Alena Erke
Rune Elvik
TØI report 889/2007

Institute of Transport Economics
Norwegian Centre for Transport Research

Making Vision Zero real: Preventing pedestrian accidents and making them less severe

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Author(s): *Alena Erke; Rune Elvik*

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Summary:
This report describes the risk of accidents and injuries for pedestrians and cyclists, factors affecting the risk of these accidents, and measures to reduce the probability and severity of these accidents. The risk of pedestrian accidents is ca. 10 times greater than the risk for motorized road users. Safety measures are effective in reducing the risk for pedestrian and cyclist accidents when one or more risk factors are reduced, e.g. vehicle speed or lack of visibility of pedestrians and cyclists in the traffic environment. Increasing the amount of walking and cycling may increase the total number of pedestrian and cyclist accidents, but would decrease accident risk and would lead to a more fair distribution of injury rates between non-motorized and motorized road users.

Tittel: Realisering av nullvisjonen: Forebygging av fotgjengerulykker og redusering av ulykkenes alvorlighet

Forfatter(e): *Alena Erke; Rune Elvik*

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Rapporten beskriver risikoen for ulykker og skader blant fotgjengere og syklister, faktorer som påvirker ulykkesrisikoen, og tiltak for å redusere sannsynligheten og alvorligheten av ulykkene. Risikoen for fotgjengere er ca. 10 ganger større enn for motoriserte trafikanter. Sikkerhetstiltak reduserer risikoen for fotgjengere og syklister hvis en eller flere risikofaktorer er redusert, for eksempel motorkjøretøyenes fart eller manglende synlighet av fotgjengere og syklister i trafikken. Økt gange og sykling vil øke det totale antall ulykker med fotgjengere og syklister, men vil redusere risikoen for disse trafikantgruppene relativt sett, og føre til en mer rettferdig fordeling av skaderisikoen mellom motoriserte og ikke motoriserte trafikanter.

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Telephone +47 22 57 38 00 - www.toi.no

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Preface

This report is part of the operationalization of Vision Zero. The main focus is on pedestrian and cyclist accidents. It summarizes Norwegian authorities work with risk factors for pedestrians and cyclist accidents and measures to reduce the probability of pedestrian and cyclist accidents or to make them less severe.

The project has been funded by the Ministry of Transport. Contact persons at the Ministry of Transport has been Anne-Sophie Redisch and Marte Lillehagen.

Project manager at the Institute of Transport Economics has been Alena Erke. The report has been written by Alena Erke and Rune Elvik. Quality check was performed by Marika Kolbenstvedt.

Oslo, June 2007
Transportøkonomisk institutt

Sønneve Ølnes
Deputy managing director

Marika Kolbenstvedt
Head of department

Contents

Summary:

Making Vision Zero real: Preventing pedestrian accidents and making them less severe

This report describes how the risk of pedestrian and cyclist accidents has developed over time, factors affecting the risk, and measures to reduce the probability and severity of pedestrian accidents. Accident patterns are found by analysing Norwegian accident statistics and through literature review.

Pedestrians and cyclists have higher risk than motorised road users

The risk of fatal accidents among pedestrians and cyclists is about the same in Norway as in the other Nordic countries, and lower than in other European countries. Fatality risk has been decreasing over the last 20 years. It is on average ca. 10 times as large as the fatality risk per million person-km of travel by car. The case fatality rate (the proportion of all those injured who are killed), is greater for pedestrians than for cyclists, except when cyclists collide with pedestrian and in single bicycle accidents, where the risk is greater for cyclists. Estimations of fatality or injury risk for pedestrians and cyclists are more uncertain than for motor vehicles. The level of accident reporting for non-motorized road users is lower in Norway than in most other European countries.

Accident patterns are related to exposure

- Among pedestrians the highest risk to be seriously injured is found among those above 64 years. Among cyclists the highest risk is found among those below 15 years.
- The proportion of fatal or severe injuries among pedestrians and cyclists where there is suspicion of the presence of alcohol or drugs seems to be quite constant over time. It is greater among pedestrians than among cyclists.
- The total numbers of severe injuries is constant Monday through Friday and somewhat lower in weekends.
- The largest numbers of pedestrian and cyclist accidents occur at higher temperatures when more people use these transport modes. Whether or not injury severity is different at different temperatures is not clear.

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Accident patterns with respect to road and traffic conditions

- Injuries for pedestrians and cyclists are more severe at higher speed limits.
- Accidents in non-urban areas are more severe than accidents in urban areas.
- Road conditions (holes in the asphalt, slippery roads, high curbs etc.) contribute to accidents of pedestrians and cyclists.
- The number of severe accidents is greater on dry roads than on wet roads, especially among cyclists, probably due to the greater amount of cycling. This difference can not be found for fatal accidents.
- The number of severe pedestrian accidents is greater in daylight than in the dark, but the difference between daylight and dark is smaller than for other groups.
- The risk of cyclist accidents is lower when cyclists and cycling lanes are made visible in the traffic environment.

Accident patterns with respect to collision type

- Most fatal injuries to pedestrians and cyclists occur in collisions with motor vehicles, mostly cars. Collisions with trucks are far more fatal than collisions with other motor vehicles. Collisions with cyclists are less often fatal than other collisions.
- In most collisions between a pedestrian or cyclist and a motor vehicle, the pedestrian / cyclist is hit by the front of the motor vehicle. The injuries are least severe when the pedestrian / cyclist is hit by the rear of a motor vehicle.
- The most severe head injuries are sustained when being rolled over by a motor vehicle.

Accident patterns with respect to safety equipment

- The injury risk is higher for pedestrians not wearing reflective materials than for pedestrians doing so.
- The risk of severe injuries in an accident is slightly greater for cyclists wearing a helmet than for cyclists not wearing a helmet.
- In collisions with cars the most severe injuries are caused by the bumper, followed by the engine bonnet and the windscreen.
- The a-pillar, the roof and other parts of the car are only occasionally causing injuries. If a pedestrian is thrown through the air by the car, the throwing range depends on the stiffness and speed of the car.

Several measures can reduce risk

Measures that have been found to reduce pedestrian or cyclist accidents are:

- Speed reduction for motor vehicles on roads used by motorized and non-motorized road users reduces the probability and severity of pedestrian and cyclist accidents. This can be achieved by reductions of speed limits, speed enforcement, or physical measures or separating high-speed motor vehicle traffic from pedestrian and cyclist traffic.

- An active safety vehicle measure that can reduce the probability and severity of collisions between motor vehicles and pedestrians by reducing the speed of the vehicle before the collision is brake assistant systems (BAS).
- Safe crossing facilities for pedestrians (grade separated facilities; bridge, tunnel), signalized pedestrian crossings, a refuge (median) in pedestrian crossings or raised pedestrian crossings reduce accident risk for pedestrians.
- Visualisation of pedestrians and cyclists paths /lanes in the traffic environment.
- Winter maintenance that reduces the slipperiness of the roads will reduce the numbers of falling accidents and the numbers of collisions with motor vehicles. The most effective method is warming up of sidewalks.
- Visibility aids for pedestrians and cyclists reduce the probability and severity of pedestrian and cyclist accidents. Visibility aids are most effective when they improve both detection and recognition.
- Bicycle helmets may reduce the severity of accident consequences by preventing or reducing the severity of head, brain, and face injuries. The size of the effect is highly controversial, especially for adults. Mandatory use of cycle helmets may reduce the amount of cycling.
- Passive vehicle safety measures can reduce the severity of pedestrian and cyclist injuries, i.e. by increasing the deformability of the vehicle front: bumper, engine bonnet, windscreen, and a-pillar. The form and height of front protection systems are also relevant, especially for injuries among children.

Measures that have not been found to significantly reduce pedestrian and cyclist accidents are different crossing facilities for cyclists (marked bicycle lanes and advanced stop line for cyclists in signalised junctions) marked crosswalks for pedestrians (curbed central islands at intersections can provoke more pedestrian crossings on roads where pedestrians otherwise would not cross). Other measures of the kind are sidewalks and cycle paths that do not always reduce pedestrian and cyclist accidents and winter maintenance which can increase the numbers of accidents if it leads to more slippery roads.

General purpose policy instruments must support actions

Institutional measures can improve pedestrian and cyclist safety indirectly by supporting the implementation of effective safety measures. Organisation of planning and implementation processes so that safety for pedestrians and cyclists can be focused are important. They will also constitute important premises for measures that can increase pedestrian and cyclist volumes and safe behaviour of pedestrians and cyclists.

Examples are specific goals for pedestrian and cyclist safety and plans designed to achieve these goals, task groups that represent the interests of pedestrians and cyclist, and that contribute to decisions and planning processes that are relevant for pedestrians and cyclists, safety audits for pedestrian and cyclist facilities, incentives for car dealers and consumers to sell and buy cars that offer good pedestrian protection.

Some measures have a high cost-benefit ratio

Evaluations of safety measures for pedestrians and cyclists by cost-benefit analysis may take into account a number of factors in addition to safety. It is particularly important to take into account that safety measures may change the amount of walking or cycling. Monetary valuations that can be used in cost-benefit analyses are available for killed and injured road users, travel times, vehicle operating costs, environmental impacts (noise, pollution), and health impacts (insecurity, short term sick leave, serious illness). Safety measures for pedestrians and cyclists that yielded net cost-benefit ratios greater than zero (benefits are greater than costs) are:

- combined sidewalk and cycle path at motor vehicle volumes above 8 000,
- grade-separated crossings for pedestrians and cyclists at motor vehicle volumes above 8,000,
- improvement of pedestrian crossings at motor vehicle volumes above 1 200.

Safety measures for pedestrians and cyclists that have been evaluated with cost-benefit analysis that yielded net cost-benefit ratios below zero (cost greater than benefits) are traffic signals at pedestrian crossings and marking of cycle paths.

Pedestrians and cyclists account for a minor proportion of all road traffic, but have a considerably higher injury rate than other road users. The risk pedestrians run in road traffic is imposed by other groups of road users. A transport policy that increases the amount of walking and cycling would probably increase the total numbers of pedestrian and cyclist accidents and injuries. However, this will make the motorised road users less dominant and would thereby also decrease accident risk for each pedestrian and cyclist, and promote a more fair distribution of injury rates between non-motorized and motorized road users.

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Realisering av nullvisjonen: Forebygging av fotgjengerulykker og redusering av ulykkenes alvorlighet

Rapporten beskriver hvordan risikoen for ulykker blant fotgjengere og syklister har utviklet seg over tid, faktorer som påvirker ulykkesrisikoen, og tiltak for å redusere sannsynligheten og alvorligheten av ulykkene. Viktige ulykkesmønstre er basert på norske ulykkesdata og litteraturstudier.

Fotgjengere og syklister har høyere ulykkesrisiko enn andre trafikanter

Risikoen for dødsulykker i trafikken er omtrent den samme i Norge som i andre nordiske land, men lavere enn i andre europeiske land. Risikoen for dødsulykker blant fotgjengere og syklister er blitt redusert i løpet av de siste 20 årene. Likevel er risikoen for fotgjengere i dag ca. 10 ganger så stor som risikoen pr person-km for bilister. Andelen av skadde som blir drept er høyere for fotgjengere enn for syklister, dog med unntak av syklister som kolliderer med fotgjengere og singel-ulykker med sykkel. I disse tilfellene har syklister størst risiko. Det er større usikkerhet knyttet til estimeringene av risikoen for fotgjengere og syklister enn for motorkjøretøy. Rapporteringsgraden for ikke-motoriserte trafikanter er lavere i Norge enn i de fleste andre europeiske land.

Ulykkesmønstre henger sammen med eksponering

- For fotgjengerne er andelen alvorlige skadde størst blant de over 64 år. Blant syklistene er de under 15 år som er mest utsatt for alvorlig skade.
- Andelen drepte eller alvorlig skadde fotgjengere og syklister i ulykker med mistanke om alkohol eller narkotika er ganske konstant over tid. Andelen er høyere blant fotgjengere enn blant syklister.
- Det totale antall alvorlige skader er nesten konstant fra mandag til fredag og blir så noe lavere i helgene.
- Det skjer flest ulykker med fotgjengere og syklister når det er varmere. Hvordan skadenes alvorlighetsgrad varierer med temperaturen er ikke klarlagt.

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Ulykkesmønstre for veg og trafikkrelaterte forhold

- Skader ved fotgjenger- og syklistulykker blir mer alvorlige når farten øker.
- Ulykker utenfor tettbygde strøk er mer alvorlige enn i tettbygde strøk.
- Vegforhold som for eksempel hull i asfalten, glatt veg og høye kantstein bidrar til økt ulykkesrisiko for fotgjengere og syklister.
- Antallet alvorlige ulykker er høyere på tørr enn på våt veg, spesielt blant syklister. Dette skyldes trolig mer sykling i tørt vær. Når det gjelder dødsulykker er det ikke en slik forskjell forskjellen tørr og våt veg.
- Antallet alvorlige fotgjengerulykker er større i dagslys enn i mørket, men forskjellen mellom dag og kveld/natt er mindre enn for andre trafikanter.
- Risikoen for sykkelulykker er mindre når syklistene og anlegg for syklister er synlige i trafikken og trafikkmiljøet.

Ulykkesmønstre for ulike ulykkestyper

- De fleste dødsulykker med fotgjengere og syklister skyldes at de kolliderer med et motorkjøretøy, som oftest en bil. Kollisjoner med tunge kjøretøyer er langt farligere enn kollisjoner med andre kjøretøy.
- I de fleste kollisjoner mellom biler og en fotgjenger/syklist blir den myke trafikanten truffet av bilens front. Skadene blir minst alvorlige når det er baken på bilen som treffer.
- De alvorligste hodeskadene inntreffer når den myke trafikanten blir kjørt rett over.

Ulykkesmønstre relatert til sikkerhetsutstyr

- Skaderisikoen er større for fotgjengere som ikke bruker refleks enn for de som gjør det.
- Risikoen for alvorlige skader i en ulykke er litt større for syklister som bruker hjelm enn for syklister som ikke bruker hjelm.
- Trafikksikkerhetstiltak som reduserer farten av motorkjøretøy reduserer ulykkesrisikoen for fotgjengere og syklister.
- De alvorligste fotgjengerskadene i kollisjoner med personbiler skyldes sammenstøt med støtfangeren, panseret, og vindusruten.
- A-stolpen, taket og andre bildeler forårsaker som regel mindre alvorlige skader. Når en fotgjenger kastes gjennom luften avhenger kastelengden særlig av bilens fart og stivheten i bilens konstruksjon.

En rekke tiltak kan redusere risken og alvorlighetsgraden

- Fartsreduksjon for motorkjøretøy på veger som brukes av både motorisert og ikke motorisert trafikk. Dette kan oppnåes gjennom fartsreduserende tiltak eller ved å separere motorisert og ikke motorisert trafikk.
- Et aktivt sikkerhetstiltak for kjøretøy som kan redusere risikoen for kollisjoner med fotgjengere eller syklister er bremseassistenter (BA).
- Sikre kryssingsmuligheter, for eksempel bruer eller tunneler, lysregulerte fotgjengeroverganger eller opphøyde gangfelt kan redusere risikoen for fotgjengerne.

- Synliggjøring av fotgjenger/syklister og gang/sykkelveger i trafikkmiljøet.
- Vintervedlikehold som fører til at vegene blir mindre glatte vil redusere antall fallulykker og antall kollisjoner med motorkjøretøy. Den mest effektive metoden er oppvarming av fortau.
- Refleks og lys for fotgjengere og syklister er mest effektive hvis både synligheten og gjenkjenneligheten blir forbedret.
- Sykkelhjelm kan redusere alvorligheten av hodeskader. Det er stor usikkerhet mht størrelsen på effekten, spesielt når det gjelder voksne syklister. Obligatorisk bruk av sykkelhjelm kan redusere sykling.
- Passive sikkerhetstiltak for motorkjøretøy kan redusere fotgjenger- og sykkelulykkenes alvorlighet f eks gjennom økt deformasjonsevne på bilens front. Form og høyde av støtfangeren er også viktig, spesielt i kollisjoner med barn.

Tiltak som ikke nødvendigvis bidrar til en signifikant reduksjon av ulykker med fotgjengere og syklister, er oppmerkede fotgjengeroverganger, midtdeler med kantstein (kan øke antall fotgjengerulykker hvis de fører til at flere fotgjengere krysser vegen), framskutte stoppelinjer i lyskryss eller vintervedlikehold som fører til at fortau eller veger blir glattere. Fortau og sykkelveg reduserer heller ikke alltid ulykker med fotgjengere og syklister.

Generelle overordnede virkemidler må støtte opp om tiltaksarbeidet

Institusjonelle tiltak kan indirekte forbedre sikkerheten for fotgjengere og syklister gjennom å støtte opp om implementeringen av effektive sikkerhetstiltak. Organisering av planlegging og gjennomføringsprosesser slik at fortgjengeres og syklisters sikkerhet blir synliggjort er viktig. Eksempler er målsettinger eller handlingsplaner som fokuserer på fotgjengere og syklister, sikkerhetsinspeksjoner mv. Institusjonelle tiltak er også en nødvendig forutsetning ofr å få tiltak som gjør gange og sykling mer attraktivt og som dermed kan øke antallet fotgjengere og syklister i trafikken.

Visse tiltak har en høy nytte/kostnadsbrøk

I nyttekostnadsanalyser kan man ta hensyn til flere andre faktorer i tillegg til sikkerheten, blant annet reisetid, kjøretøykostnader, miljøeffekter (støy, luftkvalitet), helseeffekter (utrygghet, sykdom) og omfanget gange og sykling. Tiltak som har større nytte enn kostnadene (N/K >0), er:

- kombinert gang- og sykkelveg på veger med over 8 000 motorkjøretøy per døgn,
- planskilte kryssingssteder for fotgjengere og syklister over eller under veger med over 8 000 motorkjøretøy per døgn,
- utbedring av fotgjengerovergang på veger med over 1 200 motorkjøretøy per døgn.

Tiltak for fotgjengere og syklister der nytten er mindre enn kostnadene (uansett ÅDT) er signalregulering av fotgjengerovergang og oppmerking av sykkelveg.

Fotgjengere og syklister utgjør bare en liten del av all vegtrafikk, men har vesentlig høyere risiko enn andre trafikanter. Risikoen fotgjengere og syklister er utsatt for skyldes andre trafikanter. En transportpolitikk som øker mengden med gange og sykling ville trolig øke det totale antall ulykker der fotgjengere eller syklister er innblandet. Økt gange og sykling ville imidlertid redusere risikoen for fotgjengere og syklister gjennom at den motoriserte trafikken ble mindre dominerende i trafikkbildet. Dette ville i sin tur kunne føre til en mer rettferdig fordeling av skaderisikoen mellom motoriserte og ikke motoriserte trafikanter.

1. Background and research problem

The three types of accidents with the most severe consequences are head-on collisions, off-the-road accidents, and pedestrian accidents. The proportions of fatal, very severe / severe and slight injuries in these types of accidents vs. in other accidents are shown in Figure 1 for the years 2001-2005 in Norway. Pedestrian fatalities are 13% of all road accident fatalities, and very severe / severe injuries are 12% of all very severe / severe injuries in road accidents. In the same period of time the proportion of cyclists fatalities was 4% of all fatalities, and the proportion of very severely / severely injured cyclists was ca. 6%.

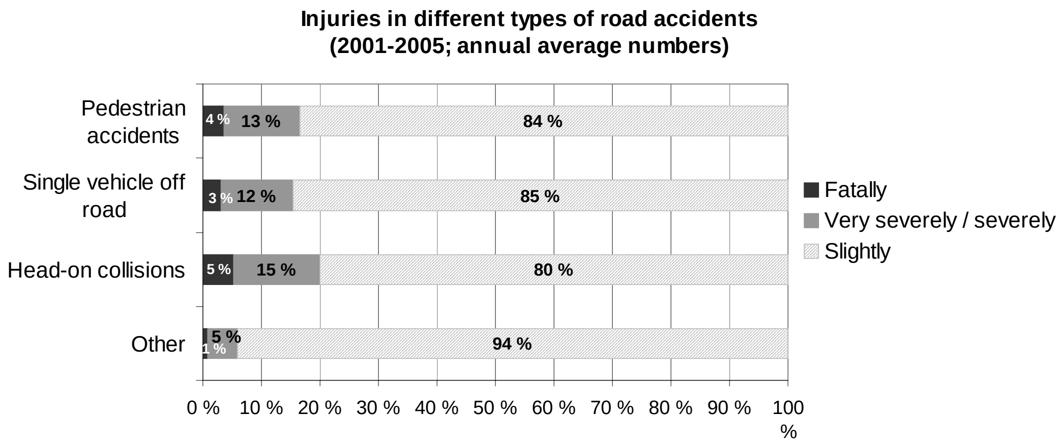

Figure 1: Injuries in different types of road accidents (2001-2005). Source: SSB.

Vision Zero describes the ideal state that nobody is ever fatally or seriously injured in road traffic. Vision Zero is incorporated in the National Transport Plan 2006-2015. It is stated that

"… means of transport and the transport system are to be designed in a way that supports correct behaviour, and as far as possible prevents human mistakes from having fatal consequences." (Stortingsmelding nr. 24, National Transport Plan 2006-2015)

The aim to reduce the numbers of fatal and very severe or severe injuries among pedestrians and cyclists can be approached in two ways: Preventing accidents or minimizing consequences of accidents. The aim of this report is to give an overview of pedestrian and cyclist accidents and injuries in Norway, describe factors that affect the risk of accidents and injuries among pedestrians and cyclists, and summarize evaluations of measures that may prevent pedestrian or cyclist accidents and injuries.

2. Pedestrian accidents

Pedestrians and cyclists have a higher risk of injury per kilometre of travel than other groups of road users, except moped and motorcycle riders (Elvik, 2005).

2.1 International comparison

2.1.1 Numbers of fatalities

The numbers of inhabitants, pedestrian fatalities, and pedestrian fatalities per mil. inhabitants are shown in Table 1. The number of pedestrian fatalities per inhabitant is about the same in Norway and in the three other Nordic countries, and lower in Norway than in EU-25. This difference may reflect differences in fatality risk or differences in exposure.

Table 1: Numbers of inhabitants, annual pedestrian fatalities, and pedestrian fatalities per mil. inhabitants (source: Kühn et al., 2006)

	Mil. inhabitants	Annual pedestrian fatalities	Pedestrian fatalities per mil. inhabitants
Norway	4.5	45	10.0
Sweden	8.8	87	9.9
Denmark	5.4	49	9.2
Finland	5.2	62	12.0
EU-25	376.0	5,640	15.0

2.1.2 Time trends of fatality numbers

The total numbers of fatalities in road accidents in Norway (1983-2005) and in EU-25 and the other Nordic countries (1992-2002) are shown in Figure 2 (numbers of fatalities in EU-25 are divided by 100).

