Pedestrians and Cyclists

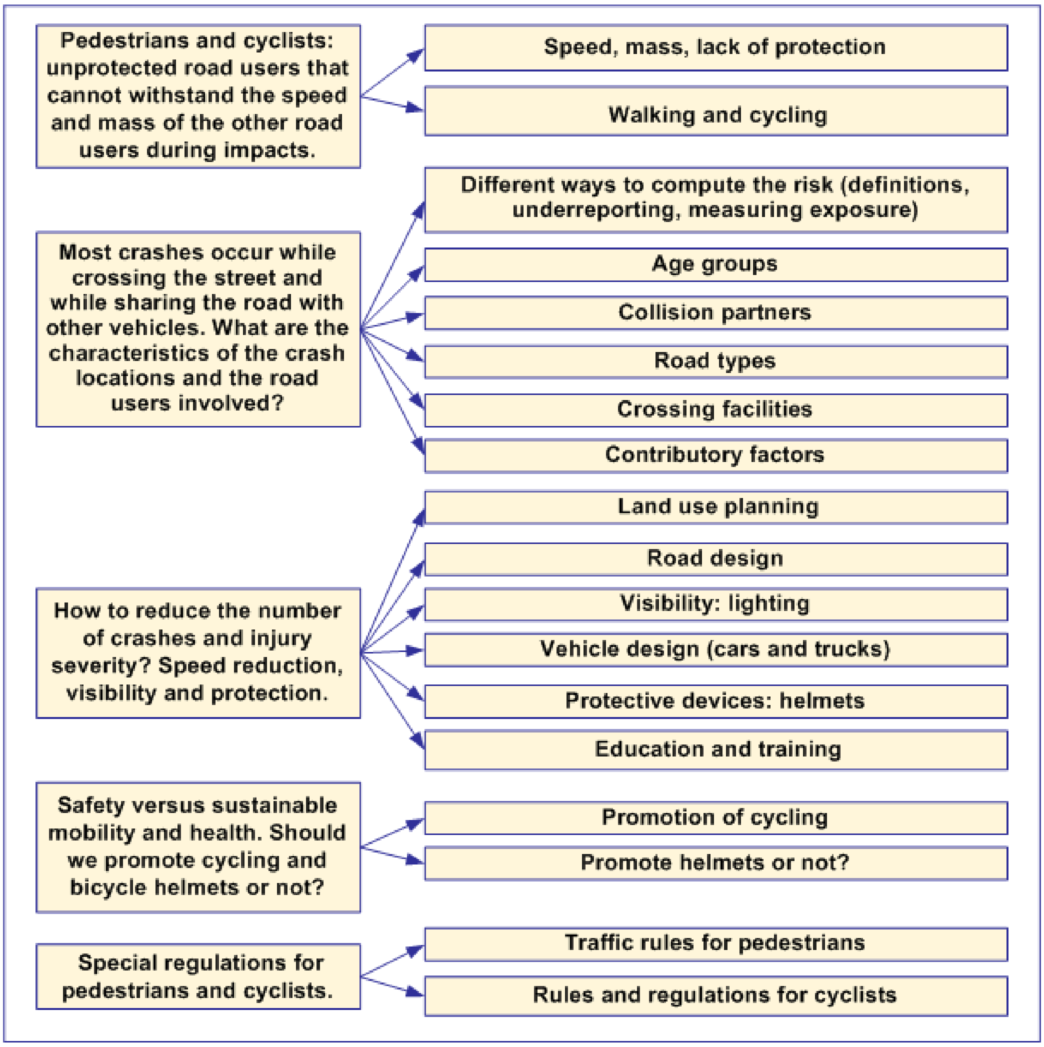
Please refer to this document as: DaCoTA (2012) Pedestrians and Cyclists, Deliverable 4.8l of the EC FP7 project DaCoTA

Project co-financed by the European Commission Directorate General for Mobility & Transport

Contents

1 Overview

This text on the safety of pedestrians and cyclists reviews scientific studies on the magnitude and nature of the safety problem, the contributing crash and crash injury factors and the effectiveness of countermeasures.



For information on the development of casualty frequencies and trends please consult the Basic Fact Sheet Pedestrians and the Basic Fact Sheet Bicycles on the Data section of the ERSO web site.

Unprotected road users
Walking and cycling are transport modes where relatively unprotected road users interact with traffic of high speed and mass. Pedestrians and cyclists are vulnerable road users and suffer the most severe consequences in collisions with other road users, since they are unprotected against the speed and mass of the other party.

Of all journeys, 20-40% are travelled by cycle or on foot, with the highest percentage in the Netherlands and the lowest in Finland. Trips on foot take place most frequently in Great Britain, whereas bicycle trips are most frequent in the Netherlands, Denmark, and Sweden. Some groups of traffic participants walk or cycle more than others. These differences are also reflected in their crash involvement. Walking is particularly important for children below the age of 12 and adults aged 75 and above. The bicycle is used most frequently by adolescents (12-17 years of age).

Crash characteristics
Pedestrians and cyclists comprise around 17% and 6% of all road traffic deaths in EU countries. The age groups having the highest percentage of *pedestrian* deaths are children younger than 10 years of age and adults aged 65 years or older and for *cyclist deaths*, children between 6 and 14 years of age. The percentages of total deaths for these age groups are twice as high as the average for all age groups.

