more careful driving. This may improve subjective safety for school children and other vulnerable road users walking and cycling next to buses.

Based on the above considerations, it is classified that safety standards for transporting school children may have a small positive impact on subjective safety of school children.

1.5.2 Education of pre-school children

Children learn how to behave in traffic in several ways: (1) by copying the behaviour of others, (2) through their own experiences in traffic, (3) through organized educational measures. Educating pre-school children refers to the last type of education (Elvik and Vaa 2004).

A few studies have attempted to measure the effect of education of pre-school children on the number of accidents (objective safety of the road uses). Two of the studies described in Elvik and Vaa (2004) show highly conflicting results: The Norwegian study found that children who where members of Barnas Trafikklubb had, on average, a 30 % lower risk in traffic (accidents per 10,000 children per year) than children who were not the club members. On the other hand, the Swedish study found that children who were members of Barnas Trafikklubb had an average a 67 % higher risk of being injured in traffic per 100 hours spent in traffic than children who were not members of the club. However, both studies are non-experimental, and it is possible that the results be due to weaknesses in the study methods.

Regarding the subjective safety, education can reduce feelings of insecurity or anxiety of children according to Elvik and Vaa (2004). This is obviously due to the fact that children's skills, as pedestrians or cyclists, are improved by participating in organized educational programs. Learning about traffic rules gives them a sense of comfort and safety, and reduce their anxiety when travelling in traffic. From this point of view, education of pre-school children has positive effect on subjective safety of vulnerable road users considering the "skills" factor.

Table 1.50. Possible effects of education for pre-school on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	-	-	-	-	-	-	-	-	-	-	-	↑	↑	↑

TØI report 1009/2009

Moreover, during the education they will learn about how to protect themselves when moving as a pedestrian or cyclists. For example, it can encourage them to use helmets when cycling. From this point of view, education of pre-school children possibly has positive effect on subjective safety of vulnerable road users considering the “personally protection” factor.

The result of the qualitative assessment are summarised in table 1.50. Summarizing the qualitative assessments, the overall effect education of pre-school children on subjective safety of vulnerable road users is possibly positive.

1.5.3 Education in schools

According to Elvik and Vaa (2004), organized road safety education in schools is designed to give children lower accident rates than they would otherwise have, by practising knowledge and skills that children can travel as safely as possible.

Therefore, the same as education for pre-school children, education in school has positive effect on subjective safety of vulnerable road users considering the “skills” and “personally protection” factors.

The results of the qualitative assessments are summarised in table 1.51.

Summarizing the qualitative assessments, the overall effect of education in school on subjective safety of vulnerable road users is possibly positive.

Table 1.51. Possible effects of education in schools on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	-	-	-	-	-	-	-	-	-	-	-	↑	↑	↑

TØI report 1009/2009

1.5.4 Stationary speed enforcement

Different methods for police speed enforcement exist. Stationary speed enforcement includes the following techniques (Elvik and Vaa 2004):

- Radar or instruments that measure mean speed between two fixed points, and stopping points staffed by uniformed police officers and cars.
- Aeroplanes as observation posts and visible stopping points with patrol cars.
- The police observer measures speed, using radar mounted on the window and then pursues offending vehicles in order to stop and punish the driver.

As described in chapter 2.4 of the main report several studies have shown that reduced speed improves subjective safety among vulnerable road users. Thus, if the enforcement succeeds in reducing traffic speeds, the measure will have positive effect on subjective safety.

A number of Norwegian studies have shown that speed decreases where speed enforcement increases. The average reduction in speed is around 2 km/h. A time halo effect of between two days and 10 weeks after the period of intensified speed enforcement has been found (Vaa et al. 1995). The distance-halo effects vary from around 1 km to 22 km (Vaa 1993).

It is concluded that stationary speed enforcement has positive effect on subjective safety in a limited area and for a limited period of time. This is summarised in table 1.52.

Table 1.52. Possible effects of stationary speed enforcement on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↑	-	-	-	-	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

1.5.5 Patrolling

Patrolling consists of mobile methods of enforcement and is carried out using both marked patrol cars and civilian vehicles. Patrols can be used in a more general way than stationary enforcement since the latter is usually confined to enforcing speed, drink-driving or the use of seat belts.

Like other kinds of speed enforcement and speed-reducing devices, the measure has a positive effect on subjective safety if traffic speed is reduced. In addition, it may have a little positive effect on thoughtfulness because it is not only speed which is controlled. This is however not documented in any studies. Table 1.53 summarizes the possible effects.

Table 1.53. Possible effects patrolling on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↑	-	-	-	-	-	-	-	-	-	(↑)	-	-	↑

TØI report 1009/2009

1.5.6 Automatic speed enforcement

Automatic speed enforcement" refers to the use of speed cameras. The system is designed to detect traffic violations and identify the vehicle/driver automatically -

i.e. without police officers being physically present at the scene. Identification is based on photographs of the vehicle and driver (Elvik and Vaa 2004).

Table 1.54 summarizes the possible effects on subjective safety of vulnerable road users. A study by Ragnøy (2002) concerning three road sections in Norway concludes that automatic speed enforcement reduces speed with 4-6 km/h at all camera sites. Speed is also reduced between cameras, but the effect is smaller.

Table 1.54. Possible effects of automatic speed enforcement on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	↑	-	-	-	-	-	-	-	-	-	-	-	-	↑

TØI report 1009/2009

1.5.7 Red light cameras

Red light cameras are the same as speed cameras with the exception that they detect vehicles going against red signals instead of the vehicles driving too fast.

The effect of red light cameras on subjective safety of vulnerable road users has not been studied in any reviewed project.

As summarized in table 1.55 red light camera may however have a little positive effect on subjective safety. It may reduce the number of vehicles going against a red light. This may improve the separation of crossing pedestrians and motor vehicles in time.

Table 1.55. Possible effects of automatic speed enforcement on subjective safety.

Traffic volume	Heavy vehicle	Vulnerable road users	Speed	Distance	Crossing distance	Paths	Separation/integration	Intersections, design	Crossings, number	Road conditions	Sight	Road Light	Thoughtfulness	Skills	Personally protection	**Total**
-	-	-	(↑)	-	-	-	(↑)	-	-	-	-	-	(↑)	-	-	(↑)

TØI report 1009/2009

It is also possible that speed is decreased because some drivers stop at yellow traffic signal instead of driving through the intersection.

Finally, thoughtfulness may improve due to the surveillance system. This is however more doubtful, and no studies verifies this hypothesis.

Visiting and postal address:
Institute of Transport Economics
Gaustadalléen 21
NO 0349 Oslo

Telephone: +47 22 57 38 00
Telefax: +47 22 60 92 00
E-mail: toi@toi.no

www.toi.no

Institute of Transport Economics
Norwegian Centre for Transport Research

- carries out research for the benefit of society and industry
- has a research staff of around 70 highly qualified staff working in various areas of transport research
- co-operates with a number of organisations, research institutes and universities in Norway and in other countries
- carries out high quality research and assessment projects within topics such as traffic safety, public transport, the environment, travel behaviour, tourism, planning, decision-making processes, transport economics, and freight
- publishes research findings in the Centre's own report series, on the Internet, in the periodical "Samferdsel", as well as in national and international scientific journals and publications
- participates in the Oslo Centre for Interdisciplinary Environmental and Social Research (CIENS) located near the University of Oslo