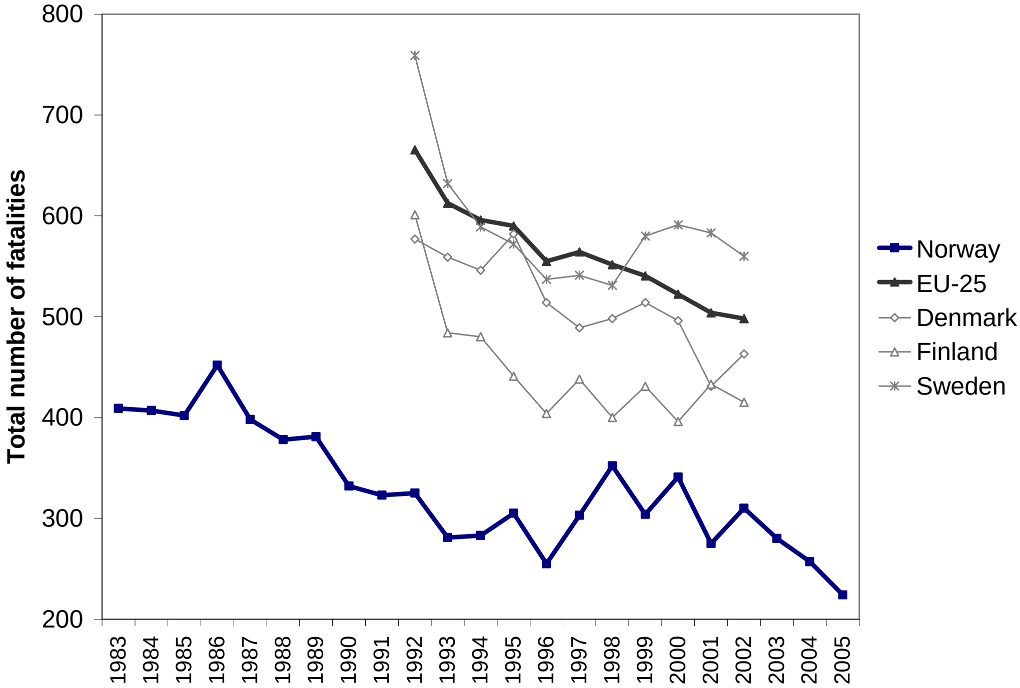

Figure 2: Annual numbers of fatalities in Norway (1983-2005), other Nordic countries and EU-25 (1992-2001; numbers of EU-25 divided by 100). Sources: SSB, EUROSTAT.

The annual numbers of pedestrian and cyclist fatalities in Norway and of pedestrian fatalities in EU-25 are shown in Figure 3. The proportions of pedestrian and cyclist fatalities in Norway and of pedestrian fatalities in EU-25 are shown in Figure 4. Proportions are computed as numbers of pedestrian / cyclist fatalities divided by the total number of road fatalities.

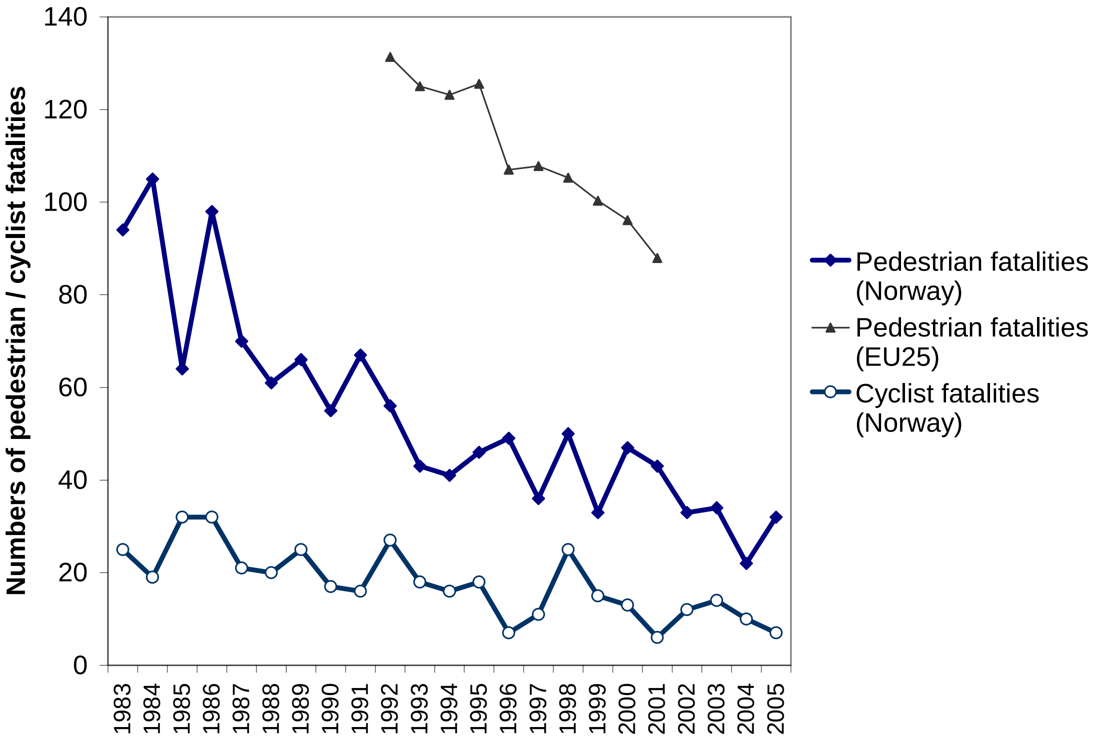

Figure 3: Annual numbers of pedestrian and cyclist fatalities in Norway (1983-2005), and EU-25 (1992-2001; numbers of EU-25 divided by 100). Sources: SSB, EUROSTAT.

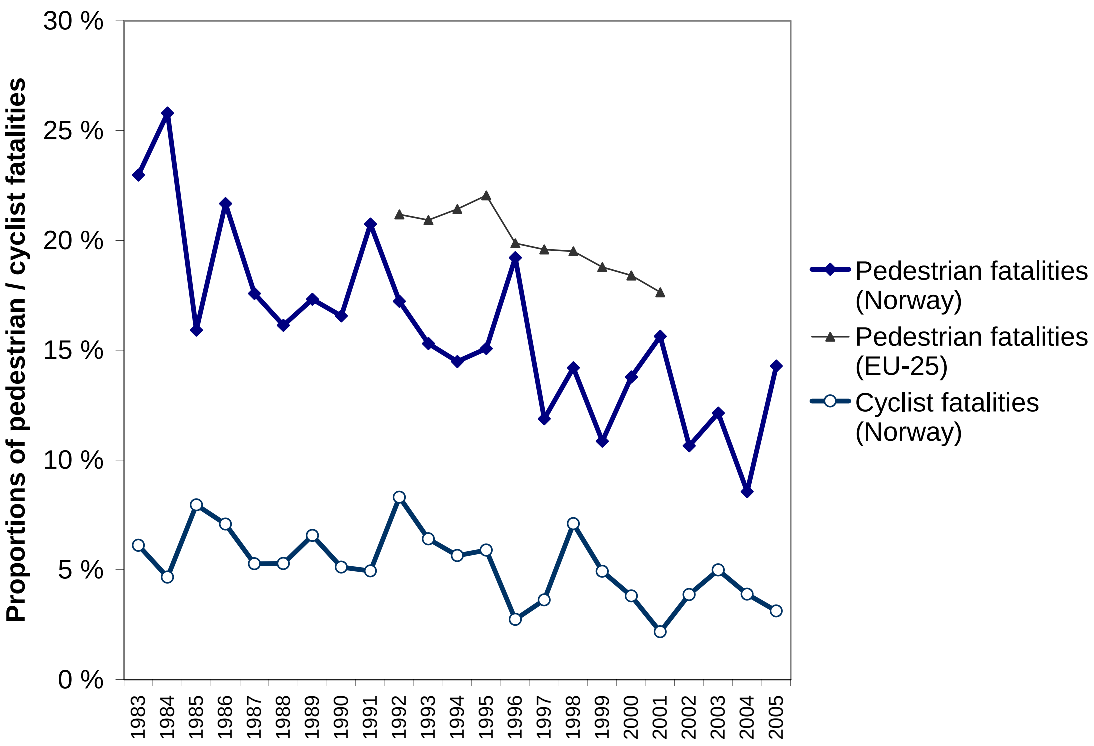

Figure 4: Proportions of pedestrian and cyclist fatalities in Norway and of pedestrian fatalities in Norway (1983-2005), and EU-25 (1992-2001; numbers of EU-25 divided by 100). Sources: SSB, EUROSTAT.

In order to compare the time trends of fatalities and proportions of pedestrian and cyclist fatalities mean annual percentage changes have been computed by fitting exponential functions to the annual numbers and percentages respectively. The results are shown in Table 2. The total number of road fatalities has decreased more in EU25 than in Norway, but both numbers and proportions of pedestrian fatalities have decreased more in Norway than in EU25. The decrease of numbers and proportions of cyclist and pedestrian fatalities in Norway are nearly the same.

Table 2: Mean annual changes in the numbers and proportions of fatalities in Norway and EU-25. Source: TØI.

	Mean annual change (%)	
	Norway (1983-2005)	**EU-25 (1992-2001)**
Total number of road fatalities	-2.0 %	-2.5 %
Number of pedestrian fatalities	-5.1 %	-4.2 %
Number of cyclist fatalities	-5.0 %	
Proportion of pedestrian fatalities	-3.0 %	-2.2 %
Proportion of cyclist fatalities	-2.9 %	

2.2 Pedestrian accident fatalities and injuries in Norway

2.2.1 Reporting in official road accident statistics

Incomplete road accident reporting means that not all reportable road accidents are actually recorded in official statistics. In Norway, accidents are not reportable if they involve pedestrians only (no vehicles involved) or if only ”inconsequential” (minor) personal injuries are sustained. The level of accident reporting in Norway has been estimated by Elvik (1998) for accidents with different counterparties. The results for accidents in which pedestrians or cyclists are counterparties are summarized in Figure 5. Only about half of all injury accidents where the heaviest party is a motor vehicle and where the counterparty is a pedestrian or a cyclist are reported. For accidents where a heavy truck is the heaviest party the level of reporting is lower if a pedestrian or a cyclist is the counterparty than for all counterparties combined. If a light vehicle is the heaviest party, the level of reporting is about the same for pedestrians, cyclists and others as counterparty. For pedestrian and cyclist accidents where no motor vehicle is involved (where a cycle or pedestrian is the heaviest party), the level of reporting is very low.

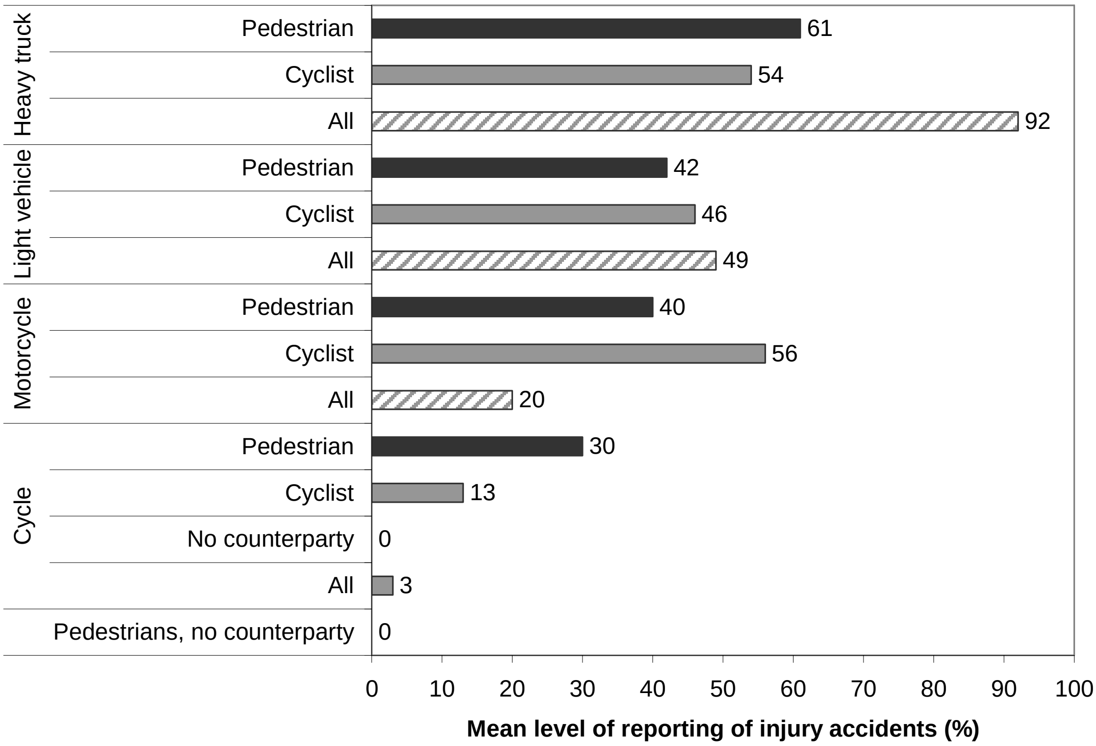

Figure 5: Mean levels of reporting of injury accidents with different counterparties in Norway; heaviest part and counterparty. Source. Elvik (1998).

In general the level of reporting is highest for fatal accidents, and lowest for slight injury accidents and for property damage only accidents (Elvik & Vaa, 2004). These estimates are based on comparisons between official accident statistics and hospital statistics. Usually, more injuries are reported in hospital statistics.

According to a more recent analysis (Bjørnskau, 2005), the level of reporting in Norway is higher than assumed in the analysis of Elvik & Mysen. In 2004, it is estimated that the injury numbers in official accident statistics must be weighted with a factor of ca. 7 – 8 (i.e. a reporting level of ca. 13-14%). The level of reporting for different severities has been estimated by Veisten et al. (2007) at 12% for slight injuries, 33% of severe injuries, and 71% of very severe injuries. The levels of reporting for pedestrian and cyclist injury accidents in 12 different countries have been estimated in a meta-analysis by Elvik & Mysen (1999, Figure 6). Norway is among the countries with the lowest levels of reporting for both pedestrian and cyclist injury accidents.

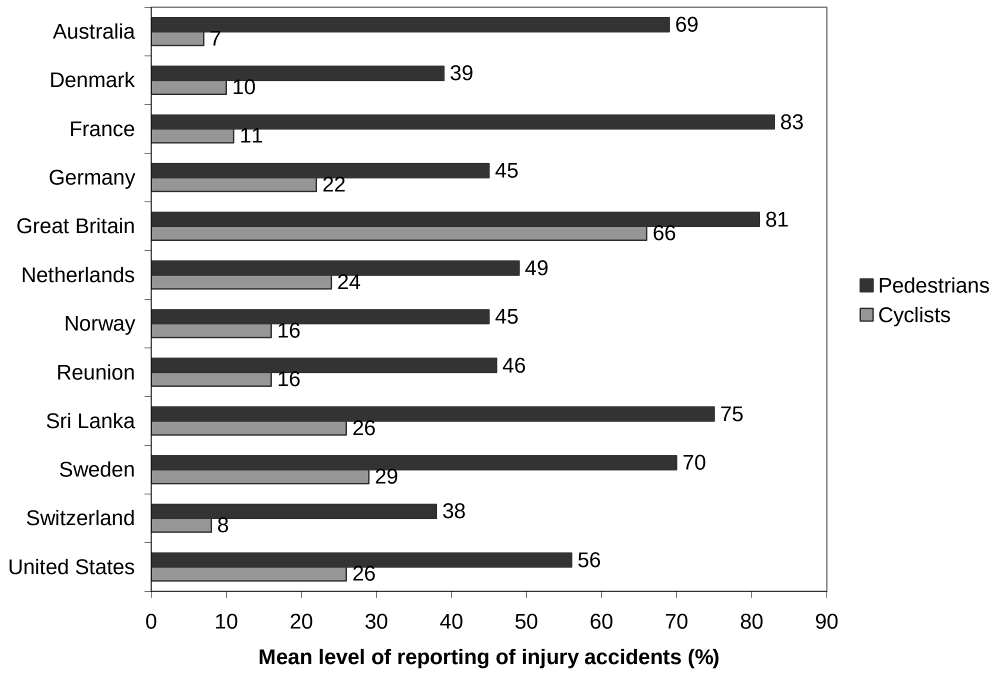

Figure 6: Mean levels of reporting of injury accidents in different countries. Source: Elvik & Mysen (1999).

2.2.2 Numbers of fatalities and injuries

The numbers of killed or seriously injured pedestrians and cyclists has been considerably reduced in the last 20 years. Numbers of killed, very seriously or seriously injured pedestrians and cyclists are shown in Figure 7 and 8, respectively, based on official accident statistics (SSB).

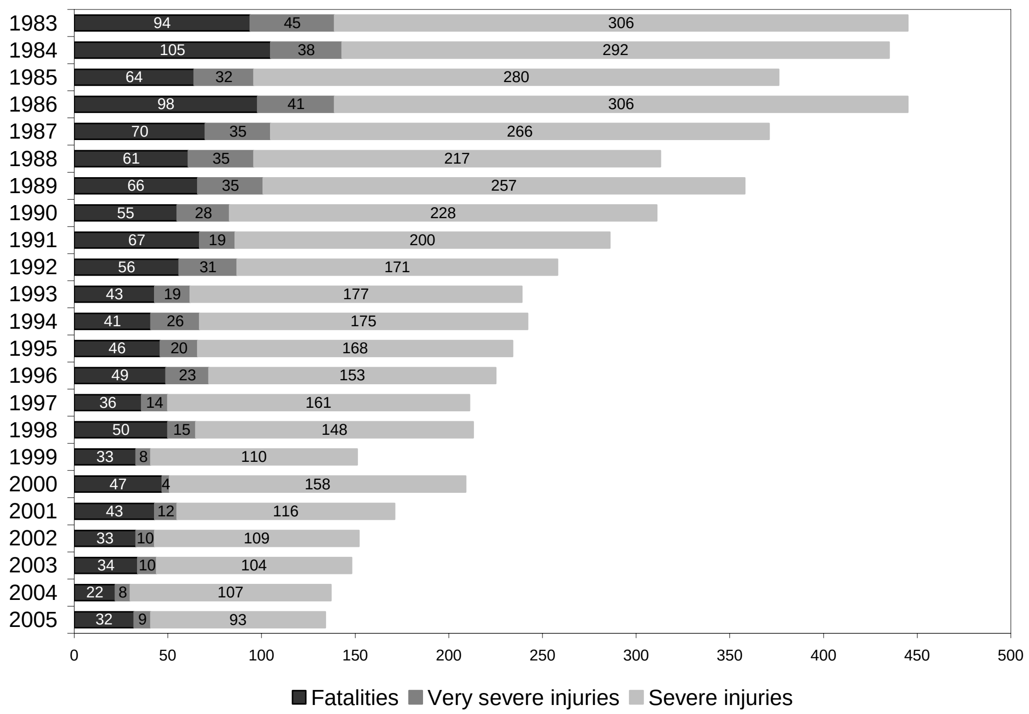

Figure 7: Annual numbers of pedestrian fatalities, very severe injuries and severe injuries in Norway . Source: SSB.

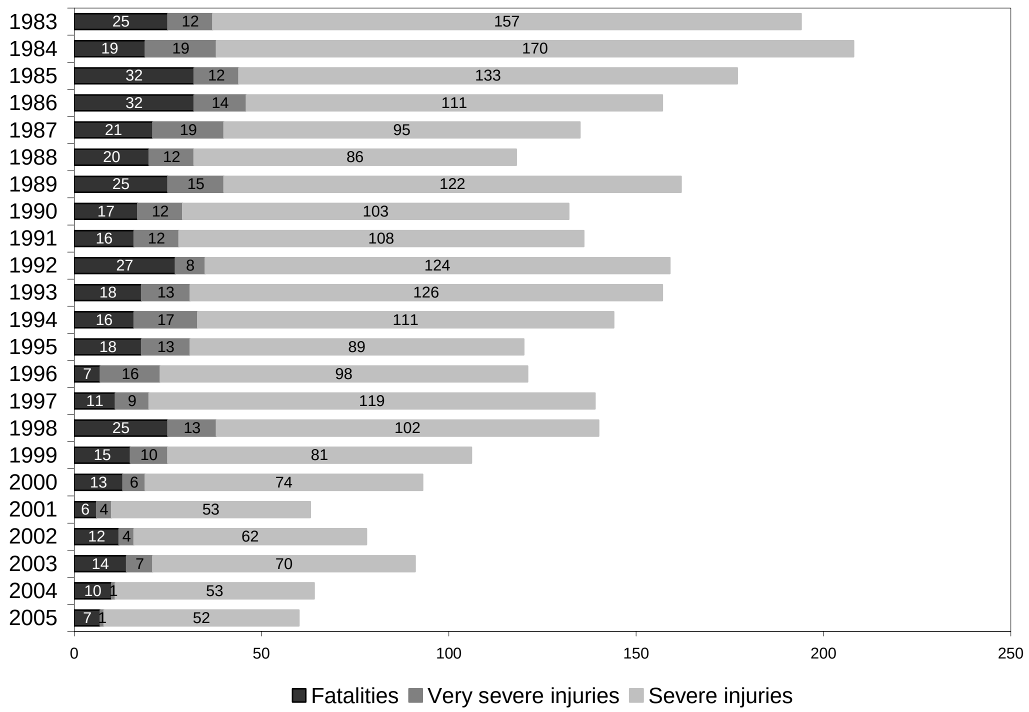

Figure 8: Annual numbers of annual cyclist fatalities, very severe injuries and severe injuries in Norway . Source: SSB.

These figures are based on official accident statistics. Due to low levels of reporting of non-fatal accidents, the numbers of very severely or severely injured pedestrians and cyclists must be assumed to be larger than shown in these figures. Veisten, Sælensminde & Hagen (2005) estimated the annual numbers of injured cyclists in the period 1996-2004 based on official accident statistics and on hospital statistics as shown in Figure 9.

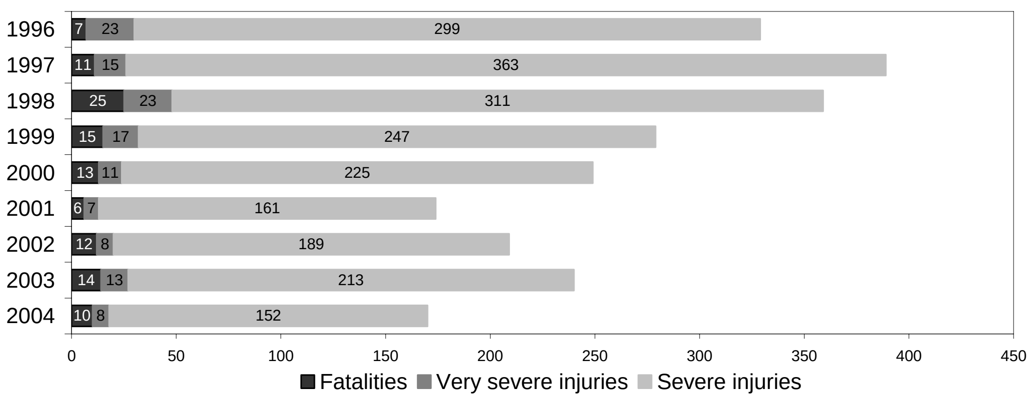

Figure 9: Annual numbers of cyclist fatalities, very severe injuries and severe injuries in Norway, adjusted based on hospital statistics . Source: Veisten et al. (2005).

The annual numbers of fatally or very severely injured pedestrians and cyclists are shown in Figure 10, together with the exponential trend functions. The mean annual decrease of the number of severely or fatally injured pedestrians is 5.9%, the mean annual decrease of the number of severely or fatally injured cyclists is 5.8%. This is slightly more than the average annual decrease of the numbers of fatally injured pedestrians and cyclists.