Most injuries to pedestrians and cyclists occur in urban areas. Motor vehicles (cars, lorries, and buses) account for over 80% of vehicles striking pedestrians and cyclists. Crashes involving pedestrians and cyclists occur frequently at facilities designed for pedestrians and cyclists such as pedestrian crossings, cycle tracks, and cycle lanes. This indicates that these facilities are insufficiently safe. At the same time, pedestrian crossings may also be the location at which roads are most often crossed.

Factors that have been identified as contributory factors to pedestrian and cyclist crashes and injuries are the speed of motorised vehicles, the weight and design of motor vehicles, the lack of protection of pedestrians and cyclists, their visibility and vehicle control, and the alcohol consumption of both drivers and of bicyclists and pedestrians.

System-wide countermeasures
Measures that can be taken to reduce the future number of crashes involving pedestrians and cyclists, and/or to decrease the severity of resulting injuries, relate to:

- The planning, design and operation and use of the road network, such as separation of motorised traffic from non-motorised traffic, area-wide speed reduction, the provision of walking and cycling networks.
- Proper design of pedestrian and cyclist facilities.
- Improvement of the visibility of pedestrians and cyclists.
- Vehicle design, in particular crash-friendly car fronts and side-underrun protection on lorries.
- The use of protective devices like bicycle helmets.

- Ensuring compliance of all users with key safety rules including education and training of pedestrians and cyclists as well as drivers.
- Improvements in the emergency medical system and post crash care aiding users in general.

Special regulations for pedestrians and cyclists

Pedestrians and cyclists are both subject to the traffic rules defined in the Vienna Convention of 1968. In some countries, additional regulations have been defined. These relate to supplementary regulations regarding mandatory equipment to ensure cyclists' visibility (e.g., pedal reflectors, spoke reflectors), standards for children's bicycle seats (e.g., seat attachment, footrests), minimum age for cycling on public roads, and helmet legislation.

2 Pedestrians and cyclists: unprotected road users

Walking and cycling are transport modes where relatively unprotected road users interact with traffic of high speed and mass. Pedestrians and cyclists are vulnerable road users and suffer the most severe consequences in collisions with other road users, since they are unprotected against the speed and mass of the other party. This vulnerability can be expressed in terms of inequality in protection. One way to compare the vulnerability of a particular group of road users against other user groups in serious crashes is using the *inequality factor.* This is determined, for example, in car-pedestrian crashes by dividing the number of severely injured car occupants by the number of severely injured pedestrians in for instance car-pedestrian crashes. The higher the factor, the higher the vulnerability is. Table 1 shows the inequality factor for pedestrians and bicyclists in pedestrian-other vehicle type crashes and bicyclist-other vehicle type crashes in the Netherlands.

Table 1: Inequality factor in serious crashes involving vulnerable road users: 2004-2008

Mode of transport	Mode of transport crash opponent				
	Bicycle	Moped	Motorcycle	Car or Van	Lorry
Pedestrian	1.7	3.8	3.9	202.6	-
Bicycle	1	1.8	2.4	126.2	245.0

Source: Ministry of Infrastructure and Environment in the Netherlands

Preventing collisions between fast and slow-moving traffic is, therefore, one of the most important requirements for ensuring the safety of pedestrians and cyclists. Other measures have to be sought in making the crash opponents less harmful to pedestrians and cyclists, such as in vehicle design.

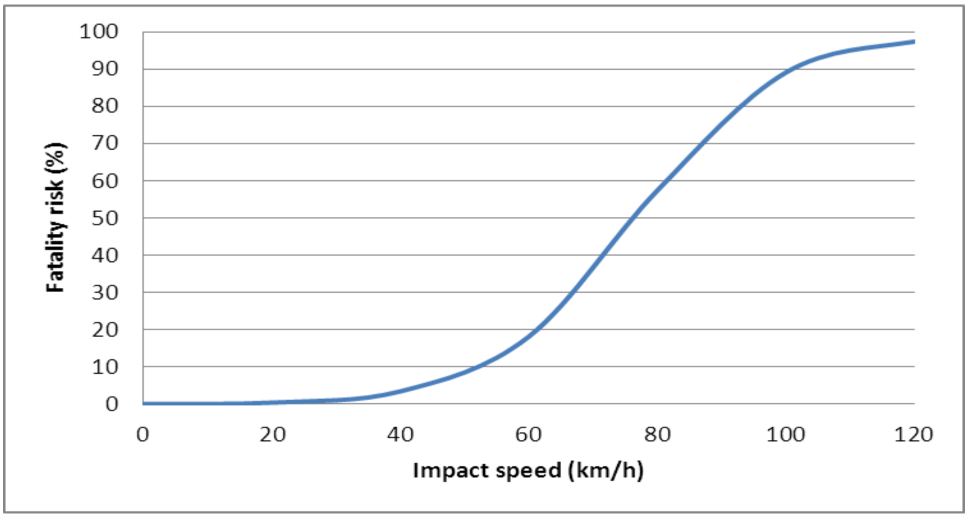
Of all journeys, 20-40% are travelled by cycle or on foot, with the highest percentage in the Netherlands and the lowest in Finland. Trips on foot take place most frequently in Switzerland, whereas bicycle trips are most frequent in the Netherlands and Denmark (See Table 2). Some groups of traffic participants walk or cycle more than others. These differences are also reflected in their crash involvement. Walking is particularly important for children below the age of 12 and adults aged 75 and above. The bicycle is used most frequently by adolescents (12-17 years of age) (OECD, 1998).

2.1 No speed, no mass, and no protection

Speed is a fundamental risk factor in traffic. Firstly, speed is related to crash rate (Aarts & Schagen, van, 2006). From several studies of the relationship between speed and crash rate, we can conclude that higher absolute speeds of individual vehicles are related to an exponential increase in crash rate (Kloeden et al., 1997, 2001). Secondly, speed is related to crash and injury severity. When the collision speed increases, the amount of energy that is released increases as well. Part of the energy will be 'absorbed' by the human body. However, the human body tolerates only a limited amount of external forces. When the amount of external forces exceeds the physical threshold, severe or fatal injury will occur. Hence, higher speeds result in more severe injury. This is particularly true for occupants of light vehicles, when colliding with more heavy vehicles, and for unprotected road users, such as pedestrians and cyclists when colliding with motorised vehicles. See also ERSO web text on Speeding.

Weight (mass) also plays a very prominent role in the outcome of crashes. When a heavy and a light vehicle collide, the occupants of light vehicles are far more at risk of sustaining severe injury (Broughton, 2005). This is because the energy that is released in the collision is mainly absorbed by the lighter vehicle. There are mass differences from a factor of 10 (light cars) to nearly 700 (lorries of 50 tons). In addition, pedestrians and cyclists do not have an ‘steel cage’ around them that can absorb some of the energy released in a collision. Laboratory tests show that in a collision between a car and a pedestrian, the survival rate of the pedestrian decreases enormously as the car speed increases. The probability of fatal injury for a pedestrian colliding with a vehicle is shown in Figure 1.

Figure 1: Fatality risk as a function of impact speed for pedestrians struck by the front of a passenger car

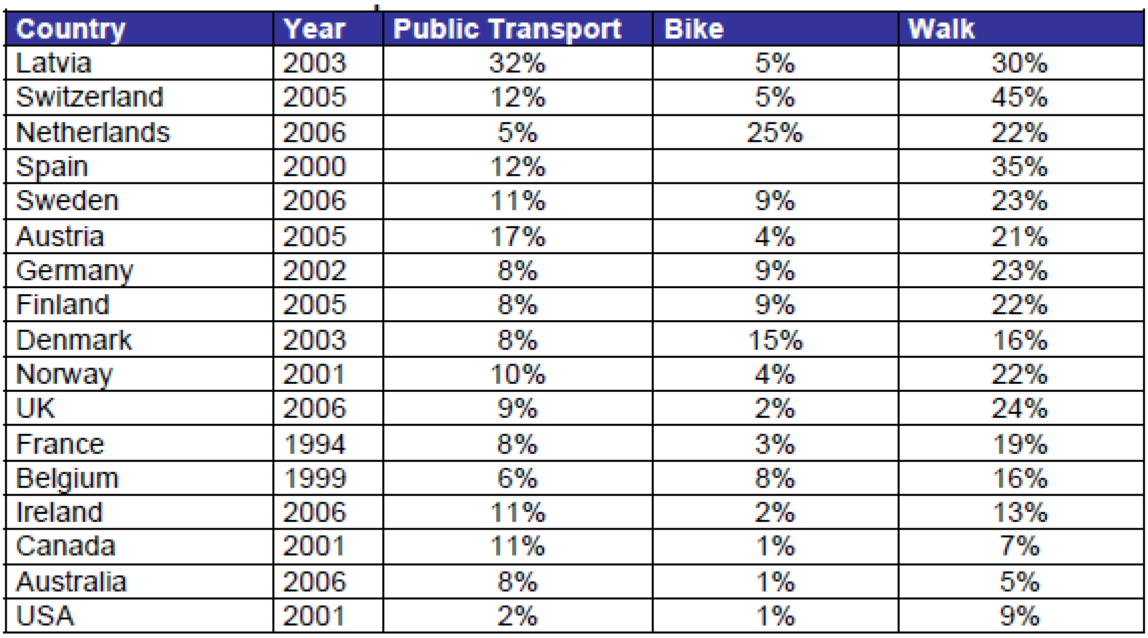


Source Rosén et al., 2011

2.2 Walking and cycling as transport modes

Table 2 presents the average percentage of the daily time spent in traffic as a passenger in public transport, as a bicyclist and as a pedestrian in various countries. The year is the year of measurement (Cabello et al., 2010). In each country on average about one hour per day is spent on travelling.