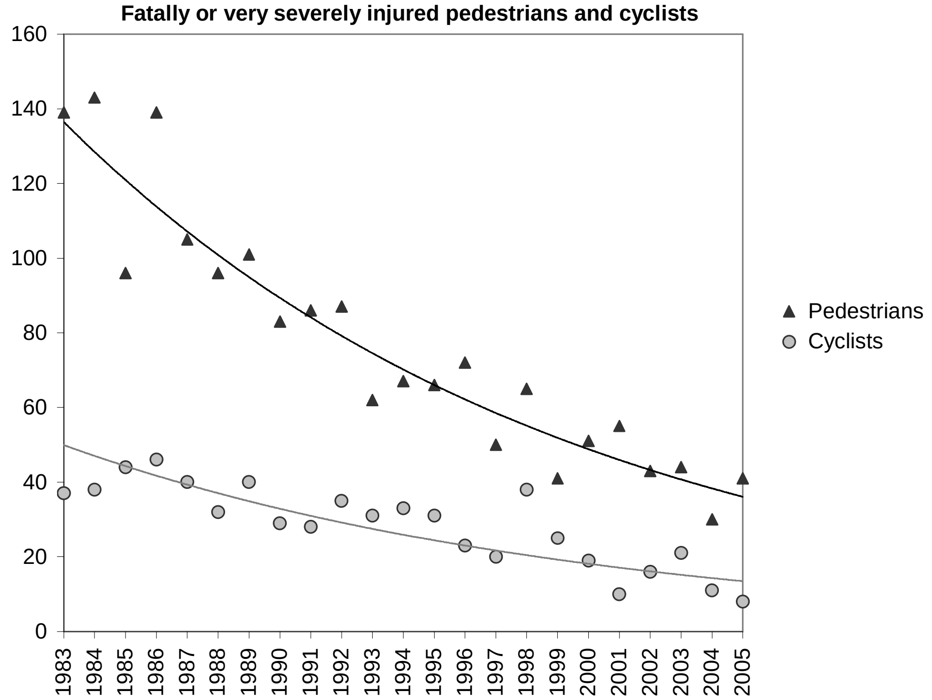

Figure 10: Annual numbers of cyclist fatalities, very severe injuries and severe injuries in Norway . Source: SSB.

Accident trends and the prediction of future numbers of accidents are discussed by Elvik (2007). Among the models for predicting total numbers of accident fatalities in Norway, an exponential trend function produces the most credible predictions of future fatality numbers. If an exponential trend function is applied to the annual numbers killed or severely injured pedestrians and cyclists in Norway, as shown in Figure 10, these numbers are not likely to decrease much further over the next years. An estimation of several scenarios of future implementation of road safety measures in Norway showed that the total number of road fatalities may decrease substantially if optimal combinations of road safety measures are implemented. However, the implementation scenario with the largest fatality reduction is the least likely to be implemented.

If all road safety measures are used optimally (Elvik 2007), the annual number of pedestrian fatalities can be reduced by about 15. The mean annual number during 2001-2005 was 33 pedestrian fatalities per year. Optimal use of road safety measures may further reduce the annual number of bicyclist fatalities by about 6. The mean annual number during 2001-2005 was 10 cyclist fatalities per year. It should be noted, however, that part of this potential reduction is attributable to vehicle-related safety measures that the Norwegian government cannot introduce on its own.

According to the study by Bjørnskau (2005) the decrease in the annual numbers of injuries is strongest for children and adolescents, and stronger for women than for men.

2.2.3 Fatality risk

Changes in total numbers of fatalities say little about changes in risk. The annual numbers of pedestrian fatalities and fatality risk for pedestrians in Norway are shown in Table 3. The numbers of pedestrian fatalities is based on official accident statistics (SSB). Exposure (million person-km per year) is estimated from the National Travel Surveys 1979, 1985, 1992, 1998, 2001, and 2005. The survey results from 1979 trough 2001 are adjusted values (Elvik, 2005). The survey result from 2005 is based on Vågane (2006). For computation of risk, exposure values for the years between the survey years are interpolated linearly. Although the fatality risk for pedestrians and cyclists seems to be decreasing over time, it is on average ca. 10 times as large as the fatality risk per million person-km of travel by car (which is between 0.002 and 0.006 in the years 1983-2005, and also decreasing over time).

Table 3: Pedestrian fatalities, exposure, and fatality risk in Norway. Sources: SSB, Elvik (2005), Vågane (2005).

	Exposure (mill. person-km)		Fatalities		Fatality risk	
	Walking	**Cycling**	**Pedestrians**	**Cyclists**	**Pedestrians**	**Cyclists**
1983			94	25	0.062	0.043
1984			105	19	0.066	0.034
1985	1,658	534	64	32	0.039	0.060
1986			98	32	0.061	0.057
1987			70	21	0.045	0.035
1988			61	20	0.041	0.032
1989			66	25	0.046	0.038
1990			55	17	0.040	0.025
1991			67	16	0.051	0.022
1992	1,248	755	56	27	0.045	0.036
1993			43	18	0.034	0.024
1994			41	16	0.032	0.022
1995			46	18	0.035	0.026
1996			49	7	0.037	0.010
1997			36	11	0.027	0.016
1998	1,357	666	50	25	0.037	0.038
1999			33	15	0.025	0.023
2000			47	13	0.035	0.021
2001	1,319	592	43	6	0.033	0.010
2002			33	12	0.023	0.019
2003			34	14	0.022	0.021
2004			22	10	0.013	0.014
2005	1,832	760	32	7	0.018	0.009

3. Factors influencing the number and severity of pedestrian accidents

This chapter gives an overview of risk factors that affect the probability or the severity of pedestrian and cyclist accidents. The first section summarizes risk factors that are represented in Norwegian accident statistics, then research results concerning several risk factors are summarized. Some of these factors can be directly addressed by safety measures (see Chapter 4).

3.1 Norwegian accident statistics

Relationships between the numbers of fatal, very severe and severe pedestrian and cyclist injuries and several risk factors have been investigated based on Norwegian accident statistics. The analysis focuses on the most severe injuries, not only because these are most in the focus of accident prevention strategies, but also because of the low reporting level of less severe injuries. Detailed results can be found in the appendix.

The routines for registration of accident data were changed in 2001. This lead to increased proportions of “unknown” for several variables. Some risk factors have not been recorded after 2001, therefore some of the analyses that are presented in the following sections are restricted to the period 1983 until 1999.

All results refer to numbers of injuries, and partly to proportions of fatalities, not to accident or injury risk.

3.1.1 Urban vs. non-urban areas

Most severe injuries occurred in urban areas until around 2000, which is comparable to most European countries where the proportion of fatally injured pedestrians in urban areas is around 60-70%. From the year 2000 there was a shift towards more severe injuries in non-urban areas. This has been found for both pedestrians and cyclists. A possible explanation is the larger proportion of “unknown” injury severity after the year 2000 in non-urban areas.

The proportion of fatal and very severe / severe injuries is declining over time for both pedestrians and cyclists. This proportion is higher in non-urban than in urban areas. For cyclist accidents it represents over 90% of all injuries. Two likely explanations are higher speed of motor vehicles outside urban areas, and lower probability for slight injuries of being reported outside urban areas (e.g. because of the absence of witnesses) than in urban areas. The latter seems especially relevant for cyclist accidents, it is highly unlikely that 90% of all injuries are serious or fatal.

3.1.2 Road conditions

Most severe injuries occur on dry roads. This proportion is larger for cyclists than for pedestrians. The most likely explanation is that roads are most often dry and free from snow or ice, and that road users without roof over their heads prefer dry weather, especially cyclists. The proportions of fatally injured pedestrians and cyclists is not different between dry roads and not dry roads (wet, snowy/icy, partly snowy/icy, slippery else).

3.1.3 Light conditions

About half of all severe pedestrian injuries occur in daylight. Exposure is likely to be much higher in daylight than in the dark, injury risk can therefore be assumed to be larger at night than in daylight. For cyclists the proportion of daylight injuries is much larger than for pedestrians. This may reflect exposure to a larger degree than risk, i.e. the difference in injury risk seems smaller for cyclists than for pedestrians, although this can not be confirmed or numerically estimated because of the lack of exposure data for daylight and dark.

3.1.4 Collision partner

The numbers of fatally injured pedestrians per accident is larger than the numbers of killed cyclists per accident in almost all types of collision. Only collisions with a pedestrian and non-collisions (single accidents) are more fatal for cyclists than for pedestrians.

3.1.5 Direction of impact

The direction of impact is expressed as 1 through 12 o'clock. A 12 o'clock impact is a collision where the pedestrian / cyclist is hit by the front part of the vehicle, in 3 o'clock collision the pedestrian or cyclist is hit by the right side of the vehicle. Most impacts are 12 o'clock. Because of the small numbers of severe injuries at each of the impact directions except at 12 o'clock a comparison of injury severity is made based on all injury severities. There are small differences between the proportions of severe injuries at different impact directions, but the proportion of fatally, very severely or severely injured cyclists in 6 o'clock impacts seems to be somewhat lower than for other directions. In 6 o'clock impacts a cyclist is hit by the rear of a car, i.e. where the car is reversing and hitting the cyclist, or the cyclist is hitting the car.

3.1.6 Reflective materials for pedestrians

Between 95% and 99% of all severely injures pedestrians did not use reflectors. The proportion of severe injuries is larger among pedestrians not using reflectors than among pedestrians using reflectors. Implications of these results for injury risk are discussed in Chapter 4.

3.1.7 Bicycle helmets

The proportion of severely injured cyclists wearing helmets has increased in the last 20 years, from near zero to ca. 30% in the last five years. The proportion of severe injuries is somewhat larger among cyclists not using a helmet compared to cyclists with helmets. Implications of these results for injury risk are discussed in Chapter 4.

3.1.8 Alcohol or drugs involved

The proportions of severely injured pedestrians and cyclists where there is suspicion of the presence of alcohol or drugs (driving under influence, DUI, although this term is not quite correct for pedestrians who are not driving) seems to be quite constant over time, but the last 5 years of data are missing. The proportion of fatal, very severe and severe injuries (in relation to all injury severities, including slight injuries) with suspicion of DUI is greater among pedestrians than among cyclists. The assessment of DUI is however not very reliable.

3.1.9 Days of the week

The total numbers of severe injuries is constant Monday through Friday and somewhat lower in weekends.

3.1.10 Temperature

The largest numbers of pedestrian and cyclist accidents occur, not surprisingly, at higher temperatures. Whether or not injury severity is different at different temperatures is not quite clear. The proportion of fatal injuries (relative to all fatal, very severe or severe injuries) is higher at lower temperatures. The proportion of all severe injuries (fatal, very severe, severe; relative to all injuries, including slight injuries) seems to be largest for the highest and lowest temperatures. Many possible explanations for an U-shaped relationship are possible (e.g. reporting, behavioural adaptation, direct influence of temperature on severity, …), but all of them are speculative.

3.1.11 Age

The proportions of 15-64 old severely injured is about identical for pedestrians and cyclists. Among pedestrians there are more seriously injured among those above 64 years old than among cyclists. Among cyclists there are more seriously injured among those below 15 years old. This may reflect differences in both risk and exposure.

3.1.12 Speed limit

The proportions of severely injured pedestrians at different speed limits are similar to those of cyclists. Injuries are more severe at higher speed limits.

3.2 Exposure to risk

The effect of exposure (million kilometres of travel) on total numbers of fatalities and injures and on the proportion of fatally or severely injured road users in Norway has been investigated by Elvik (2005). Exposure data are available only for 5 years in the period 1979-2001, exposure in the years in between has been interpolated linearly. Poisson regression models were estimated with the following predictor variables: Numbers of person kilometres of travel (total, pedestrians and cyclists, heavy vehicles, novice drivers, motorways), number of new cars registered, seat belt wearing rate for drivers, fixed penalties per mill. vehicle kilometres as an indicator of enforcement intensity, and annual trend. By far the largest and most significant predictor for fatalities, injuries, and severity rate was annual trend. Pedestrian and cyclist exposure contributed significantly to the annual total numbers of fatalities, but not to the annual numbers of injuries or to the proportion of fatally or severely injured road users. This analysis focused not specifically on killed or injured pedestrian or cyclists but on all killed or injured road users. It is however unlikely that pedestrian or cyclist exposure contributes significantly to the number of fatally injured motor vehicle occupants.

A number of studies that have investigated the relationship between volumes and accident risk among pedestrians and cyclists have found decreasing accident risk at increasing volumes. A British study (Franklin, 2002) found less dangerous behaviour and lower accident risk when cyclists are cycling on roads then when they cycle on separate cycle lanes. A Finnish study found the same result when cycling on two way cycle paths was compared with cycling on roads (Pasanen, 2000). In a Swedish study (Jonsson, 2005) increasing exposure of pedestrians and cyclists was related to decreasing accident risk.

3.3 Motor vehicle volumes

The effect of motor vehicle volume on injury accidents has been investigated in Norway by Fridstrøm & Ingebrigtsen (1996). According to the model an increase of motor vehicle volume by 1% leads to an increase in the numbers of pedestrian and cyclist injuries of about 1.1%. The total number of injury accidents increases by about 1%.

Brüde and Larsson (1993) have estimated functions for the prediction of the numbers of pedestrian and cyclist accidents with motor vehicle volume and volumes of pedestrians and cyclists respectively as independent variables. The functions are as follows:

- Number of pedestrian accidents = 0.0000734 x $MV^{0.50}$ x $PED^{0.72}$
- Number of bicycle accidents = 0.0000180 x $MV^{0.52}$ x $CYC^{0.65}$

MV is the number of motor vehicles (AADT = annual average daily traffic), PED is pedestrian volume, and CYC is cyclist volume. According to this function an increase in motor vehicle volume of 1% leads to an increase in the number of pedestrian and cyclist accidents of 0.5%. An increase in pedestrian volume of 1% leads to an increase of the number of pedestrian accidents of 0.7% and an increase in the number of cyclists leads to an increase in the number of cyclist accidents of 0.6%. Consequently, for each individual pedestrian or cyclist, accident risk decreases as pedestrian or cyclist volume increase, respectively. Possible explanations are increased attention and lower speed at higher traffic volumes, and improved interactions between road users (Elvik & Vaa, 2004, Jonsson, 2005).

3.4 Type of collision: Collision partner and impact direction

Most fatally injured pedestrians and cyclists are killed in collisions with motor vehicles, mostly with cars. The proportions of different collision partners for injured pedestrians in Germany and for injured pedestrians and cyclists in Norway are shown in Table 4. Collisions with trucks are far more often fatal than collisions with other motor vehicles. Collisions with cyclists are less often fatal than other collisions.

Table 4: Collision partners in accidents where pedestrians / cyclists are injured. (Germany: Kühn et al., 2006; Norway: SSB).

	Pedestrians (Germany)		Pedestrians (Norway)		Cyclists (Norway)	
Collision partner	**Fatally injured**	**All injured**	**Fatally injured**	**All injured**	**Fatally injured**	**All injured**
Car	72 %	76 %	79 %	86 %	83 %	89 %
Truck	17 %	6 %	11 %	3 %	11 %	3 %
Motorcycle	3 %	3 %	1 %	2 %	1 %	2 %
Bus	2 %	2 %	4 %	4 %	1 %	1 %
Cycle	2 %	11 %	1 %	2 %	2 %	4 %
Other vehicle	4 %	2 %	4 %	3 %	2 %	1 %

The majority of collisions between a motor vehicle and a pedestrian are collision where a the front of a car hits a pedestrian on the side (Norwegian accident statistics, see section 3.1.4; Kühn et al., 2006). In Norway, the proportions of impacts on the left and on the right side of the vehicle are about equal, in Germany (Kühn et al., 2006, based on a larger number of accidents) the proportion of impacts on the right side of the vehicle is about twice that of the left side.

Being rolled over by the car is one of the more rare causes of injuries, but head injuries sustained from being rolled over are by far more often fatal than from all other types of contact with the vehicle (Kühn et al., 2006).

3.5 Impact speed

The severity of injuries pedestrians and cyclists sustain in collisions with motor vehicles is higher at higher impact speeds. According to a German study (Kühn et al., 2006), 82% of all pedestrian accidents occur at speeds below 40 km/t. Pedestrians sustain severe injuries in ca. 62% of all collisions below 40km/t.

The relationship between impact velocity for the cumulative percentages of severely and fatally injured pedestrians in collisions with motor vehicles has been estimated in a number of studies (Anderson et al., 1997; Brandberg, Johansson & Gustafsson, 1998; Kühn et al., 2006; Mizuno, 2003). Based on these studies, the relationship between impact speed and the proportion of injured pedestrians is approximated in Figure 11.

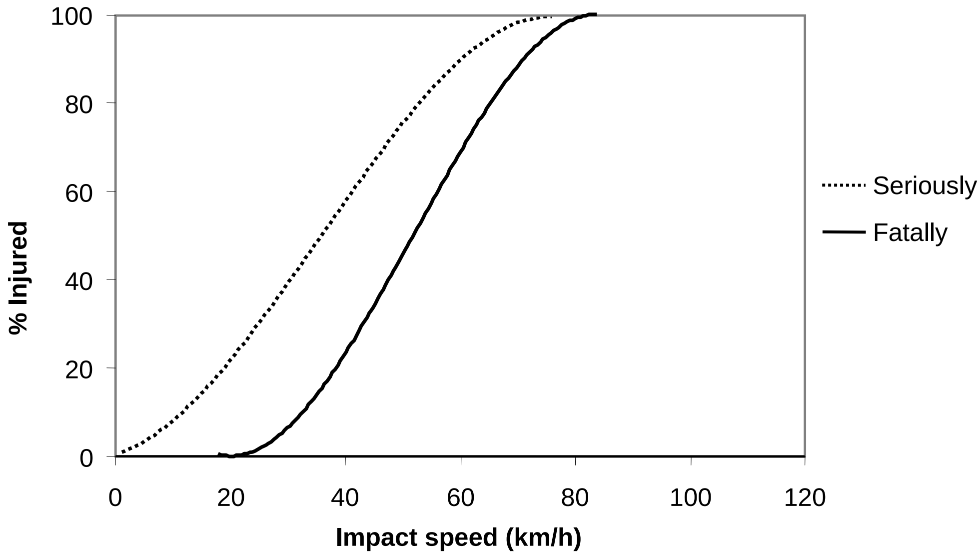

Figure 11: Fatally and seriously injured pedestrians in collisions with motor vehicles (cumulative %): Source: TØI.

3.6 Vehicle configuration

The configuration of vehicles can affect the severity of injuries pedestrians sustain from contact with the vehicle in a collision. Most injuries, and the most severe injuries are caused by the bumper, followed by the engine bonnet and the windscreen. The number of severe injuries caused by the engine bonnet has been decreasing during the last 20 years. The a-pillar, the roof and other parts of the car are only occasionally causing injuries. Body parts that are injured in collisions with vehicles are mostly the head and legs (ca. 33% each), followed by chest (10%), arms (8%), and pelvis (6%) (Kühn et al., 2006).

Motor vehicle - pedestrian collisions can have up to 4 phases:

- the primary impact which is the first pedestrian-vehicle contact,
- the flight phase if the pedestrian is thrown through the air,
- the secondary impact when the pedestrian hits the ground and possibly slides over the ground, and
- the tertiary impact if a vehicle additionally rolls over the pedestrian (this may be a different than the one in the primary impact) or if the pedestrian is thrown against some object (e.g. another vehicle, a curb, or a light pole).

Vehicle properties that can affect the severity of pedestrian and cyclist injuries include height, form, and elasticity of bumpers, engine bonnet, and windscreen. Injuries sustained in the primary collision are mainly affected by the local stiffness (not by the overall stiffness of the vehicle) and form of parts of the vehicle front. The injured body parts are additionally dependent on the height of the pedestrian. A high bumper may for example cause a leg injury when the pedestrian is a high adult, and a head injury is the pedestrian is a child. The form of the vehicle front, in combination with the height of the pedestrian, determine to a large degree where and at what angle the head of the pedestrian hits the car. This may be crucial for the severity of the injuries.

The flight phase is affected by the form and the overall stiffness of the vehicle front, in combination with the height of the pedestrian. The most important factor that determines the throwing range however is the speed of the vehicle.

Injuries sustained from direct contact with the vehicle are far more dependent on impact speed than injuries that are sustained when the pedestrian is thrown through the air.

The probability of collisions with pedestrians might be reduced by active safety systems that integrate automatic pedestrian detection and a brake assist strategy (Fröming, Kühn & Schindler, 2006). However, such systems are currently not widely available.

Injuries that vehicles inflict on pedestrians in collisions are tested in the EuroNCAP programme. More EuroNCAP stars for pedestrian safety can be assumed to result in less severe pedestrian injuries in collisions between a motor vehicle and a pedestrian. There are to date no tests of pedestrian safety that are obligatory for registration of motor vehicles.

3.7 Road layout

Studies of safety effects of infrastructure measures (e.g. cycle paths, crossing facilities) often find that the number of cycle accidents is lower when cyclists are visibly integrated in the traffic environment. According to Bjørnskau (2005) many collisions between cyclists and motor vehicles happen because the cyclist and driver have not seen each other, or because the behaviour of cyclists has been unpredictable for the motor vehicle driver. Attention and predictable behaviour might be enhanced by a road layout that makes pedestrians and cyclists visible by integrating them in the traffic environment, and that supports clear behaviour patterns for both cyclists and drivers. Increased numbers of pedestrians and cyclists are also likely to increase the attention motor vehicle drivers.

3.8 Road conditions

Road conditions (holes in the asphalt, slippery roads, high curbs etc.) contribute especially to single accidents of pedestrians and cyclists. Single accidents of cyclists have to be reported to the police but it is quite unusual that they are reported. It is therefore hardly possible to estimate effects of road conditions on single accidents based on accident statistics.

3.9 Other factors

Accident and injury risk are higher for older pedestrians. According to Zegeer et al. (2005) the accident risk for pedestrians at pedestrian crossings is higher for older pedestrians.

A Norwegian study of cyclist accidents and injuries (Bjørnskau, 2005) found higher accident risk for

- men than for women,
- adolescents than for children or medium-aged adults,

- cyclists that do not have a driving licence for motor cycle or moped,
- cyclists that have new and expensive cycles than for cyclists that have old and cheap cycles,
- cyclists cycling fast, easily getting angry, and engaging in cycling races.

According to the analysis of Kühn et al. (2006) the accident risk for pedestrians in the dark is six times higher when they wear dark clothes than when they wear light clothes. In daylight the colour of the clothes has no influence on the probability of an accident.

The walking speed of pedestrians also may affect the probability of an accident. According to Kühn et al. (2006) about a quarter of pedestrians who are hit by the front of a car have been running immediately before the collision. Usually most pedestrians are walking, not running, it is therefore likely that accident risk for running pedestrians is higher than for those walking.

3.10 Road safety measures not aiming at reducing pedestrian or cyclist accidents and injuries

A number of road safety measures in recent years can be assumed to have contributed to the decrease in the numbers of fatalities and severe injuries in Norway (Elvik, 2005). Most of these measures can not be assumed to have contributed to the decrease in the numbers of pedestrian or cyclist fatalities (e.g. increased seat-belt enforcement). Measures aiming at reducing speed may have contributed to some extent to a decrease in pedestrian and cyclist fatalities: Lowered speed limits on hazardous road sections from 80 to 70 km/h, and installation of speed cameras.

4. Measures to reduce the probability and severity of pedestrian and bicycle accidents

The probability or severity of accidents can be reduced by measures which achieve at least one of the following effects:

- reduced speed of motor vehicles,
- reduced total number of motor vehicles,
- reduced number of motor vehicles the pedestrian has to attend to when crossing a road (e.g. by installing medians),
- reduced road width,
- give right of way to pedestrians,
- vehicle active and passive safety,
- pedestrian / cyclist measures (e.g. visibility aids, personal protection equipment, infrastructure design).