Table 2: Percentage of the daily time spent on mobility as a passenger in public transport, as a bicyclist and as a pedestrian



Country	Year	Public Transport	Bike	Walk
Latvia	2003	32%	5%	30%
Switzerland	2005	12%	5%	45%
Netherlands	2006	5%	25%	22%
Spain	2000	12%		35%
Sweden	2006	11%	9%	23%
Austria	2005	17%	4%	21%
Germany	2002	8%	9%	23%
Finland	2005	8%	9%	22%
Denmark	2003	8%	15%	16%
Norway	2001	10%	4%	22%
UK	2006	9%	2%	24%
France	1994	8%	3%	19%
Belgium	1999	6%	8%	16%
Ireland	2006	11%	2%	13%
Canada	2001	11%	1%	7%
Australia	2006	8%	1%	5%
USA	2001	2%	1%	9%

Source: Cabello et al., 2010

2.2.1 Walking as a transport mode

Walking as a means of transport is commonly used for short trips. However, assessing pedestrian mobility at country level can be difficult since national travel surveys do not usually register the shorter trips. Also, the walking parts of trips made primarily by public transport are typically not taken into account. At present, the importance of walking is, therefore, underestimated (Wittink, 2001).

Survey data from seven selected European countries show that 12-30% of all trips is made by walking (as the main transport mode), the highest figure being for Great Britain (OECD, 1998). For short trips under 5 km, the share of walking is higher, with a maximum of 45% in Great Britain. The average length of walking trips varies from just under 1 km (Great Britain) to 2.8 km (Finland). It should be noted, however, that the extent of coverage of short trips may vary from country to country in national travel surveys. This will affect the comparability of average trip length and the share of walking. In Great Britain, all trip lengths are included, whereas in Denmark trips shorter than 300 metres are excluded from the survey and all trips between 300 and 1500 metres are recorded to be 1 km (OECD, 1998).

Walking is a means of travelling used mainly for two purposes: short trips to specific destinations such as shops for small items and leisure trips, where walking is in itself the main purpose (Hydén, Nilsson & Risser,1998). About 15-30% of all person kilometres walked (on an average day) is for shopping purposes. Home-leisure trips cover about 30-55% of the person kilometres, with Switzerland at the top and Finland at the bottom (OECD, 1998).

2.2.2 Cycling as a transport mode

In most countries, a high proportion of people own a bicycle (in Norway, for instance, 70% of adults own a bicycle, in Switzerland, 69% of households own a bicycle). The number of bicycles per 1 000 inhabitants ranges from 52 in the Czech Republic to 1.000 in the Netherlands. What differs considerably from one country to another is the way in which the bicycle is used. Some cyclists use it every day, as a means of transport, while others do so only occasionally (ECMT, 2000).

Survey data from a selection of seven European countries show that 3-28% of all trips are made by cycling, the highest figure being for the Netherlands (OECD, 1998). For short trips under 5 km, the share of cycling varies from 12% (Finland) to 39% (the Netherlands). The average trip length for cycling is around 3 km in most European countries.

The bicycle is used for short trips to shops and for leisure purposes where the bicycle-tour probably is an aim in itself. However, cycling is also a common way for travelling to work (Hydén, Nilsson & Risser,1998). Between about 30 and 40% of the person kilometres by bicycle is travelled on home-work trips. Home-leisure trips cover about 20-45% of the person kilometres, with the most made in Switzerland and the least in Finland (OECD, 1998).

2.2.3. Age groups most involved in walking and cycling

Some groups of traffic participants walk or cycle more than others. These differences are also reflected in their crash involvement. Age groups for which walking is particularly important, are children below the age of 12 and adults aged 75 and above. Data from the Netherlands illustrate this. People aged over 75 years make one-third of their trips on foot. They use the car slightly more often (38%), but considerably less often than younger adults aged 25 to 74 years, who use this vehicle for more than half of their trips. The bicycle is considerably less popular for elderly people: they use the bicycle for only 17% of all trips. Together with people aged between 25 and 29, they use the bicycle the least.

The bicycle is more important in the youngest age categories. Data from the Netherlands (Table 3) show that children in the age group from 0 to 11 years travel by bicycle as often as they walk (both 29%). The same is the case for young adults aged between 18 and 24 years. Next to walking (20%) and cycling (23%), public transport (18%) is a commonly used mode of transport among these groups. For young people in secondary school (12 to 17 years of age), the bicycle is by far the most important vehicle: they use their bicycle for no less than 52% of all trips.

Data from other European countries show the same pattern: young children and older adults walk the most, whereas somewhat older children cycle the most (OECD, 1998; Hydén, Nilsson & Risser, 1998).

Table 3: Modal split by age group in the Netherlands.

	0-11	12-17	18-24	25-29	30-39	40-49	50-59	60-74	75+
Pedestrian	29%	18%	20%	19%	18%	17%	18%	25%	34%
Bicycle	29%	52%	23%	17%	20%	23%	22%	24%	17%
Moped/mofa	0%	3%	2%	1%	1%	1%	1%	0%	1%
Motorcycle/scooter	0%	0%	0%	0%	0%	0%	0%	0%	0%
Passenger car	40%	17%	37%	56%	56%	55%	54%	46%	38%
Bus	1%	5%	8%	2%	1%	1%	2%	2%	4%
Tram/metro	0%	1%	3%	2%	1%	1%	1%	1%	1%
Train	0%	2%	6%	3%	2%	2%	1%	1%	1%
Other	1%	1%	0%	0%	0%	0%	0%	1%	3%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Wegman & Aarts, 2005

3 Crash characteristics: where and how?

The number of fatalities among pedestrians and cyclists in Europe decrease (See the Basic Fact Sheet Pedestrians and the Basic Fact Sheet Bicycles). However, the decline is slower than the decline of fatalities among car occupants. Age groups that have the highest percentage of pedestrian fatalities are children younger than 10 years of age and adults aged 65 years or older. Cyclist fatalities have the highest share among children between 6 and 14 years of age. The percentages for these age groups are about twice as high as the average percentages for all age groups. The following sections contain information about the circumstances in which pedestrian and cyclist crashes take place and starts with some data considerations: what crashes are considered to be traffic-related, and how well are they reported in the police crash statistics.

3.1 Data considerations

3.1.1 Definition of a traffic-related crash

Not all crashes involving pedestrians and/or cyclists are considered to be traffic-related. According to the UNECE definition, road traffic crashes are those (1) which occurred or originated on a way or street open to public traffic; (2) which resulted in one or more persons being killed or injured and (3) in which at least one moving vehicle was involved.

These crashes include collisions between vehicles, between vehicles and pedestrians, and between vehicles and animals or fixed obstacles. Single vehicle crashes in which one vehicle alone (and no other road user) is involved, are included. Multi-vehicle collisions are counted as only one crash but can lead successive collisions happen at very short intervals. (United Nations Economic Commission for Europe, 2005).

As a result, an impact in which a pedestrian fell as a result of loose paving stones is not regarded as a road traffic crash. The same applies for an impact where the pedestrian fell while boarding or alighting from a bus.

3.1.2 Certain types of crashes are underreported

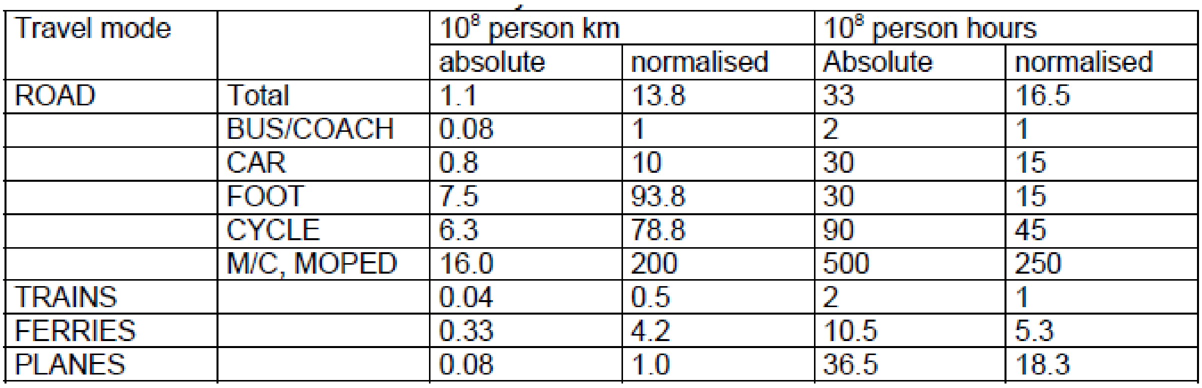
Pedestrian and cyclist crashes are heavily and disproportionally underreported in the police crash statistics compared to what hospital records and other studies show (OECD, 1998). Single-vehicle crashes, in particular, in which the ‘vehicle’ is a pedestrian or a bicyclist, are grossly underreported in police statistics. Pedestrian falls, even where this may be due to the poor quality of the pavement or in reaction to the action of another road user (and without impact with that other road user), is not considered to be a road crash and these are not reported in the police statistics. A comparison between medical data and police data in the Netherlands indicates that only 4% of the single-vehicle crashes in which the vehicle was a bicycle and the cyclist was seriously injured (MAIS 2 or more), are recorded by the police (Reurings & Bos, 2009) whereas it is estimated that 70% of the bicycle impacts are single-vehicle crashes (Kampen,van, 2007).

3.1.3 Risk and measurement of exposure

Comparing the crash risks of cyclists and pedestrians with those of car occupant can be problematic. Risk is the ratio between some measure of adverse consequences (e.g. crashes in which people are severely injured or killed) and some measure of exposure to conditions under which those consequences are possible. In the case of transport the most widely used measure of exposure is distance travelled, yet the speed at which such travel is conducted also influences risk. Since speeds for various transport modes (walking, cycling, motorised transport) are widely different, it has been suggested that exposure (vehicle kilometres travelled) should be normalised by multiplying by speed to produce a risk measure which is expressed as crashes or casualties per hour of exposure.

Table 3 shows the fatality risk of different modes of transport both in terms of the number of fatalities per distance travelled and the number of fatalities per hour travelled. In the columns with the heading 'normalised' the risks of the different modes of transport are compared with the risk of a passenger in public transport. This risk is set on 1.

Table 4: Fatality risks over distance and time for various modes of transport.