4.1 Infrastructure measures

4.1.1 Safe crossing facilities

More than half of all fatalities (54%) and very severe / severe injuries (60%) in pedestrian accidents occur when a pedestrian is crossing a road. Most of the remaining fatalities (43%) and very severe / severe injuries (32%) occur when a pedestrian is walking alongside the road. Ca 2% of all fatally injured and 4% of all very severely / severely injures pedestrians are injured while they are on the sidewalk. Children playing on a road are 1% of all fatally injured and 4% of all severely / very severely injured pedestrians. The distribution of fatal and non-fatal severe injuries suggests that the severity of accidents with pedestrians crossing roads is lower than in accidents where a pedestrian is walking alongside a road. A possible explanation is that many pedestrians cross roads at junctions, where vehicle speeds are lower.

Marked crosswalks

Marked crosswalks do not always reduce pedestrian accidents. In a review of studies from between 1965 and 1996 (Elvik et al., 1997) the summarized effects on accidents are a significant increase of pedestrian accidents of 28%, and a significant increase of motor vehicle accidents of 20%. There was no difference between crosswalks in intersections and on midblock sections. The increase of the number of motor vehicle accidents is likely to be due to increased rear-end collisions. Possible explanations for increased accident risk at marked cross-walks is exaggerated confidence of pedestrians in drivers of motor vehicles. Drivers may not be aware of the presence of a cross walk or they may for different reasons not give way to pedestrians. Studies in Norway showed that only 50% of all motor vehicles give way for pedestrians at pedestrian crossings (Sakshaug, 1997). Ekman & Hyden (1999) also found higher crash rates in intersections with marked crosswalks compared to intersections without crosswalks in three Swedish cities. Conflict rates were about twice as high in intersections with marked crosswalks. These relationships were found for intersections with more than 10 vehicles per hour. A possible weakness of these studies is that they have not controlled for selection effects, time trends and other differences between the locations of marked and unmarked crosswalks.

Zegeer et al. (2005) conducted a study which is based on a large number of accidents and that has controlled for many other factors like traffic volume and road characteristics by using Negative binomial regression models. The results of the study can be summarized as follows:

- Accident numbers and accident severity are not different between marked and unmarked crosswalks on two-lane roads, independent of traffic volume. This applies independently of daylight conditions.
- On multi-lane roads, accident numbers increase with increasing volume of motorized traffic on marked, but not on unmarked crosswalks. The difference between marked and unmarked crosswalks is significant from traffic volumes of 12,000 on multi-lane roads without a median, and from traffic volumes of 15,000 on multi-lane roads with a median. Increasing pedestrian traffic volumes on marked crosswalks leads to reduced numbers of accidents. Accident severity increases on marked compared to unmarked crosswalks on multi-lane roads.
- Accident numbers are independent of speed limits, but accidents are more severe at higher speed limits.
- Accident numbers are lower in the presence of a raised median or a raised crossing island. This result conforms to other studies of effects of cross-section on the number of accidents (Erke, 2006).
- There were no differences between effects of marked crosswalks on accidents between midblock and intersection accidents.
- “Multiple-threat” crashes (pedestrian crosses before waiting vehicle and hit by second vehicle coming from behind the waiting vehicle) occurred only at marked crosswalks (17% of all accidents at marked crosswalks), not at unmarked crosswalks.
- Pedestrians above 65 years are generally overrepresented accidents. Accident risk for pedestrians above 65 is higher on marked than on unmarked crosswalks.
- Raised medians decreased numbers of pedestrian accidents on marked crosswalks.

A study with behaviour observations (Knoblauch, Nitzburg & Seifert, 2001) found slightly improved pedestrian behaviour and reduced vehicle speeds after installation of marked crosswalks. This seems to contradict the explanation of behavioural adaptation that is usually given for the adverse safety effects of marked crosswalks (Zegeer et al., 2005).

Other crossing facilities for pedestrians

Effects on accidents of different crossing facilities for pedestrians have been summarized by Erke & Elvik (2006). The results are shown in Table 5.

Table 5: Effects on injury accidents of crossing facilities for pedestrians. (Source: Erke & Elvik, 2006).

	Effect on number of injury accidents (%)		
	Accident type	**Best estimate**	**95% confidence interval**
Grade separated crossing facilities (bridge, tunnel)	Pedestrian accidents	-82	(-90; -69)
	Motor vehicle accidents	-9	(-29; +15)
	All accidents	-30	(-44; -13)
Signalized pedestrian crossing	Pedestrian accidents	-12	(-18; -4)
	Motor vehicle accidents	-2	(-9; +5)
	All accidents	-7	(-12; -2)
Refuge (median) in pedestrian crossing	Pedestrian accidents	-18	(-30; -3)
	Motor vehicle accidents	-9	(-20; +3)
	All accidents	-13	(-21; -3)
Raised pedestrian crossing	Pedestrian accidents	-49	(-75; +3)
	Motor vehicle accidents	-33	(-58; +6)
	All accidents	-39	(-58; -10)

The crossing facility that is most effective in reducing pedestrian accidents is a grade separated crossing (tunnel or bridge). Signalized pedestrian crossings, median barriers at pedestrian crossings, and raised pedestrian crossings also reduce the number of pedestrian accidents. The number of motor vehicle accidents is also reduced, although the effects are smaller and not statistically significant. These results are however likely to be affects by publication bias and methodological weaknesses, e.g. lack of control for time trends and regression to the mean.

Delays, crossing times, behaviour and conflicts between pedestrians and motor vehicles at different types of unsignalized pedestrian crossings have been investigated by Fitzpatrick et al. (2006). Most pedestrian crossings in this study were on urban roads with large traffic volumes. Observations showed that almost all (94%) pedestrians looked in both directions before crossing. Delays for pedestrians at pedestrian crossings are correlated with risk taking behaviour. Motorist compliance was equally high only at pedestrian crossings with red signal or beacon devices (95% of all motorists gave way to pedestrians). At other crossing devices compliance ranged from 17% to 87% but with no clear differences between different types of crossing devices. The authors conclude that there are other factors which affected compliance rates. On two-lane roads the compliance was over 75% at all except one of the devices. On four-lane roads there was large variety in the compliance rates, and red light devices were most effective. Compliance of motorists seemed to be greater at larger pedestrian volumes. With respect to effectiveness and safety the authors conclude that a combination of crossing treatments is likely to be most effective. Crossing treatment include: Median refuge islands, advanced yield lines, curb extensions with parking restrictions, overhead flashing beacons, high-visibility motorist and pedestrian signs.

Curbed central islands at intersections can also be associated with larger numbers of pedestrian accidents, when they provoke more pedestrian crossings on roads where pedestrians otherwise would not cross (many lanes, high motor vehicle volumes; Summersgill et al., 2001).

Crossing facilities for cyclists

Effects on accidents of different crossing facilities for cyclists have been summarized by Erke & Elvik (2006). The results are shown in Table 6.

Table 6: Effects on injury accidents of crossing facilities for cyclists. (Source: Erke & Elvik, 2006).

	Effect on number of injury accidents (%)		
	Accident type	**Best estimate**	**95% confidence interval**
Bicycle lanes (road markings)	Bicycle accidents (straight section)	-25	(-44; 0)
	Bicycle accidents (intersection)	-26	(-36; -14)
	Pedestrian accidents	-30	(-42; -16)
	Motor vehicle accidents	-39	(-44; -33)
	All accidents	-35	(-40; -30)
Advance stop line for cyclists in signalised junctions	Bicycle accidents	-27	(-61; +36)
	Motor vehicle accidents	-66	(-88; -5)
	All accidents	-40	(-65; +1)

Bicycle lanes reduce most types of accidents, but the effect on bicycle accidents on straight sections is not statistically significant. The reduction of pedestrian accidents is likely to be due to reduced conflicts between cyclists using sidewalks and pedestrians.

4.1.2 Sidewalks and cycle paths

Effects on accidents of sidewalks, cycle paths, and combined sidewalks and cycle paths have been summarized by Erke & Elvik (2006). The results are shown in Table 7.

Table 7: Effects on injury accidents of sidewalks and bicycle paths. (Source: Erke & Elvik, 2006).

	Effect on number of injury accidents (%)		
	Accident type	Best estimate	95% confidence interval
Path for walking and cycling	Pedestrian accidents	-10	(-32; +22)
	Bicycle accidents	+1	(-29; +45)
	Motor vehicle accidents	+1	(-10; +14)
	All accidents	0	(-11; +11)
Sidewalk	Pedestrian accidents	-5	(-26; +22)
	Bicycle accidents	-30	(-36; -22)
	Motor vehicle accidents	+16	(+6; +27)
	All accidents	-7	(-13; -1)
Bicycle path	Pedestrian accidents	-5	(-12; +3)
	Bicycle accidents	-2	(-7; +4)
	Motor vehicle accidents	-5	(-9; -2)
	All accidents	-4	(-7; -2)

All three measures decrease the numbers of pedestrian and cyclist accidents, but the effects are small and not statistically significant. Bicycle accidents are reduced only by the installation of sidewalks, not by bicycle paths.

Possible explanations for the small and non-significant effect are increased numbers of pedestrians and cyclists, and increased speed of motor vehicles (speed limits were often increased when sidewalks are built).

4.1.3 Road layout, integration of pedestrians and cyclists in the traffic environment

The integration of pedestrians and cyclists in the traffic environment affects accident risk for these road users. A separation from motorized traffic reduces the attention of motor vehicle drivers for cyclists and pedestrians. Consequently they are more likely to overlook cyclists and pedestrians (Räsänen og Summala, 1998). A study from England (Franklin, 2002) found less adequate cycling behaviour among cyclists cycling separated from motorized traffic and reduced accident risk among cyclists cycling on the road instead of on cycle lanes or paths. In Helsinki accident risk for cyclists is lower on roads than on two-way cycle paths beside the road (Pasanen, 2000). These findings suggest that even if separate cycle paths or lanes may reduce the numbers of potential conflict points they have effects on traffic behaviour that is detrimental for safety.

4.1.4 Winter maintenance

Accident risk for pedestrians increases in winter and on icy or snowy roads. The relative risk of injuries in falling accidents in different road conditions is shown in Figure 12 according to a study by Öberg et al. (1996). The increase in risk is greatest for pedestrians, but risk tends to increase for cyclists as well. Injury risk for pedestrians increases even more for older pedestrians. In addition to increased number of injuries in falling accidents it is possible that also the numbers of collisions between motor vehicles and pedestrians increase because of pedestrians walking in driving lanes where the sidewalk is too slippery or blocked by snow (Elvik, 2000).

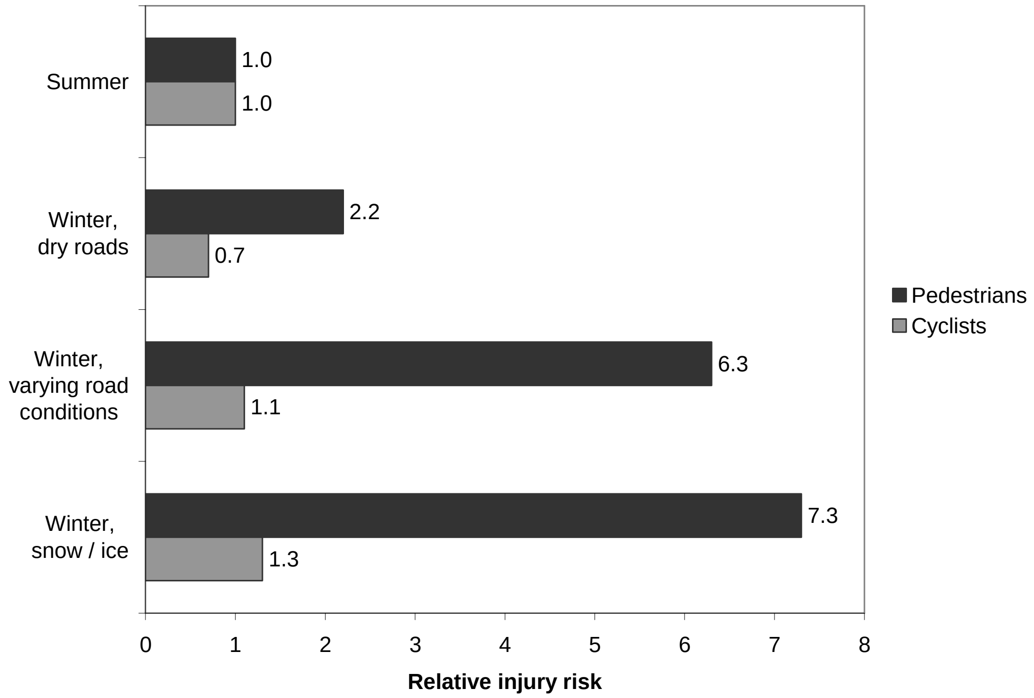

Figure 12. Relative injury risk for pedestrians and cyclists in different winter conditions (injury risk in summer = 1). (Source: Öberg, 1996).

A Swedish study of effects of increased winter maintenance (Möller, Wallman & Gregersen, 1991) found increased numbers of falling accidents. The most likely explanation is that maintenance failed to reduce the slipperiness of the roads. Potential effects of reducing the amount of walking that takes place on icy or snowy roads have been estimated by Elvik (2000). The results are shown in Table 8. It is however not clear how large reductions of walking on slippery roads can be achieved. The most effective measure is warming up of sidewalks. Clearing roads of snow or spreading sand seem to be less effective. Improved road conditions may also fail to reduce accident numbers because of behavioural adaptation (e.g. increase the amount of walking), but they can nevertheless be assumed to improve mobility.

Table 8: Effects of reduced walking on icy or snowy roads (estimated potential effects). Source: Elvik (2000).

	Effect on number of injury accidents (%)		
	Accident type	**Best estimate**	**95% confidence interval**
Reduction of walking on icy or snowy roads by 10%	Falling accidents	-15	(-22; -7)
Reduction of walking on icy or snowy roads by 100%	Falling accidents	-52	(-62; -39)

4.1.5 Speed reduction for motor vehicles

Speed is one of the factors that has the largest influence on the probability and severity of pedestrian accidents. Speed reduction in areas which are used by motorized and non-motorized road users is therefore generally an adequate measure to increase safety for pedestrians and cyclists. There are two different approaches to reducing the speed of motor vehicles in areas used by motor vehicles and pedestrians or cyclists:

- Speed reducing measures for motor vehicles.
- Separation of high-speed motor vehicle traffic and pedestrian and cyclist traffic.

Speed reducing measures for motor vehicles include reductions of speed limits, speed enforcement, or physical speed reducing measures like road narrowing, roundabouts, chicanes, or road humps. Combinations of such measures are usually most effective in reducing speed.

Separation between motor-vehicle and pedestrian / cyclist traffic may be achieved by reducing the proportion of the road network that is used by both motor vehicles and pedestrians and cyclists. This may be achieved by redirecting motor vehicle traffic, by making driving in areas that are frequently used by pedestrians or cyclists unattractive (e.g. by installing networks of one-way roads which can by used in both directions by cyclists), or by installing a separate road network for pedestrians and cyclists (with safe crossing facilities). The latter may also be favourable for pedestrians and cyclists in general and thereby increase the total mileage of pedestrians and cyclists.

Both types of measures have been found to reduce the total number of injury accidents and the severity of accidents (e.g. Elvik & Vaa, 2004; Erke & Elvik, 2006). Unfortunately, results are usually not reported for specific types of accidents or injuries, e.g. for pedestrian accidents.

4.2 Pedestrian and cyclist measures

4.2.1 Visibility aids

Late detection is one of the basic driver errors that can lead to collisions (Rumar, 1990), and pedestrian accidents are overrepresented at night (Kwan & Mapstone, 2004; see also Chapter 3.1.3). Improving the visibility of pedestrians and cyclists can contribute to reducing accident risk by reducing detection and recognition times and increasing the distance at which drivers of motor vehicles can detect and recognize pedestrians or cyclists. This reduces the probability of collisions and, if a collision can not be avoided, is likely to reduce impact speed and thereby injury severity.

Visibility and conspicuity are dependent on a number of factors, including object size, contrasts, movements, background, clutter, road and light conditions, and weather. In addition cognitive processes and the mental state of the driver affects the probability of detection and recognition. The driver's cognitive processes are related to expectations, vigilance, attention, judgement, and experience. Drivers may "look but not see" or see and fail to react. Visibility may also be affected by the behaviour of the pedestrians. Most pedestrians over-estimate their own visibility (Kwan & Mapstone, 2004). In Norway about 15% of all pedestrians are using reflective devices (TryggTrafikk, 2004).

Effects on detection and recognition

Kwan & Mapstone (2004) have conducted a systematic review of the literature on effects of visibility aids for pedestrians and cyclists. Their review includes randomized controlled trials and controlled before-and-after trials from 1964-2002. They found 29 studies with 37 different trials that have investigated effects of visibility aids on indicators of visibility: detection or recognition time, distance, or frequency. They did not find any such studies that have investigated effects on accidents or injuries. The results can be summarized as follows:

- At daytime, fluorescent colours improved all indicators of visibility. The most effective fluorescent colours are yellow, orange and red. The most effective non-fluorescent colour is yellow. White is more effective than grey or black.
- At night time the use of visibility aids generally improves visibility.
- Lamps and flashing lights are more effective in improving visibility than reflectors.
- Red and yellow retroreflective colours are more effective than other retroreflective colours.
- Bicycles reflectors yield longer detection distances than reflective tyres, but reflective tyres yield higher recognition rates.
- Retroreflective biomotion configuration shorten recognition distance compared with other configurations of reflective materials.

There was large heterogeneity in the results, combined estimates could therefore not be computed. There is also large variability in the effects of visibility aids. As an example, biomotion (vs. no biomotion) improves recognition distance by between 13% and 71%. The use of retroreflective materials increased detection and recognition distances between 180% and 820%.

Effects on accidents and injuries

Kwan & Mapstone (2004, see previous section) did not find any studies that have investigated effects on accidents or injuries. An analysis of accidents statistics in Norway (Erke & Elvik, 2006; and see Chapter 3.1) shows that

- the use of reflective materials reduces the risk of being injured in a road accident by ca. 50% for pedestrians who use reflective materials compared to pedestrians that do not use reflective materials,
- the risk of a pedestrian being fatally injured in an accident where he/she sustains injuries, regardless of severity, is 31% lower when he / she is using reflective materials.

Based on these results and on a study by Andersson et al. (1998) it is estimated that the following proportions of injuries can prevented by using reflective materials: 50% of fatalities, 40% of severe injuries, and 30% of slight injuries of pedestrians in road accidents.

The effects on accidents are due to improved visibility of pedestrians for motor vehicle drivers. This increases the time and distance drivers have at their disposal for reacting and braking and is likely to reduce speed in collisions.

Bjørnskau (2005) has conducted a survey among cyclists in Norway. Among cyclists who had been involved in accidents there are larger proportions of cyclists who are not regularly using light or reflective materials than among cyclists who have not been involved in accidents. The differences are short of being significant. The accidents in this analysis include not only collisions with motor vehicles but also single accidents of bicyclists with no other parties involved. Light and reflective materials can hardly be assumed to be effective in reducing single accidents, the effects might therefore become larger if only collisions with motor vehicle accidents were regarded.

Measure that increase the use of visibility aids can contribute to reducing accident risk by increasing the proportion of pedestrians and cyclists using visibility aids.

Effects of visibility aids on accidents seem to be somewhat smaller than the effects on detection and recognition in the literature review of Kwan & Mapstone (2004). This is an expected result because visibility can not be assumed to be the only contributing factor in pedestrian and bicycle accidents.

4.2.2 Bicycle helmets

The proportion of cyclists wearing a helmet is relatively high in Norway compared to many other countries. In 2006 the proportions of cyclists wearing helmets was 63% among children under 12 years, 25% among children between 12 and 17 years, and 34% among adults over 17 years (Vegdirektoratet, 2007). Wearing rates for female and male cyclists are shown in Table 9. Wearing rates have increased most among female children and adults, but decreased among youths between 12 and 17 years.

Table 9: Cycle helmet wearing rates 2001-2004 compared to 2004 in Norway. Source: Vegdirektoratet (2007).

	Under 12 years		12 - 17 years		Above 17 years	
	Girls	**Boys**	**Girls**	**Boys**	**Women**	**Men**
2001-2004	61%	53%	37%	26%	26%	36%
2006	69%	58%	29%	21%	30%	37%
Change	+13 %	+9 %	-21 %	-19 %	+16 %	+5 %

Ca. 20% of all cyclists involved in injury accidents in official accident statistics have been wearing a helmet in the period 1983-2005. If only the last 10 years are regarded, the proportion of cyclists in injury accidents who have been wearing a helmet is 35%.

Cycle helmets may reduce the severity of accident consequences by preventing or reducing the severity of head, brain, and face injuries. The size of the effect is controversial. Results of empirical studies seem to depend strongly on the methods used, and to date no conclusion can be drawn about whether or not, or how strongly, helmets protect adult cyclists against injuries. The effects for children are more consistent, showing reduced numbers and severity of injuries in cycle accidents.

An analysis of Norwegian accident statistics (see Chapter 3.1) shows that the risk for a cyclists of being fatally, very severely or severely injured in an accident where any injuries are sustained is significantly reduced by 25% when a helmet is worn. The Norwegian questionnaire study by Bjørnskau (2005) could not replicate this finding, there was no clear difference of injury severity between cyclists wearing and not wearing a helmet in an accident.

Attewell, Glase og McFadden (2001) conducted a meta-analysis of studies that had evaluated effects of helmet use on injuries. They found effects as large as around 60% reduction of head and brain injuries and more than 70% reduction of fatalities. The results are however very likely to be affected by publication bias and by methodological flaws of the studies included in the meta-analysis. According to Robinson (2001) time trends have contributed to a large degree to the reductions in injury risk.

There is evidence of increased accident risk per cycling-km for cyclists wearing a helmet. In Australia and New Zealand the increase is estimated to be around 14%. The introduction of a bicycle helmet law in these countries has additionally lead to a reduction of cycling-kilometers of 22%. This effect is likely to be larger for adolescents than for adults, and smallest for children (Nolén og Lindkqvist, 2003).

Studies of measures that aim to increase the use of bicycle helmets on a voluntary basis were reviewed by Nolén & Lindkqvist (2003). Voluntary measures include information campaigns, incentive systems, and personal contact (e.g. with parents). Such measures increased the use of bicycle helmets up to but not above 50% among children, and 25-30% among adults, but there was large variability in the results. Larger proportions of cyclist wearing helmets can be achieved by helmet laws. Increases of helmet use between 46% and 85% were achieved in different studies (Nolén & Lindkqvist, 2003).

A cost-benefit analysis by Taylor & Scuffham (2002) for the bicycle helmet law in New Zealand showed that the law was cost-effective for cyclists under 19 years, but not for adults.

4.3 Vehicle measures

4.3.1 Passive vehicle safety

Passive vehicle safety measures that can reduce the severity of injuries are improvements of the vehicle fronts that reduce the impact forces when the vehicle hits a pedestrian. The focus is on the vehicle front because most and the most severe injuries in pedestrian accidents are sustained in the primary collision of pedestrians with vehicle fronts.

Vehicle fronts

The most relevant parts of vehicle fronts that may be optimized with regard to pedestrian safety are as shown in Table 10.

Table 10: Part of vehicle fronts, injuries to pedestrian body regions and possible vehicle improvements for the protection of pedestrians.