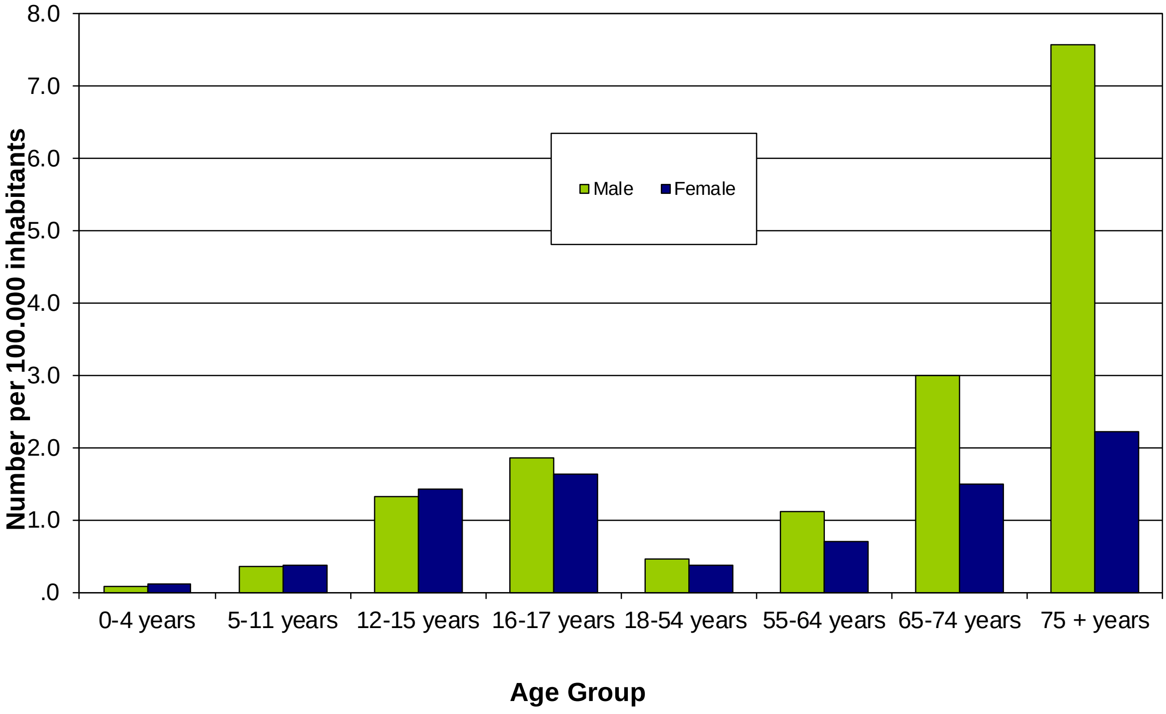


Travel mode		10^8 person km		10^8 person hours	
		absolute	normalised	Absolute	normalised
ROAD	Total	1.1	13.8	33	16.5
	BUS/COACH	0.08	1	2	1
	CAR	0.8	10	30	15
	FOOT	7.5	93.8	30	15
	CYCLE	6.3	78.8	90	45
	M/C, MOPED	16.0	200	500	250
TRAINS		0.04	0.5	2	1
FERRIES		0.33	4.2	10.5	5.3
PLANES		0.08	1.0	36.5	18.3

Source: Hakkert , A.S. (2010) and based on ETSC data (1999).

Table 4 shows that when distance travelled is used as denominator, driving in a car is more than nine times safer than walking and almost eight times safer than cycling. However, when time in traffic is used as denominator driving in a car is as safe as walking and only three times safer than cycling. Figure 2 shows the risk per age group and gender of bicyclists in the Netherlands with the number of inhabitants as denominator and Figure 3 shows this risk with the distance cycled as denominator.

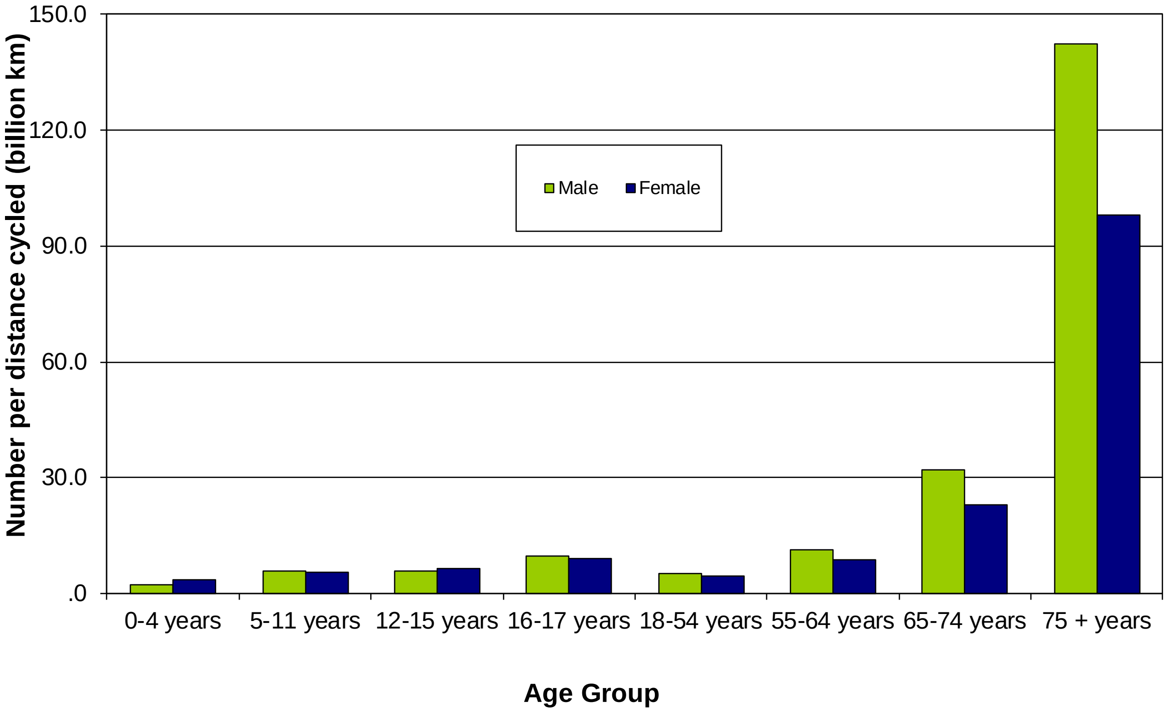
Figure 2: Number of killed bicyclists per 100.000 inhabitants by gender and age group in the Netherlands (2005-2009).