	Injured pedestrians body region		
Vehicle front	**Adults**	**Children**	**Vehicle improvements**
Bumper	tibia, knee	knee, femur, hip (head when high above the ground)	Form, size, deformability
Front protection system	tibia, knee	knee, femur, hip (head when high above the ground)	Form, deformability
Engine bonnet front edge	knee, femur	knee, femur, hip, head	Form, deformability
Engine bonnet	upper body, head	head	Deformability, space between bonnet and motor
Engine bonnet upper edge	head	(not relevant)	Deformability, curvature, airbag
Windscreen	head	(not relevant)	Elasticity of connection to car body
A-pillar	head	(not relevant)	Airbag

Deformability is an important property of most parts of the vehicle front. This includes the construction of the vehicle beneath for example the engine bonnet, which must allow enough space for deformation in a collision. The windscreen and A-pillar can not be made more deformable, but their design and placement can be improved, and A-pillars may be equipped with outward placed airbags. The stiffness of the whole construction of the vehicle front influences also the kinematics of the collisions, i.e. if and how the pedestrian is thrown by the car.

The form of all parts of the vehicle front is relevant for how and where which body part of the pedestrian hits the vehicle. The size of the surface of the bumper is relevant because a larger surface reduces the concentrated impact force. The height of the bumper and front protection systems are especially relevant for children. High front protection systems can be fatal in collisions with children, also at very low speeds. It is further relevant how single parts of the bumper and front protection systems are designed. Sharp edges and spaces between parts that are large enough for a head to fit through should for example be avoided.

The upper edges of engine bonnets can be equipped with mechanic or pyrotechnic devices which lift the engine bonnet in a collision. Additionally an airbag can be installed. This offers more space for deformation of the engine bonnet, and may prevent the pedestrian’s head from hitting the windscreen. It may also reduce the probability of the pedestrian being thrown through the air, especially if an outward airbag is installed additionally.

Legal requirements

The European Union has initiated a two phase process for the improvement of pedestrian protection (2003/102/EG). In phase I a legislation was introduced according to which all newly certified vehicles in the EEA have to pass tests for the assessment of pedestrian protection since 1. October 2005. In phase II, the tests are extended. It takes force in 2010, but it is not yet finally decided which tests have to be passed and what criteria have to be fulfilled. An overview of the tests to be performed in phase I and II is given in Table 11.

Table 11: Tests of pedestrian protection in phase I and II of EU legislation.

	Phase I (since Oct. 2005)	Phase II (from 2010)
Leg test body against the bumper	Registration approval	Registration approval
Femur test body against the front edge of the engine bonnet	For observation	Registration approval
Child's head test body against the engine bonnet	Registration approval	Registration approval
Adults head test body against the engine bonnet	For observation	Registration approval

In order to fulfil the phase I requirements a number of vehicle models had to be quite substantially redesigned. However, even if vehicles pass all required tests, there is still considerable scope for improvement as a comparison in the section above shows.

These regulations apply only to motor vehicles below 2.5t. Trucks are very likely to be far more dangerous for pedestrians, but they have lower potential for improvements, especially as regards the vehicles stiffness.

Moreover, there are several legal requirements for the construction of front protection systems which have been developed especially for the protection of children who often sustain very severe (head) injuries from collisions with vehicles equipped with front protection systems (2005/66/EG).

EuroNCAP

The European New Car Assessment Programme (EuroNCAP) conducts crash tests and provides consumers with information on the passive safety of cars. The occupant protection is evaluated with a five-star system, and the pedestrian protection is evaluated with a four-star system since 1997. The tests performed to evaluate pedestrian protection are component tests, similar to those performed according to second phase tests in European legislation (see section above). The tests with head test bodies have the largest impact on the final assessment of pedestrian protection.

No studies have been found that have evaluated the validity of these tests, i.e. to what degree cars with more stars for pedestrian protection cause less severe injuries in real-life pedestrian accidents.

4.3.2 Active vehicle safety

Active safety vehicle measures can reduce the probability and severity of collisions between motor vehicles and pedestrians by reducing the speed of the vehicle before the collision. Such systems are mainly braking assistant systems (BAS). The collision may be altogether avoided, or the injuries to the pedestrians may be less severe because of the relationship between vehicle speed and injury severity. This requires two types of performance:

- reliable identification of potential collision situations and
- initiation of an adequate (braking) reaction.

BAS differ mainly with respect to the type of interaction between the driver and the BAS, i.e. to the degree to which the BAS takes over control from the driver. The identification of approaching collisions with pedestrians may be based on driver behaviour, or on sensor information from the BAS which is independent from the driver. Relevant driver behaviour is mainly the velocity with which the driver actuates the braking pedal. More advanced systems use also releasing of the gas pedal as an indicator, but this is possible only with additional sensor information.

In-depth accident studies have shown that drivers brake immediately before a collision with a pedestrian in nearly half of all cases. In emergency situations where the driver brakes, most drivers actuate the braking pedal very fast, but not strong enough. Therefore, the braking distance is longer than it might be if the driver had applied full force.

The braking reaction that is initiated by a BAS may be a reinforcement of a driver action and shorten the braking distance, or it may be autonomously initiated by the BAS and (partly) compensate for a failure of the driver to brake. Different levels of BAS can be defined as shown in Table 12 (Kühn et al., 2006).

Table 12: Levels of braking assistant systems (BAS). Source: Kühn et al. (2006).

	Situation identification	**Braking reaction**
sBAS (standard BAS)	Driver actuates braking pedal above certain velocity	Automatic full braking
aBAS I (automatic BAS I)	Driver releases accelerator pedal BAS detects potential collision object	Automatic full braking
aBAS II (automatic BAS II)	Driver releases accelerator pedal BAS detects potential collision object	Automatic full braking
	BAS detects potential collision object	Automatic partly braking

An obvious problem of BAS is to avoid false situation identification. If an existing emergency situation (approaching collision with a pedestrian) is not identified, the BAS is not of great use. If a situation is falsely identified as an emergency situation, there may be serious or fatal consequences. More advanced BA-systems are therefore associated with much higher reliability requirements and with more legal questions concerning product liability. However, BAS have a large potential to avoid accidents and to make consequences less severe. All types of BAS can reduce the average speed in collisions. In motor vehicle – pedestrians collisions at 40 km/t where the driver is braking, the average impact speed can be reduced by 2.6 km/t by sBAS, by 11.6 km/t by aBAS I, and by 20.1 km/t by aBAS II. In motor vehicle – pedestrians collisions at 40 km/t where the driver is no braking, aBAS II can reduce the collision speed by 17.6 km/t. The number of motor vehicle – pedestrian collisions may be reduced by 6%, 26%, and 58% by sBAS, aBASI, and aBASII respectively. These results are based on in-depth accident studies by Kühn et al. (2006).

4.3.3 Potential effects of improved vehicle safety on pedestrian injuries

Kühn at al. (2004) have developed a procedure for the estimation of potential effects of measures for improving pedestrian safety. They have applied this procedure to different scenarios of improved vehicle safety. The results are shown in Figure 13.

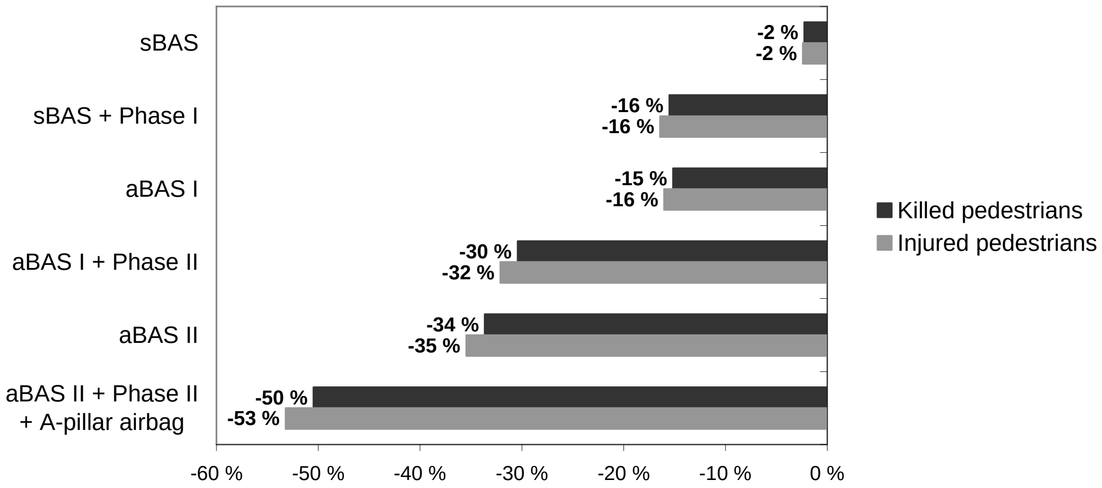

Figure 13: Potential safety effects of scenarios of different improvements of vehicle safety. Source: Kühn et al. (2006).

4.4 Institutional measures

Pedestrian and cyclist safety can be improved indirectly by measures that support the implementation of effective safety measures, or of measures that increase pedestrian and cyclist volumes and safe behaviour of pedestrians and cyclists. Examples for the first type of measures are

- specific goals for pedestrian and cyclist safety and plans designed to achieve these goals, e.g. in the National Transport Plan,
- task groups that represent the interests of pedestrians and cyclist, and that contribute to decisions and planning processes that are relevant for pedestrians and cyclists, such as for example the task group “On foot” in Vienna, and the associations for pedestrians in Germany; another example of a promotion measure for pedestrian is the Norwegian “Walking book”,
- safety audits for pedestrian and cyclist facilities, e.g. the Norwegian “sykkelveginspeksjoner” (cycle path inspections),
- incentives for car dealers and consumers to sell and buy cars that offer good pedestrian protection.

Measures that aim at increasing pedestrian and cyclist volumes and / or at improving behaviour of pedestrians and cyclists are for example

- information campaigns aiming at increased use of reflective materials or at increased use of cycle helmets among children,
- measures in organizations which improve facilities that make cycling to work more attractive (bicycle stands with roof, showers and clothes lockers) and which support safe behaviour (e.g. free provision of bicycle lamps and reflective materials),

- incentives for cycling or walking to work , e.g. neutrality of treatment as regards tax privileges or business initiatives.

No studies that have evaluated the effects of such measures on pedestrian or cyclist accidents or injuries have been found. According to Erke & Elvik (2006) a conservative estimate for the effect of cyclepath inspections is a reduction of injury accidents by 5%. Measures included in the analysis are improved signing, removal of sight obstacles and other measures that do not require land acquisition or construction projects.

5. Cost-effectiveness of preventing pedestrian accidents

5.1 Benefits of measures for pedestrians and cyclists

The impacts of safety measures for pedestrians and cyclists that are taken into account in cost-benefit analysis according to handbook 140 (Statens vegvesen, 2006) are related to

- safety,
- mobility in terms of travel time, and
- environment.

Additionally, there is a number of other impacts, that are not usually taken into account in economic analyses (Elvik, 1998):

- comfort and confidence,
- operating costs for bicycles,
- changed amount of walking / cycling,
- coherent road network for pedestrians or cyclists,
- safer ways to school and better accessibility to different activities, and
- improved health for pedestrians and cyclists,
- effects for motor vehicles.

Some of these impacts are now included, following the most recent revision of the guidelines for cost-benefit analysis of road projects in Norway (Handbook 140, Statens vegvesen, 2006).

According to Sælensminde (2004) also barrier costs should be taken into account, i.e. “benefits to society that are not realized because motorized traffic prevents people from bicycling and walking as much as they otherwise would prefer” (s. 593).

The following sections summarize the socio-economic costs that are used in benefit-cost analysis of safety measures for pedestrians and cyclists in Norway. All costs are in NOK as of 2005 (1 NOK = ca. 0,125 EUR).

5.1.1 Safety

The costs of injuries in road accidents in Norway for different levels of severity are summarized in Table 13. These costs are based on Killi, Samstad & Hagman (2006). These costs are assumed to be identical for all road users. The costs include medical costs, loss of productivity, material damage, administrative costs, travel delays, and reduced welfare. Veisten et al. (2007) suggest to adjust these costs for cyclists because of lower costs for material damages and lower production losses. For pedestrian accidents these types of costs also can be assumed to be lower than for motor vehicle accidents.

Table 13: Accident costs per injury / material damage (2005 prices). Source: Killi, Samstad & Hagman (2006).

Injury severity	Costs (NOK)
Killed	26,500,000
Very severe injury	18,100,000
Severe injury	6,000,000
Slight injury	800,000
Material damage	50,000

5.1.2 Mobility: Travel time

The socio-economic costs associated with travel time are different for different means of transport, travel purposes, and travel length. The travel-time costs for pedestrians and cyclists travelling under 100km are shown for different travel purposes in Table 14. The costs are expressed as NOK per person-hour (2005-Norwegian crowns). For comparison purpose the travel-time costs for light vehicles are shown as well

Table 14: Travel-time costs (2005 prices). Source: Statens vegvesen (2006).

	NOK per person-hour	
Travel purpose	**Walking / cycling**	**Light vehicle**
Business trip	68	198
Trip to / from work	68	57
Private trip	68	53

5.1.3 Health

Health effects of walking and cycling include accidents, exposure to air pollution, and increased physical activity. Accident costs are described in a section above, effects of exposure to air pollution are complex and currently not sufficiently known to be included.

Health effects of increased physical activity include increased personal well-being, which is currently not included in cost-benefit analyses, as the consumer surplus of walking or cycling is not known. The reductions of external costs are reductions of short-term- and long-term- sickness (see Chapter 5.1.6).

5.1.4 Comfort and security (feeling of safety)

Subjective security is associated with many factors, quite complex, and therefore difficult to quantify. Some rough estimates of the costs associated with insecurity while walking or cycling are given in handbook 140. The costs of (decreased) comfort and security are estimated as 1.00 NOK per crossing and 2.10 NOK per kilometre of travel along a road.

5.1.5 Other impacts

There are no official cost estimates for the other impacts of safety measures for pedestrians and cyclists: Environmental effects, operating costs for bicycles, changed amount of walking / cycling, coherent road network for pedestrians or cyclists, safer journeys to school, better accessibility to different activities, and impacts for motor vehicles. They can (and should) all the same be taken into account as non-quantifiable effects of safety measures.

Sælensminde (2004) has developed estimates for barrier costs that arise because motorized traffic prevents many cycled or walked trips. Barrier costs have been estimated for three Norwegian towns (Hokksund, Hamar, and Trondheim). The benefit loss per journey unrealized pedestrian and bicycle traffic are estimated at ca. 8 to 9.6 NOK. The costs per journey unrealized pedestrian and bicycle km are estimated at ca. 4 NOK. The total benefit loss for the three towns (annuity) is ca. 8.8 mil. NOK in Hokksund, ca. 19.6 mil. NOK in Hamar, and ca. 2.2 mil. NOK in Trondheim.

5.1.6 Summary of monetary valuations

Monetary valuations for a number of impacts of road safety measures are shown in Table 15. Sources are the report by Samstad, Killi and Hagman (2005), valuations of health impacts have been taken from the guidelines for impact assessment published by the Public Roads Administration (Statens vegvesen, Vegdirektoratet 2006).

Table 15: Monetary valuation of impacts of road safety measures.

Main policy objective	Unit of valuation	Valuation per unit (NOK 2005 prices)
Road safety	1 fatality	26,500,000.00
	1 police reported serious injury (adjusted for incomplete reporting)	7,800,000.00
	1 police reported slight injury (adjusted for incomplete reporting)	800,000.00
Travel time	1 vehicle hour of travel by means of passenger car	125.00
	1 vehicle hour of travel by means of van	140.00
	1 vehicle hour of travel by means of freight truck	470.00
	1 vehicle hour of travel by means of bus (including passengers)	860.00
Vehicle operating costs	Vehicle operating cost per kilometre – car	1.30
	Vehicle operating cost per kilometre – heavy goods vehicle	4.44
	Vehicle operating cost – bus	4.82
Environmental impacts	Traffic noise, per vehicle km, large and medium sized towns	0.38
	Traffic noise, per vehicle km, rural areas	0.00
	Local air pollution, per vehicle kilometre, large towns	0.25
	Local air pollution, per vehicle kilometre, small towns	0.11
	Local air pollution, per vehicle kilometre, rural areas	0.02
	Global air pollution (carbon dioxide), per vehicle kilometre	0.12
Health impacts	Insecurity in crossing road, per crossing	1.00
	Insecurity in walking or cycling in mixed traffic, per kilometre	2.10
	Reduction of short term sick leave, walking 1 kilometre	2.90
	Reduction of short term sick leave, cycling 1 kilometre	1.50
	Reduction of serious illness, walking 1 kilometre	5.20
	Reduction of serious illness, cycling 1 kilometre	2.60

5.2 Costs and benefits of various measures

Costs and benefits have been analyzed for the following measures in Norway (Erke & Elvik, 2006):

- Path for walking and cycling
- Grade-separated crossing for pedestrians and cyclists
- Traffic signals at pedestrian crossing
- Upgrading pedestrian crossing
- Marking of cycle lane
- Redesigning car fronts to reduce impact severity

For these measures benefit-cost ratios have been computed, taking into account benefits for

- safety,
- mobility,
- environment, and
- comfort and security.

The costs and benefit-cost ratios for these measures are summarized in Table 16 for different motor vehicle volumes. Benefit cost ratios are computed as

Net benefit cost ratio = $\frac{\text{Gross benefit - Costs}}{\text{Costs}}$.

If the benefits are larger than the costs, the ratio is positive, if the costs exceed the benefits, it is negative. For most measures the benefit cost ratios are positive, and larger at higher motor vehicle volumes. The benefit-cost ratios for traffic signals at pedestrian crossings and marking of cycle lanes are negative mainly because of the increased time costs for motor vehicles.

Table 16: Costs and cost-benefit ratios for safety measures for pedestrians and cyclists. Source: Erke & Elvik (2006).

Measure	Costs (mil. 2005-NOK)	Motor vehicle volume (AADT)	Benefit-cost ratio
Combined sidewalk and cycle path	6.0 per km	35,000	0.82
		19,000	0.39
		8,000	0.00
Grade-separated crossing for pedestrians and cyclists	1.6 – 22.0 per location	35,000	2.04
		12,000	0.32
		8,000	0.00
Traffic signals at pedestrian crossing	0.5-1.0 per crossing facility	35,000	-15.28
		10,000	-3.10
		3,000	-1.38
Improvement of pedestrian crossing	0.15-2.3 per crossing facility	30,000	0.51
		8,000	2.16
		1,200	0.05
Marking of cycle lane	0.5 per km	18,000	-2.12
		9,000	-1.21
		3,000	-0.78

6. Equity aspects

Pedestrians and other unprotected road users (cyclists, riders of mopeds or motorcycles) have a considerably higher fatality and injury rate per kilometre of travel than other groups of road users. Is this fair? Can the current disparities in risk levels between different groups of road users be regarded as equitable?

To most people, the obvious answer is no. By definition, all the risk pedestrians run in traffic is imposed on them by other groups of road users, since single pedestrian accidents, i.e. pedestrians falling without any other road user or vehicle being involved, are not defined as traffic accidents. Pedestrians are therefore only involved in road accidents when hit by cyclists or motor vehicles.

The notion of fairness does, however, not have a standard definition. Rather than trying to develop our own definition, we have decided to probe the possible implications of applying John Rawls' principles of justice as fairness to the distribution of injury risk in traffic (Rawls 1971, 2001). Rawls suggests that the distribution of primary goods in a society is just if it is egalitarian. Unequal distributions of primary goods, he argues, can only be justified if the departure from equality benefits everybody in society, including those who get the smallest share of goods that are unequally distributed. He refers to this principle of justice as the difference principle. It states that inequalities can be regarded as fair if they are arranged to the benefit of the least advantaged.

Application of the difference principle to transport risk requires a definition of what it means to be advantaged or disadvantaged. The advantage provided by a transport system is the opportunity to travel (or transport goods). As far as personal travel is concerned, the most advantaged group is therefore the group that performs the largest amount of travel. This group is the most advantaged by making the greatest use of a transport system, which serves several groups of road users. The least advantaged group is the one that makes the least use of the system, i.e. performs the smallest number of person-kilometres of travel.

In a static sense, differences in risk are arranged to the benefit of the least advantaged if that group has the lowest level of risk, and the most advantaged group has the highest level of risk. To determine of this is the case today, estimates of fatality risk for various groups of road users in Norway were compared. The amount of travel (the advantage) was measured in terms of person kilometres of travel, estimated on the basis of the national travel behaviour survey (Denstadli and Hjorthol 2002). Fatality risk was estimated on the basis of official accident statistics for the period 1998-2002. To obtain a numerical index of inequity, it is instructive to prepare a diagram, showing the proportion of travel performed by various groups of road users on the abscissa and their proportion of fatalities or injuries on the ordinate. Figure 14 shows such a diagram for Norway. Different groups of road users, not named in Figure 14, are shown in order of increasing fatality rate per kilometre of travel. The flattest part of the curve indicates the lowest fatality rate, the steepest part shows the highest fatality rate. Both axes in Figure 14 indicate cumulative shares of travel or of fatalities.

If all groups had the same fatality rate, they would lie on top of the dotted straight line connecting the points (0,0) and (1,1). A frequently used measure of inequality, the Gini-index, is shown in Figure 14; its value has been estimated to 0.349. The Gini-index is derived from the area of the triangle formed between the dotted straight line and the abscissa. Setting this area equal to 1, the Gini-index takes on values between 0 and 1, depending on the degree of inequality. Its value is 0 when there is complete equality, i.e. all data points are located on top of the dotted straight line. Its value is 1 when the data points are aligned along the abscissa. A value of 0.349 shows the size of the area between the curve and the dotted straight line as a proportion of a triangle with an area of 1.

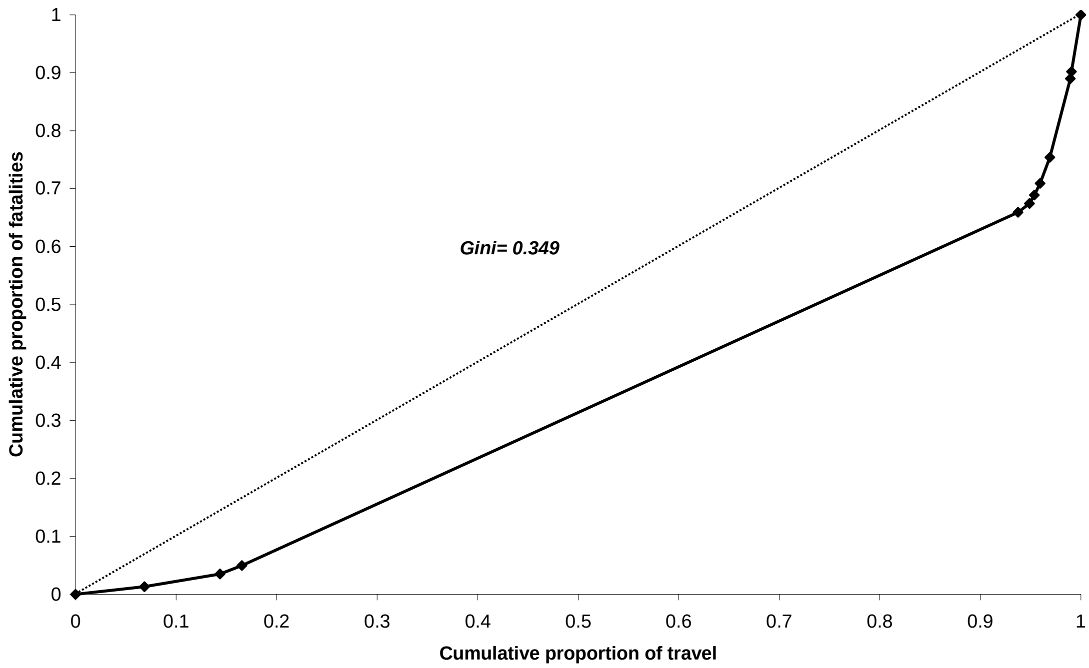

Figure 14: Inequality in the distribution of fatality risk in road traffic in Norway.