Source: Ministry of Infrastructure and Environment.

The effects of the different denominators in Figure 2 and Figure 3 to calculate risk is clearly visible. Whereas Figure 2 shows that teenage bicyclists have an increased risk, Figure 3 shows that this is hardly the case. The reason is that teenagers cycle a lot in the Netherlands as most of them go to their secondary school by bicycle. In both Figure 2 and Figure 3 the crash rate of the oldest age group is high, however the crash rate of older female bicyclists is much lower than of older male bicyclists in Figure 2 and the difference is not so extreme in Figure 3. The reason is that there are more older females than older males. The main reason that older bicyclists have such a high crash rate is predominantly caused by their increasing vulnerability with age and to a lesser extend to their decreasing road user and capabilities (e.g. longer reaction times, reduced vision) and cycling capabilities (e.g. reduced muscular strength) with age).

Figure 3: Number of killed bicyclist per billion kilometres cycled by gender and age group in the Netherlands (2005-2009).

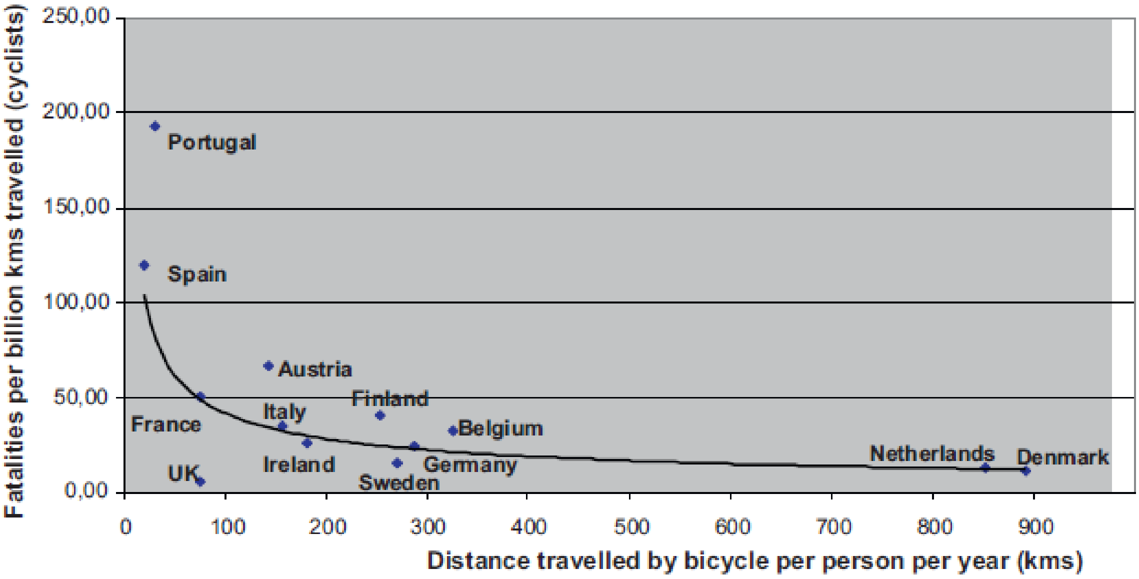


Source: Ministry of Infrastructure and Environment.

A second problem that is introduced when comparing crashes among cyclists and pedestrians with those among car drivers and/or passengers relates to the roads they use. More than one third of all car kilometres are driven on highways that have been made very safe. If only those roads are considered which are also used by cyclists and pedestrians, the crash rate for car driving will be higher (Wittink, 2001).

Thirdly, less easily quantifiable measures such as the level of congestion of the roads or behavioural factors such as whether children are accompanied on their journeys also affect exposure to risk. The same applies for cycling experience. The more experienced a cyclist is, the lower his fatality rate is, and vice versa. Not only individual kilometrage matters. Crash rates are also related to the total amount of cycling in a country. In countries where people cycle a lot, cyclists in general have a lower fatality rate. A similar inverse relationship exists for the number of pedestrians or cyclists crossing at intersections. Summersgill et al. (1996) have shown that for pedestrians crossing at intersections, increasing pedestrian flows result in lower crash rates per crossing pedestrian (Wittink, 2001; PROMISING, 2001c). Jacobson (2003) noted that the larger the group of pedestrians and cyclists in a country was the lower their crash risk was and that the relationship between group size and crash risk was non-linear. This non-linear relationship is shown by the regression line in Figure 4.