The large straight section of the curve in Figure 14 is travel by car, which makes up about 77% of all travel by road in Norway. Thus, car occupants are the most advantaged group. In Figure 15, the fatality rates for the less advantaged groups have been revised so as to become consistent with the difference principle of justice, which implies that the less the travel (i.e. the smaller the benefits derived from using the road system), the lower the fatality rate. The revision of fatality rates implied drastic reductions for pedestrians, cyclists, moped riders and motor cycle riders. Car occupants now have the highest fatality rate (although obvious not higher than today; simply higher than the other groups). The Gini-index is reduced to 0.152. The changes in fatality risk that were made for those groups of road users who had a disproportionately high fatality rate imply that the total number of fatalities would be reduced by 34%. The distribution in Figure 15 is fair in the sense those who benefit less from the transport system (i.e. travel less) also have the lowest fatality rate (small benefits go together with small costs).

When Figure 15 is compared to Figure 14, the fatality rate of pedestrians has been reduced by 97.2 %. This clearly demonstrates what was stated above, namely that most of the risk run by pedestrians today is unfair, since it is incommensurate with the advantages the current road transport system provides for pedestrians.

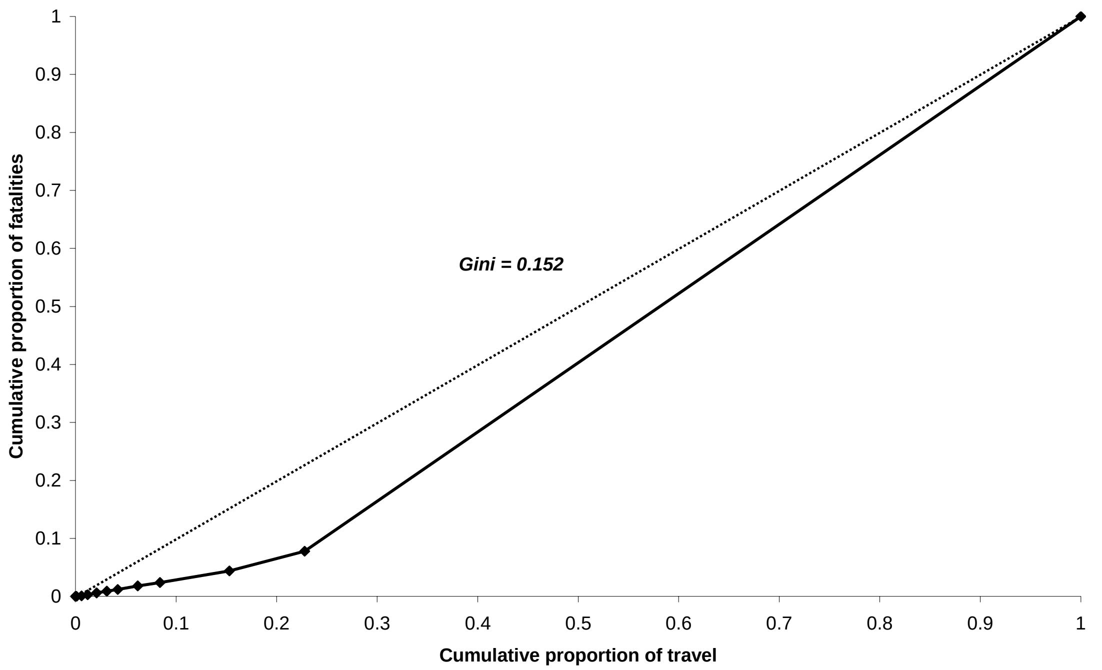

Figure 15: Inequality in the distribution of fatality risk in road travel in Norway consistent with the difference principle.

This point of view is, however, static, in the sense that it takes fatality rates as given and independent of the volume of travel. It is likely that the fatality and injury rates of pedestrians would go down if they became more numerous, i.e. if there was more pedestrian travel. The accident prediction model developed by Brüde and Larsson (1993) suggests that risks are highly non-linear with respect to traffic volume. Thus, the number of accidents involving pedestrians crossing the road is predicted as:

Number of pedestrian accidents = $0.0000734 \times MV^{0.50} \times PED^{0.72}$

MV is the number of motor vehicles entering a crossing point, PED is the number of pedestrians entering the crossing point. The prediction equation suggests that the risk of a pedestrian accident run by each road user, i.e. each car and each pedestrian declines strongly as traffic volume increases. Thus, injury risk per million motor vehicles entering a crossing at which 750 pedestrians cross per day can be estimated to:

- 0.106 if there are 500 motor vehicles entering per day
- 0.047 if there are 2,500 motor vehicles entering per day
- 0.027 if there are 7,500 motor vehicles entering per day
- 0.018 if there are 17,500 motor vehicles entering per day

Similarly, injury risk per million pedestrians crossing at a volume of 12,500 motor vehicles per day can be estimated to:

- 4.797 if 100 pedestrians cross per day
- 2.728 if 750 pedestrians cross per day
- 1.507 if 6,250 pedestrians cross per day

An interesting question is if there is a “tipping point” for the combination of motor vehicle and pedestrian volume, i.e. a combination of volumes where the risk per million pedestrians becomes lower than the risk per million motor vehicles. In fact, such a tipping point exists. The risk per pedestrian is lower than the risk per motor vehicle if more than 3,750 pedestrians cross the road per day and there are less than 500 motor vehicles entering the crossing point. At this combination of volumes, the distribution of risk would be “minimally” fair in the sense that it would be lower for the more numerous group of road users – pedestrians – than for the less numerous group of road users – motor vehicles. It would, however, not be “strictly” fair in the sense of being proportional to traffic volume.

This numerical example shows that a policy designed to promote more walking is not necessarily inconsistent with an objective of promoting a more fair distribution of injury risk in traffic. In fact, these policy objectives may be consistent, in the sense that if an increase in walking replaces motorised transport, differences in injury rates between motorists and pedestrians are likely to become smaller.

7. Summary

Accident and injury risk of pedestrians and cyclists in Norway, and developments over time are described and compared to other countries. The risk of fatal accidents among pedestrians and cyclists is about the same in Norway as in the other Nordic countries, and lower than in other EU countries. Fatality risk is on average ca. 10 times as large as the fatality risk per million person-km of travel by car. The level of reporting for accidents of non-motorized road users is is lower in Norway than in most other European countries.

Factors that affect the risk and severity of pedestrians and cyclist accidents have been identified based on Norwegian accident statistics and a literature review. The risk for severe injuries is high

- in rural areas,
- in collisions with motor vehicles, especially trucks,
- when no reflective materials or lights are used,
- for pedestrians above 64 and for cyclists below 15 years,
- when there are few pedestrians and cyclists,
- when pedestrians and cyclists are not visible,
- when vehicles do not provide pedestrian protection,
- when road conditions are poor,
- when roads are used of high speed motorized traffic and non-motorized road users.

Measures that reduce accidents and injuries among pedestrians and cyclists are

- safe crossing facilities,
- integration of pedestrians and cyclists in the traffic environment,
- speed reductions for motorized traffic,
- visibility aids,
- active and passive vehicle safety (brake assistants and pedestrian protection),
- institutional measures focusing on pedestrian and cyclist safety.

Measures that do not always reduce pedestrian and cyclist accidents are marked pedestrian crossings, curbed medians, crossing facilities for cyclists, sidewalks and cycle paths, and winter maintenance when it fails to make roads less slippery.

Pedestrians and cyclists account for a minor proportion of all road traffic, but have a considerably higher injury rate than other road users. Increasing the amount of walking and cycling would probably increase the total numbers of pedestrian and cyclist accidents and injuries. However, it would also decrease accident risk for pedestrians and cyclists, and promote a more fair distribution of injury rates between non-motorized and motorized road users.

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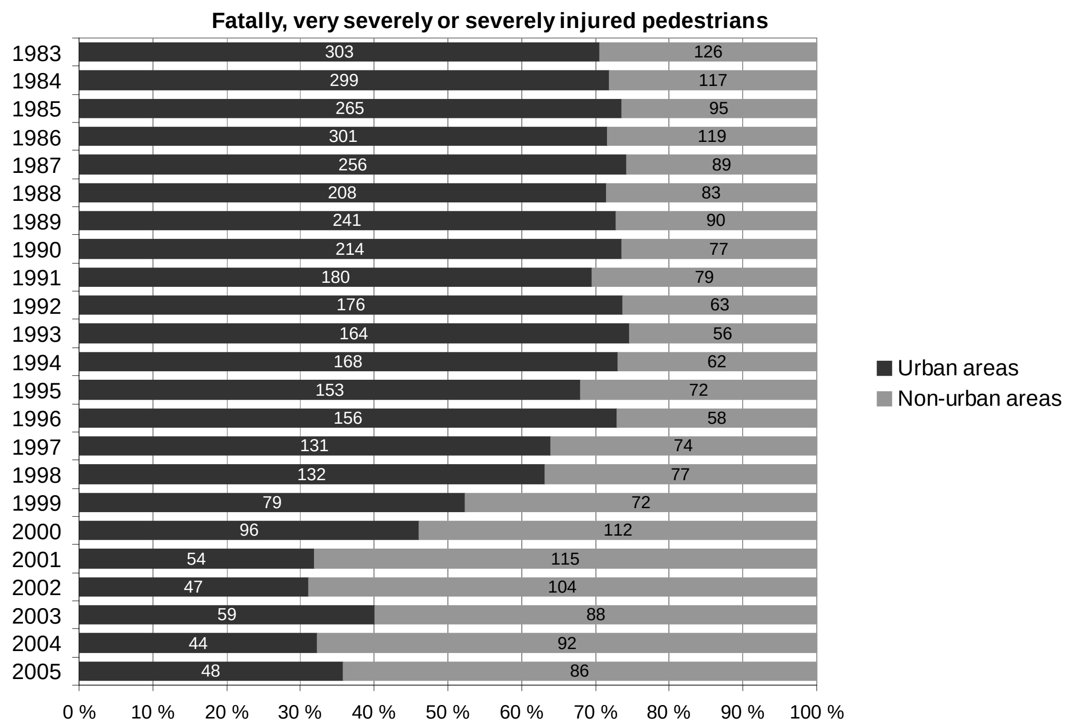
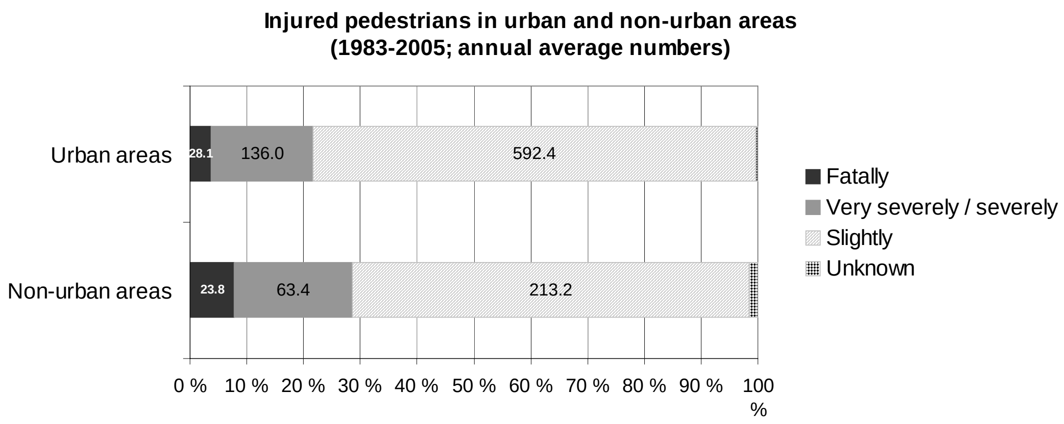
Appendix: Norwegian accident data

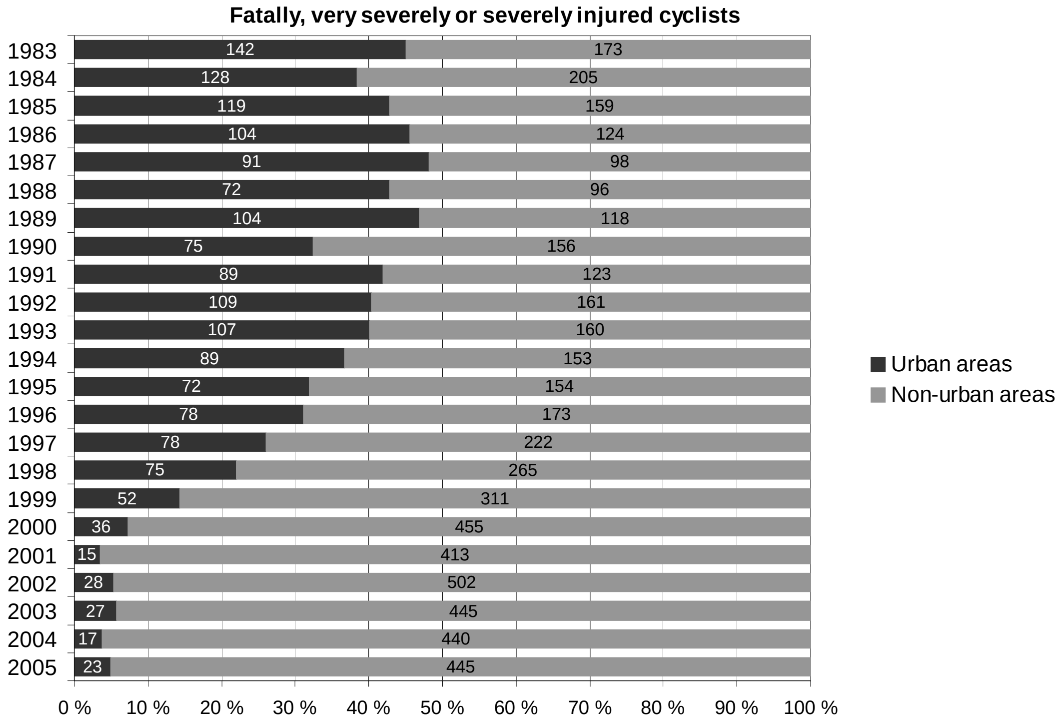
Urban vs. non-urban areas



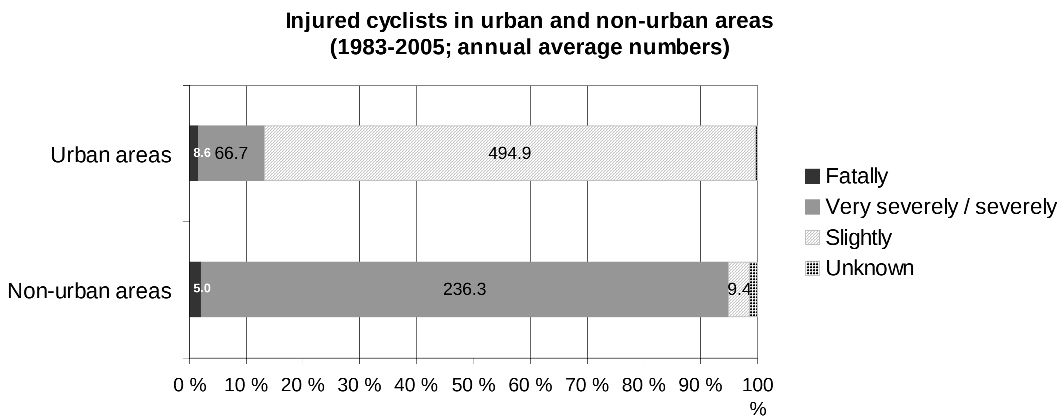
Numbers of fatally, very severely or severely injured pedestrians in urban vs. non-urban areas (1983-2005). Source: SSB.



Numbers of injured pedestrians in urban vs. non-urban areas (1983-2005; annual average numbers)

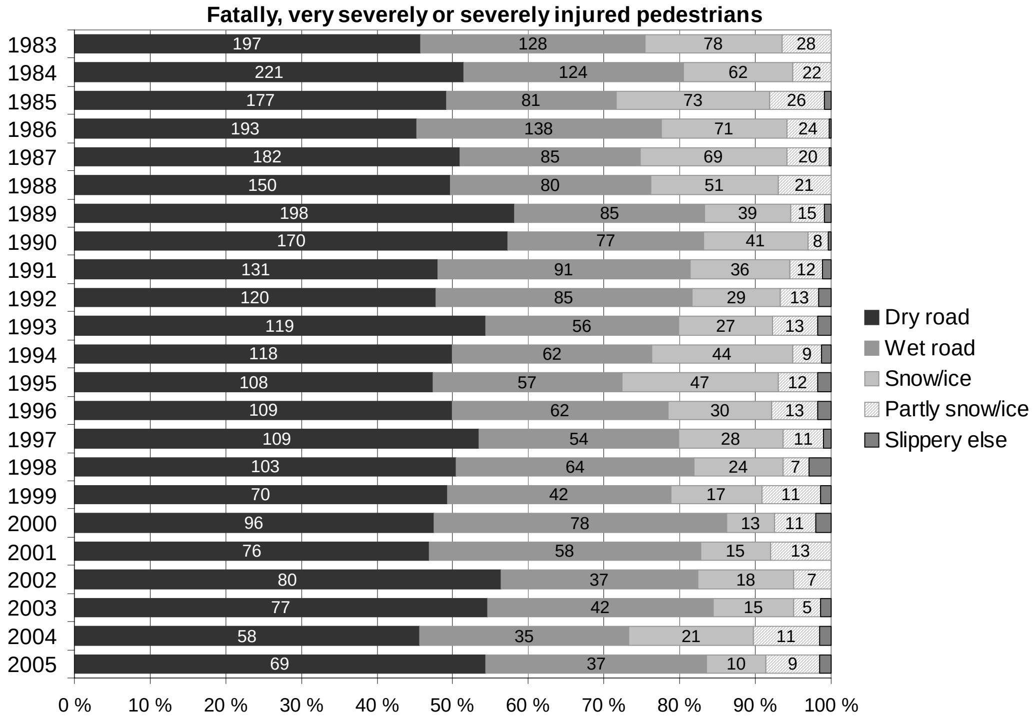


Numbers of fatally, very severely or severely injured cyclists in urban vs. non-urban areas (1983-2005). Source: SSB.

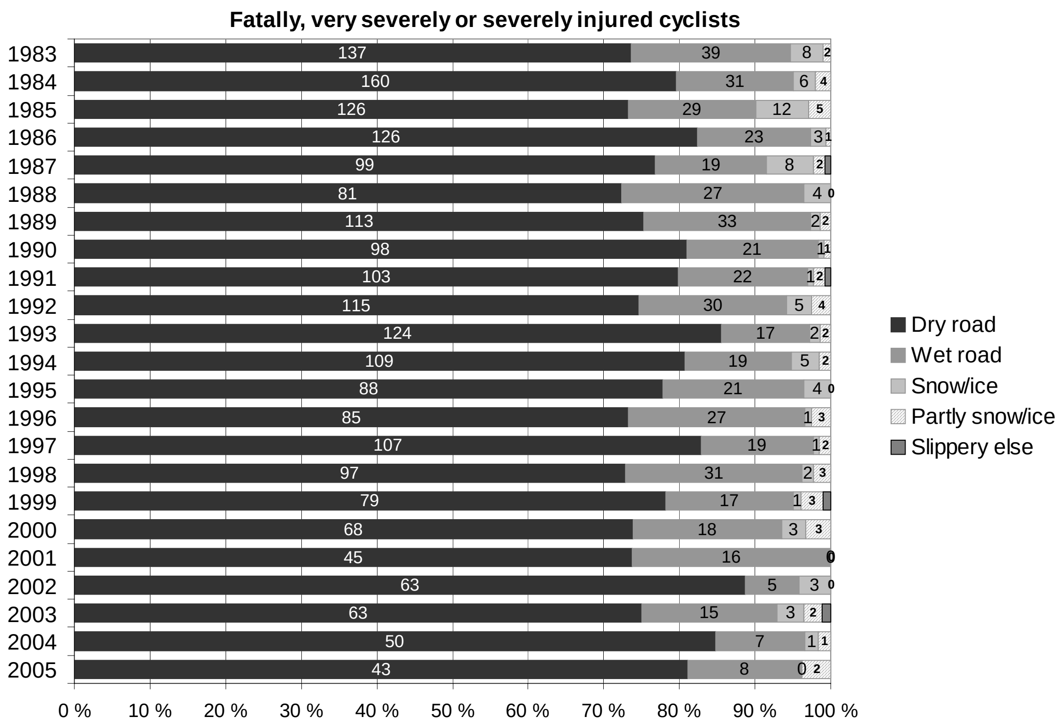


Numbers of injured cyclists in urban vs. non-urban areas (1983-2005; annual average numbers)

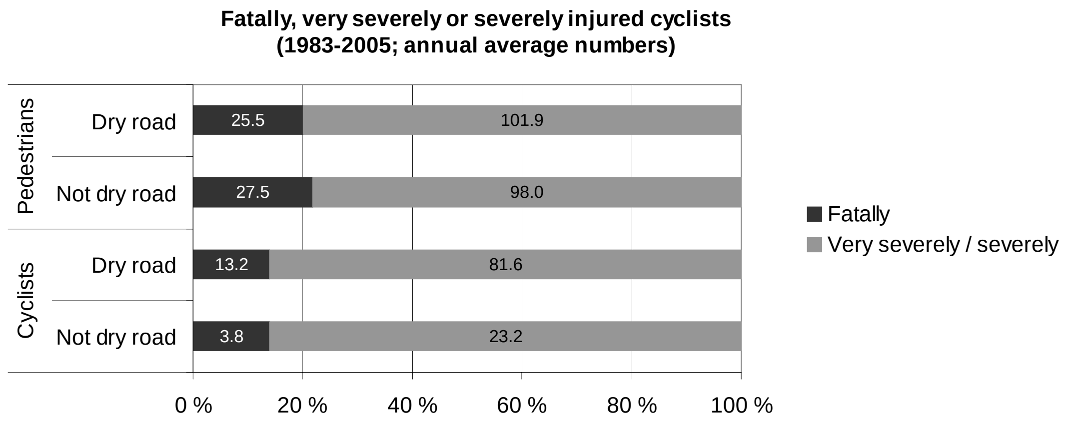
Road conditions



Numbers of fatally, very severely or severely injured pedestrians under different road conditions (1983-2005). Source: SSB.

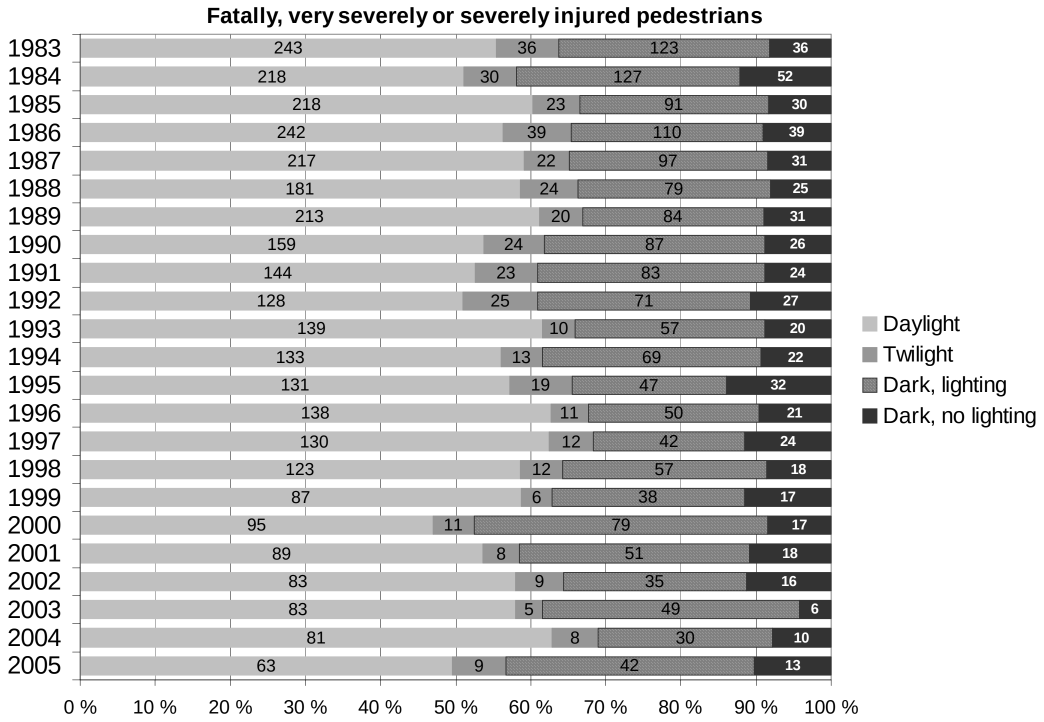


Numbers of fatally, very severely or severely injured cyclists under different road conditions (1983-2005). Source: SSB.

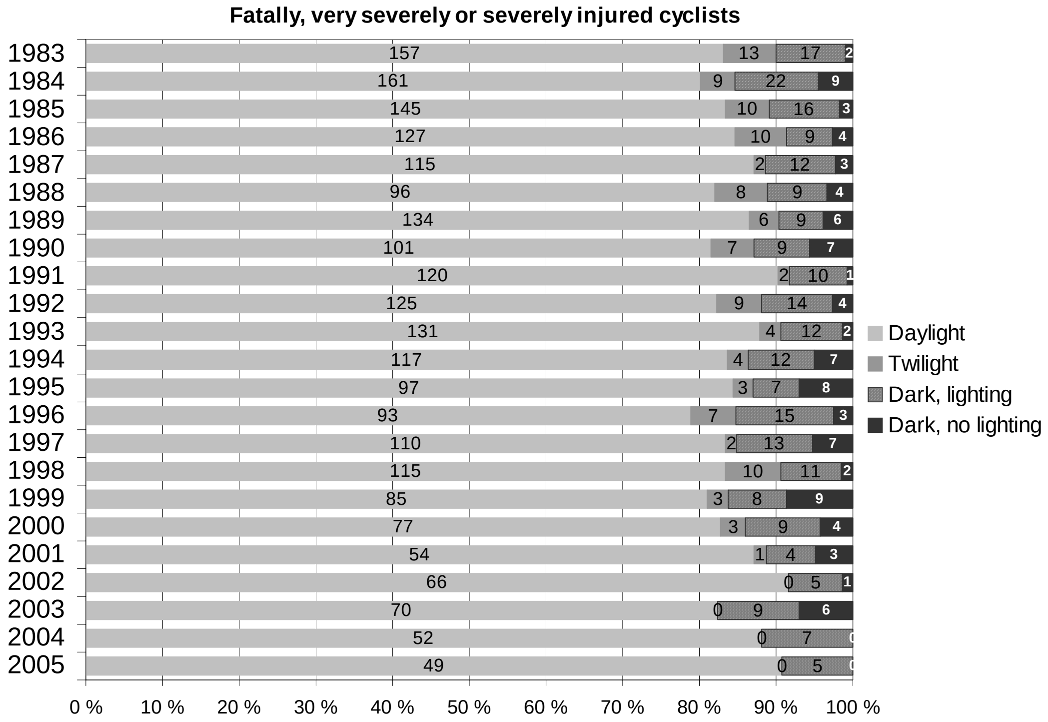


Numbers of fatally, very severely or severely injured pedestrians and cyclists under different road conditions, injury severities (1983-2005; annual average numbers). Source: SSB.

Light conditions

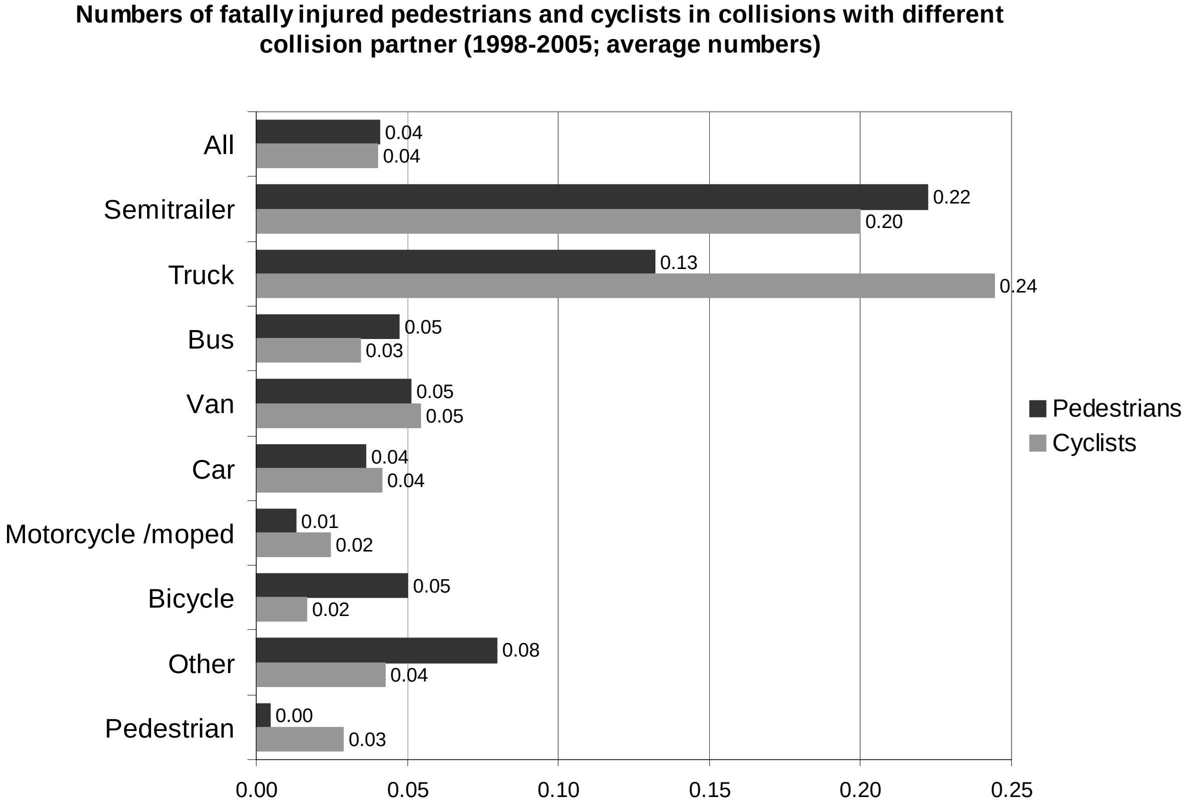


Numbers of fatally, very severely or severely injured pedestrians under different light conditions (1983-2005). Source: SSB.



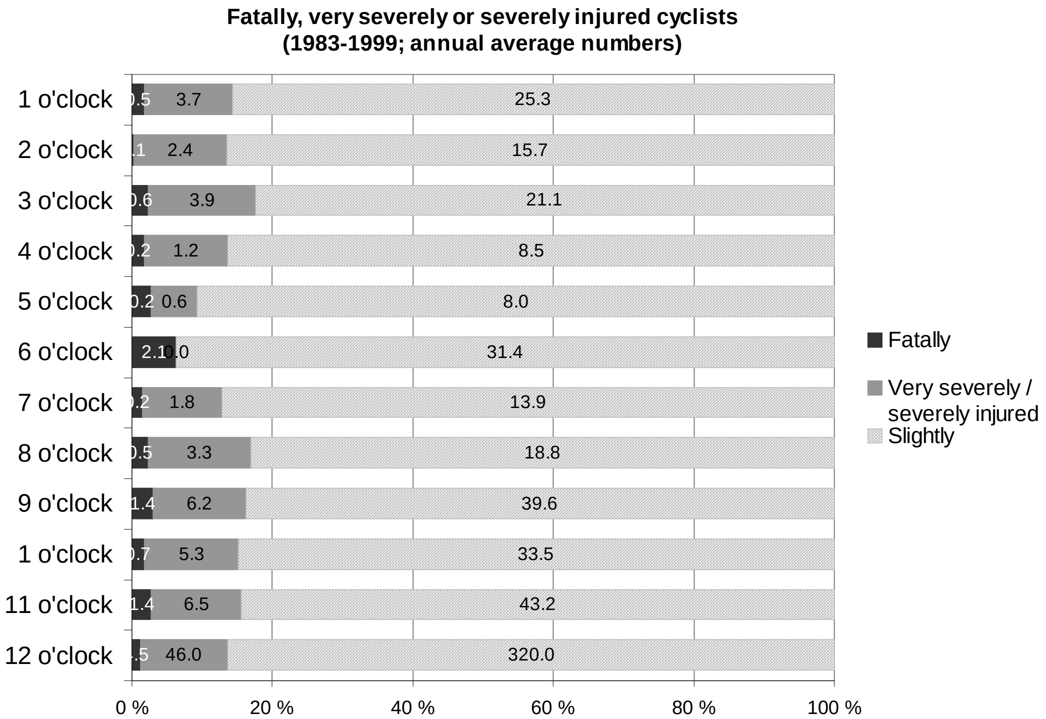
Numbers of fatally, very severely or severely injured cyclists under different light conditions (1983-2005). Source: SSB.

Collision partner

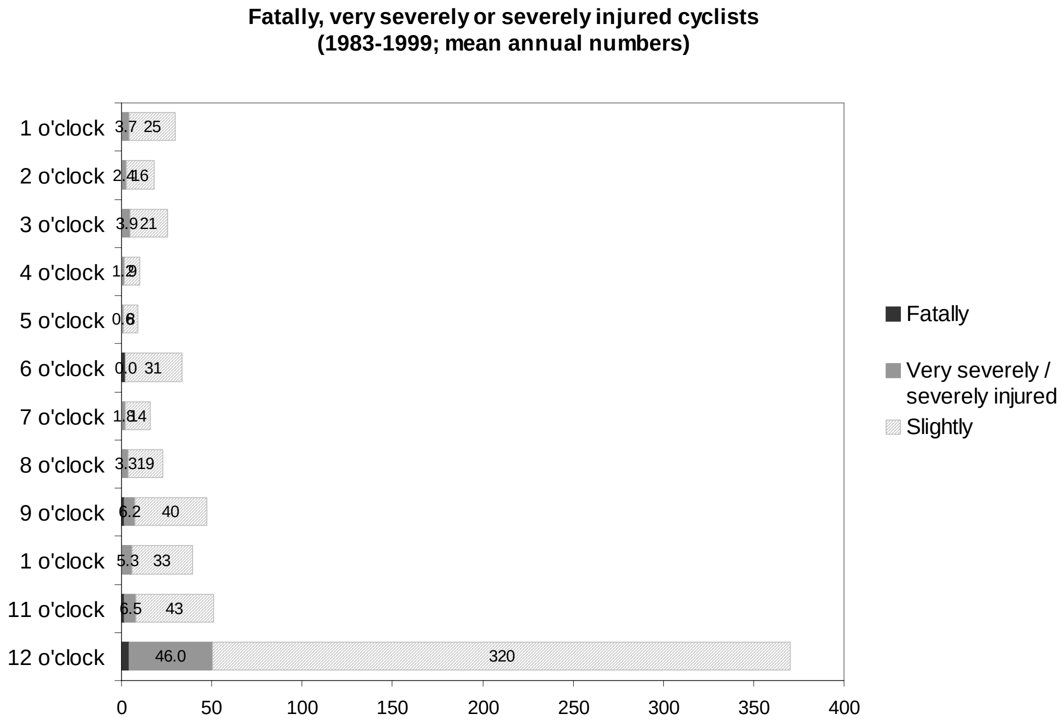


Numbers of fatally injured pedestrians and cyclists in collisions with different collision partner (1998-2005, annual average numbers). Source: SSB.

Direction of impact

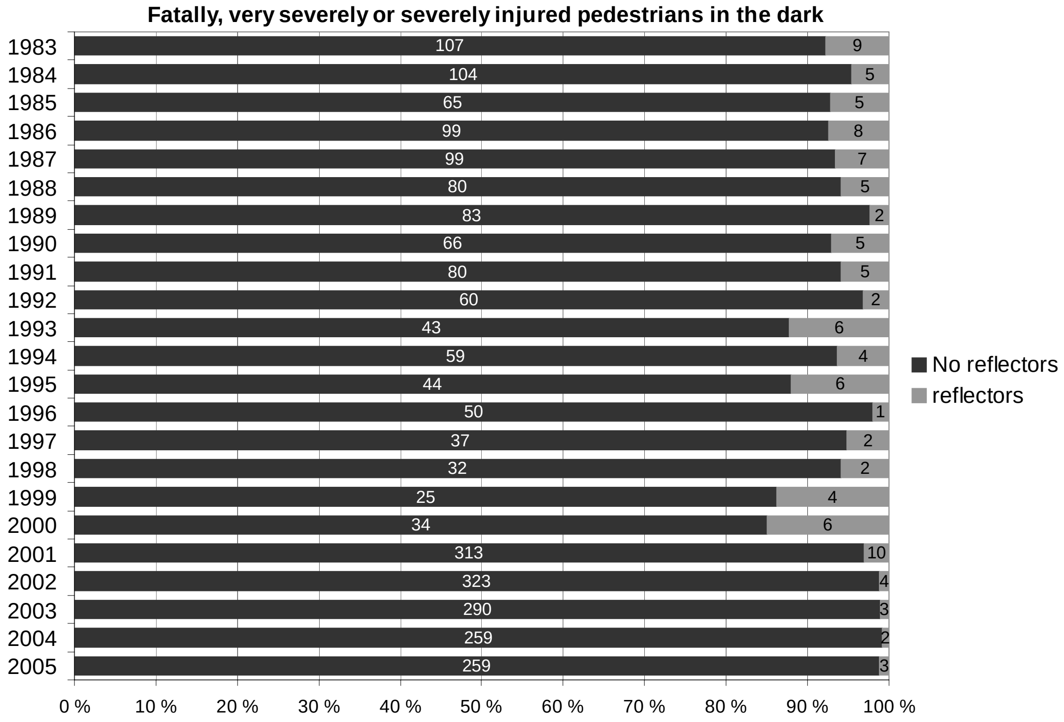


Numbers of fatally, very severely or severely injured pedestrians at different impact directions, injury severities (1983-2005, annual average numbers). Source: SSB.

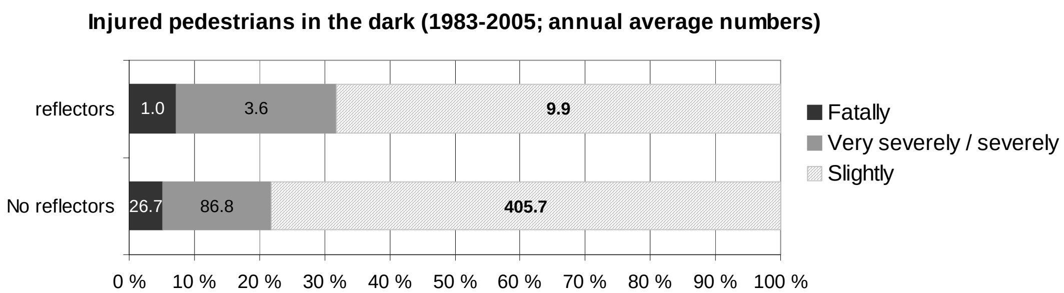


Numbers of fatally, very severely or severely injured cyclists at different impact directions, injury severities (1983-2005, annual average numbers). Source: SSB.

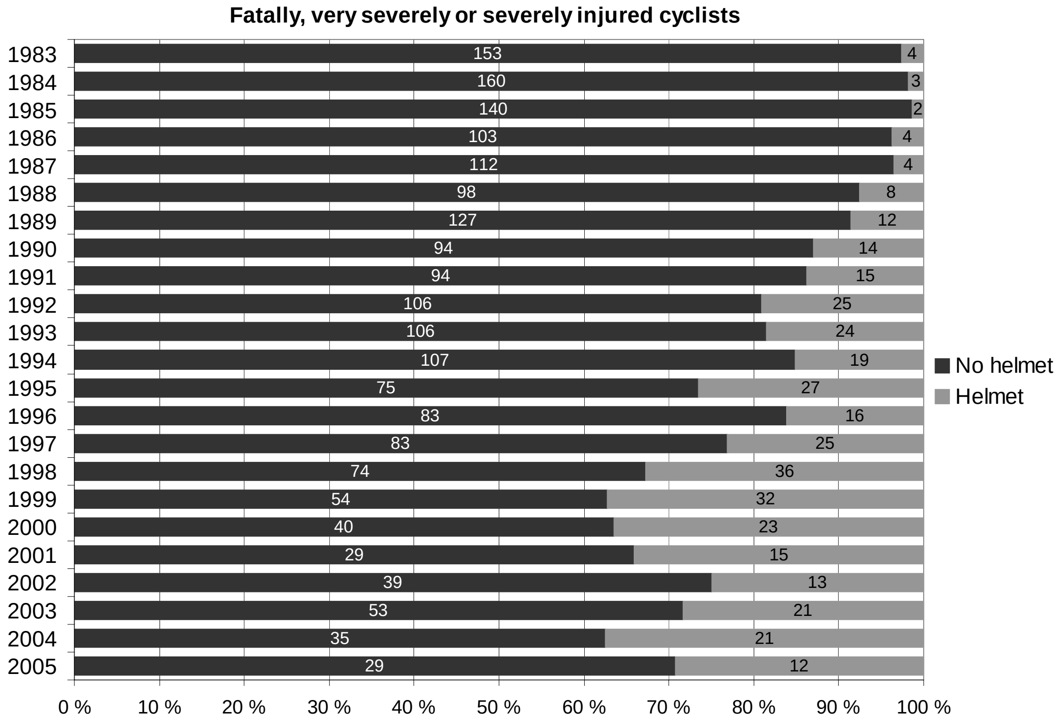
Protective equipment: Reflectors and helmets



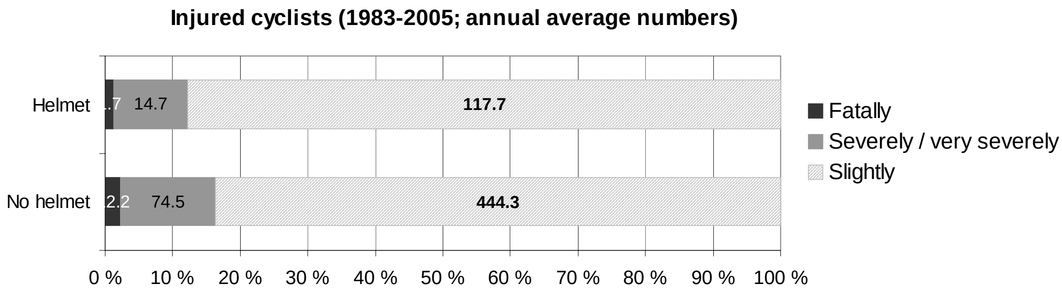
Numbers of fatally, very severely or severely injured pedestrians in the dark with vs. without reflectors (1983-2005). Source: SSB.



Numbers of injured pedestrians in the dark with vs. without reflectors, injury severity (1983-2005; annual average numbers). Source: SSB.

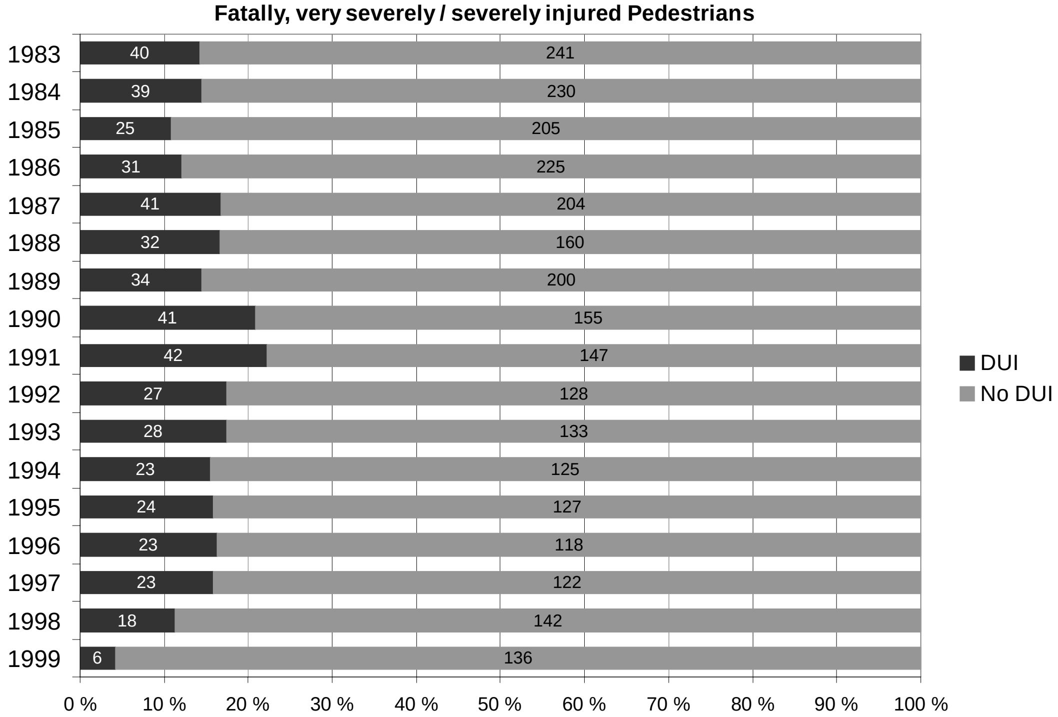


Numbers of fatally, very severely or severely injured cyclists with vs. without helmet (1983-2005). Source: SSB.

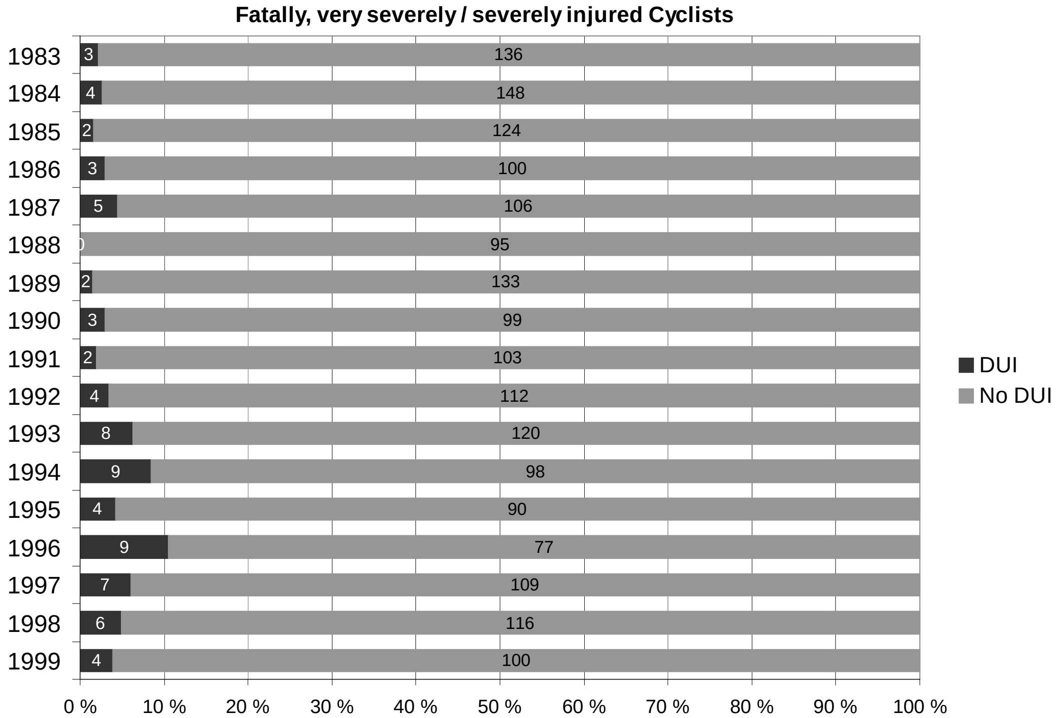


Numbers of injured cyclists with vs. without helmet, injury severity (1983-2005; annual average numbers). Source: SSB.

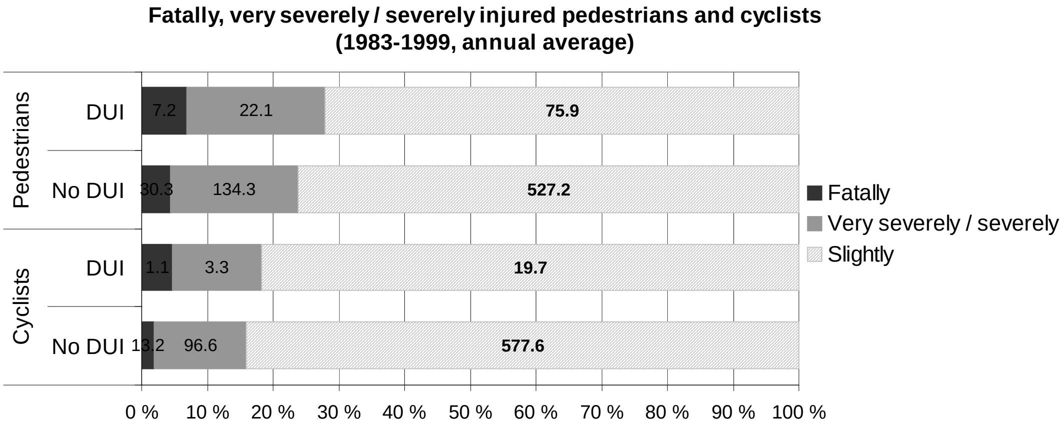
Alcohol or drugs involved



Numbers of fatally, very severely or severely injured pedestrians with vs. without alcohol or drugs (1983-2005). Source: SSB.

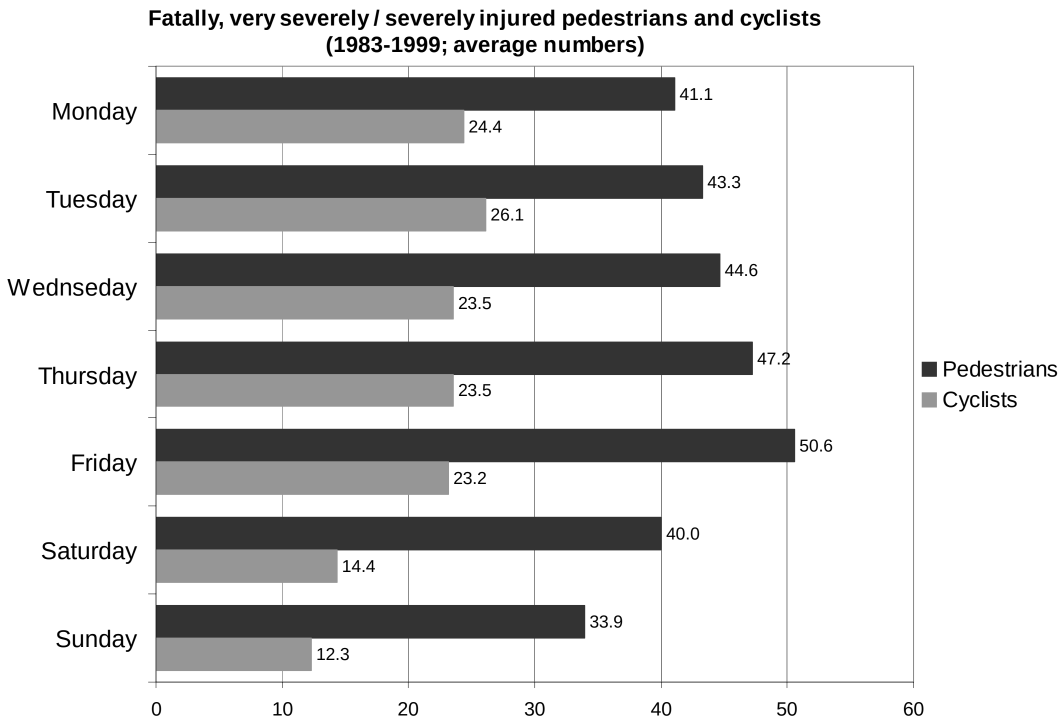


Numbers of fatally, very severely or severely injured cyclists with vs. without alcohol or drugs (1983-2005). Source: SSB.



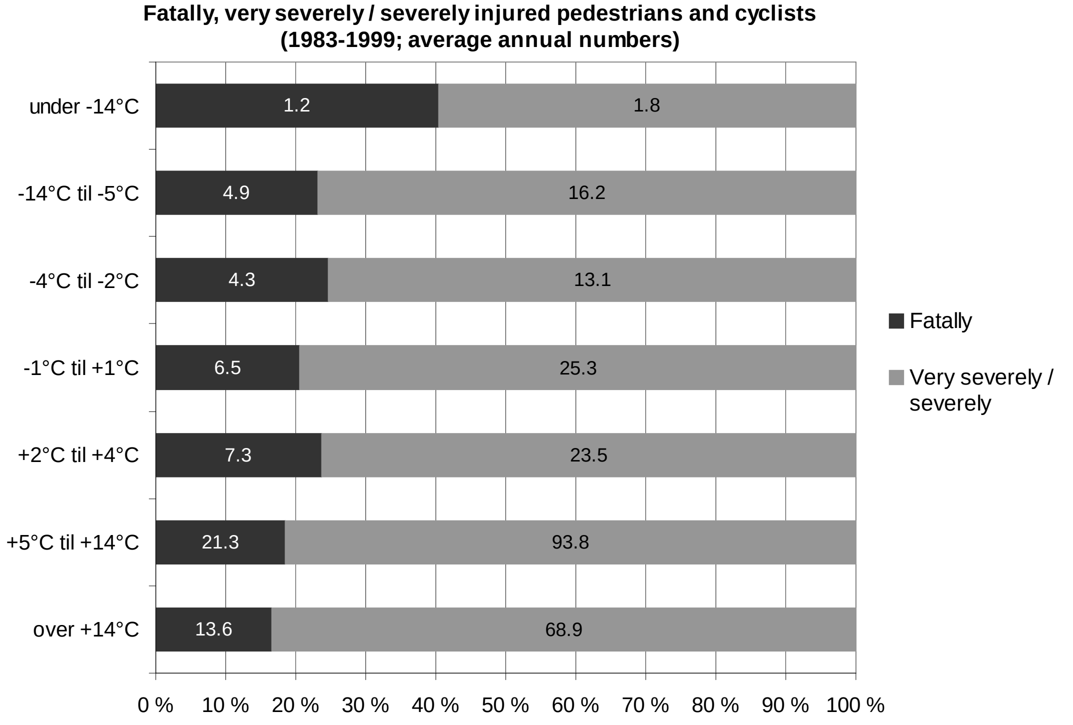
Numbers of injured pedestrians and cyclists with vs. without alcohol or drugs, injury severity (1983-2005). Source: SSB.

Days of the week

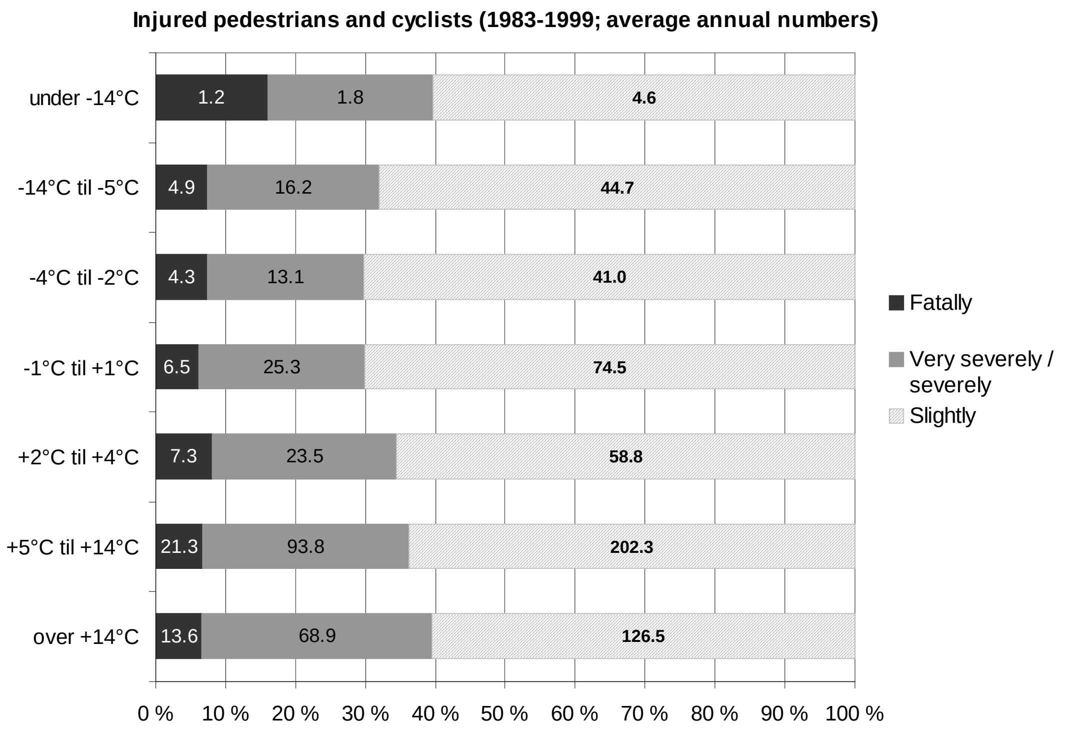


Numbers of fatally, very severely or severely injured pedestrians and cyclists , days of the week (1983-1999, annual average numbers). Source: SSB.

Temperature

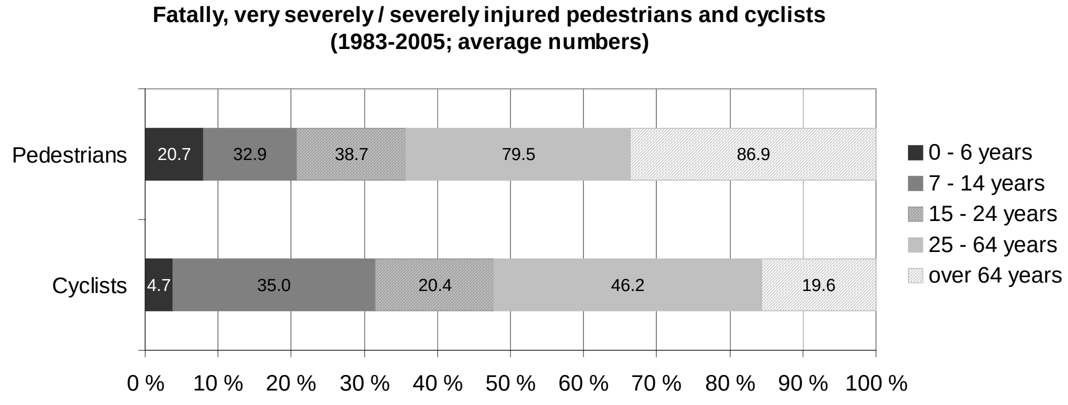


Numbers of fatally, very severely or severely injured pedestrians and cyclists at different temperatures, injury severities (1983-1999). Source: SSB.



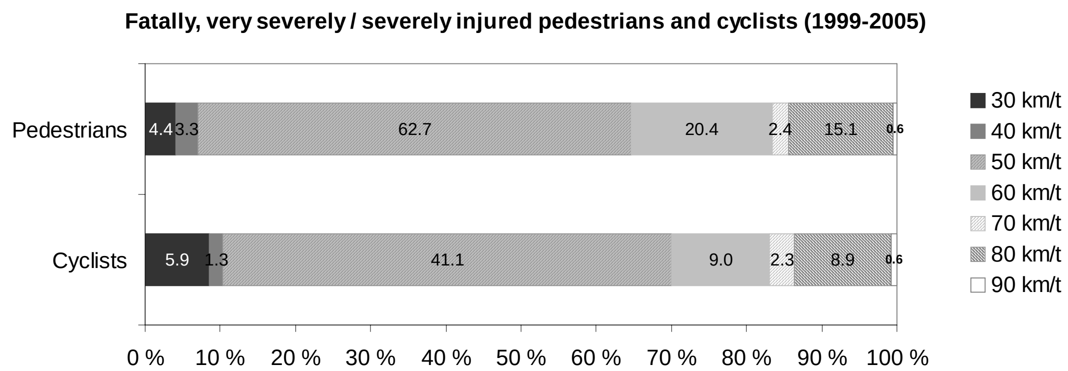
Numbers of injured pedestrians and cyclists at different temperatures, injury severities (1983-1999). Source: SSB.

Age

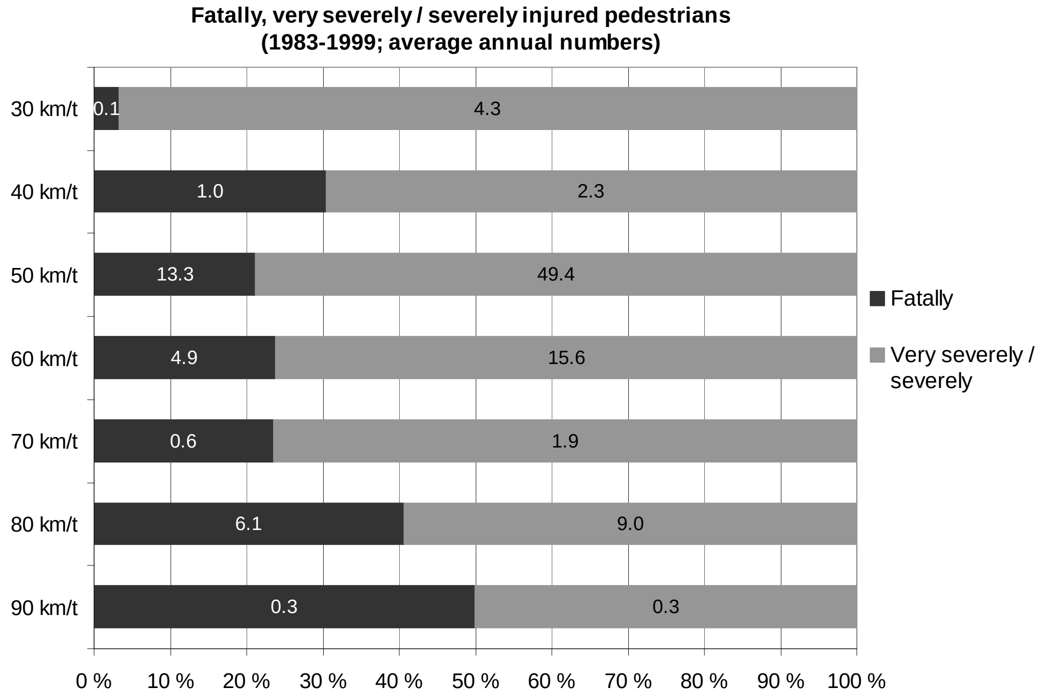


Numbers of fatally, very severely or severely injured pedestrians and cyclists, age groups (1983-2005). Source: SSB.

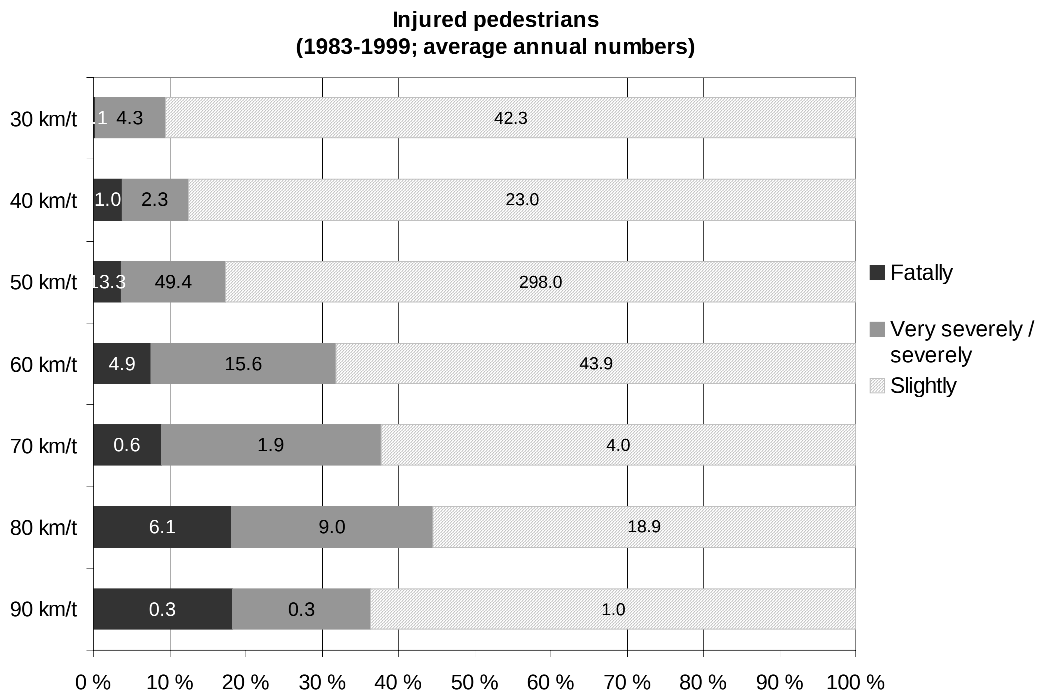
Speed limit



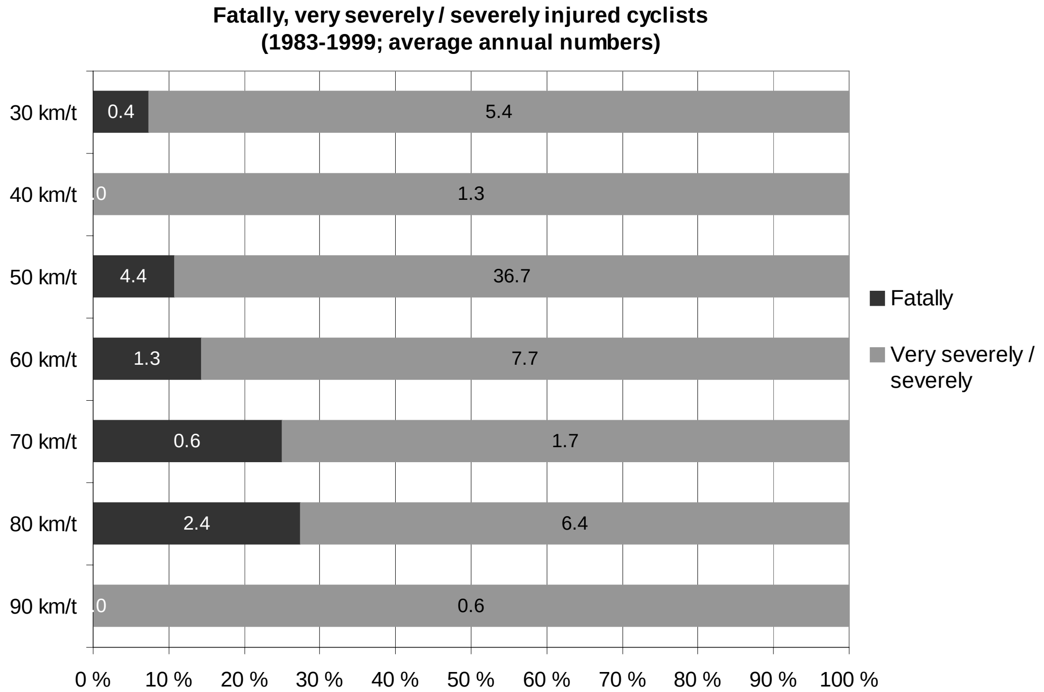
Numbers of fatally, very severely or severely injured pedestrians and cyclists, speed limits (1983-2005). Source: SSB.



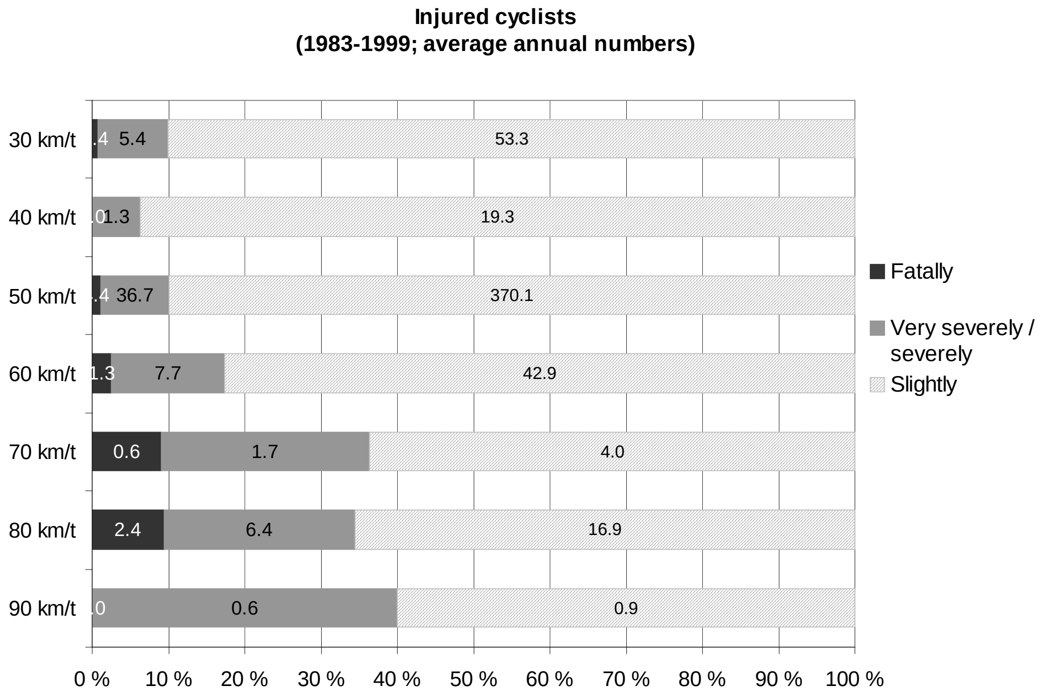
Numbers of fatally, very severely or severely injured pedestrians; speed limits and injury severity (1983-2005). Source: SSB.



Numbers of fatally injured pedestrians; speed limits and injury severity (1983-2005). Source: SSB.



Numbers of fatally, very severely or severely injured cyclists, speed limits and injury severity (1983-2005). Source: SSB.



Numbers of fatally injured cyclists; speed limits and injury severity (1983-2005). Source: SSB.

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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

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