Figure 4: Relationship between fatality rates and bicycle usage for European countries based on IRTAD-data

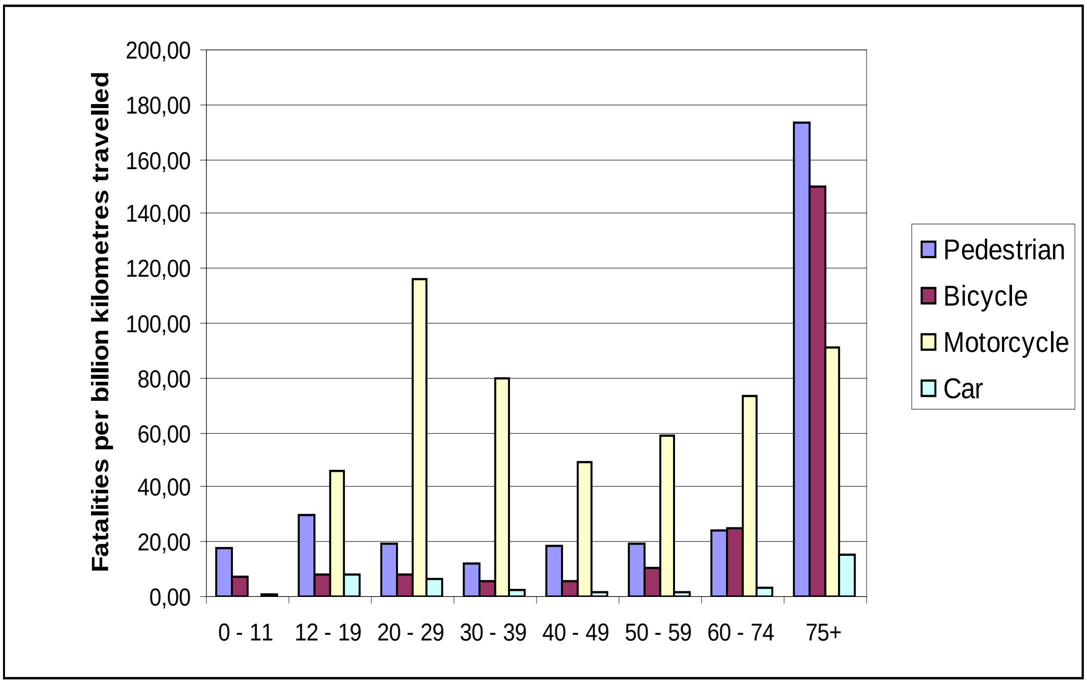


Source: Wegman et al., 2010

The non-linear relationship between the number of vulnerable road users and their crash risk is denoted as ‘safety in numbers’. There is no one explanation for the safety in numbers effect. Firstly, when there are more bicyclists and pedestrians, they expect certain behaviour in certain conditions by pedestrians and bicyclists and anticipate possible hazards. Pedestrians and cyclists take more notice of cars in countries where they are more exposed to cars (i.e. hazard anticipation by bicyclists and pedestrians). The infrastructure (bicycle paths, pavements) is better in countries with more cyclists and pedestrians. When short trips by car are replaced by trips by bicycle, the occasions where cars can collide with bicycles decrease. That car drivers learn over time to expect bicyclists coming from unexpected directions after more exposure to a particular critical situation was shown by Phillips et al. (2011). Stipdonk and Reurings (2010) deduced from data and some hypothetical conditions that when young drivers replace short car trips by bicycle trips, the number of fatalities decline, but when older drivers do this, the number of fatalities increase.

Bearing in mind the limitations that the use of crash and fatality rates, the Figure 5 gives an indication of the fatality rates for different age groups while walking, cycling, riding a motorcycle, and driving a passenger car:

Figure 5: Fatalities per billion kilometres travelled in the Netherlands; 2001-2005



Source: Dutch Ministry of Transport/Statistics Netherlands

3.2 General trends in number of fatalities

In the last decade, pedestrian fatalities have diminished by around 25% in the EU, while the total number of fatalities decreased by nearly 30%. In 2008, the proportion of fatally injured pedestrians of the total number of traffic fatalities was the lowest in the Netherlands (8%) and in Sweden (11%) and the highest in Romania and Poland (almost 50%). The EU average is 20%. See Traffic Safety Basic Facts for Pedestrians for 2010.

Bicycle fatalities make up 6.5% of the total number of road fatalities in 2008 in the EU-23 countries. In these countries 2,440 people riding bicycles were killed in traffic accidents in 2008, which is 8% less than the 2,655 bicycle fatalities reported in 2007. In the EU-16 countries (EU-23 except Germany, Estonia, Latvia, Hungary, Poland, Slovenia and Slovakia) the number of cyclist fatalities decreased by 29% during the decade 1999-2008. It should be noted, however, that reductions in the number of fatalities in a country cannot be evaluated without also looking at trends in mobility. Numbers of pedestrian and cyclist fatalities are affected both by the number of walkers and cyclists and the number of motorised vehicles with which they are likely to be in conflict. But mobility data on pedestrian kilometres and cyclist kilometres are only available for a few countries (see Table 4 for data for the Netherlands and the United Kingdom).

Table 5: Billion person kilometres travelled as pedestrian or cyclist.

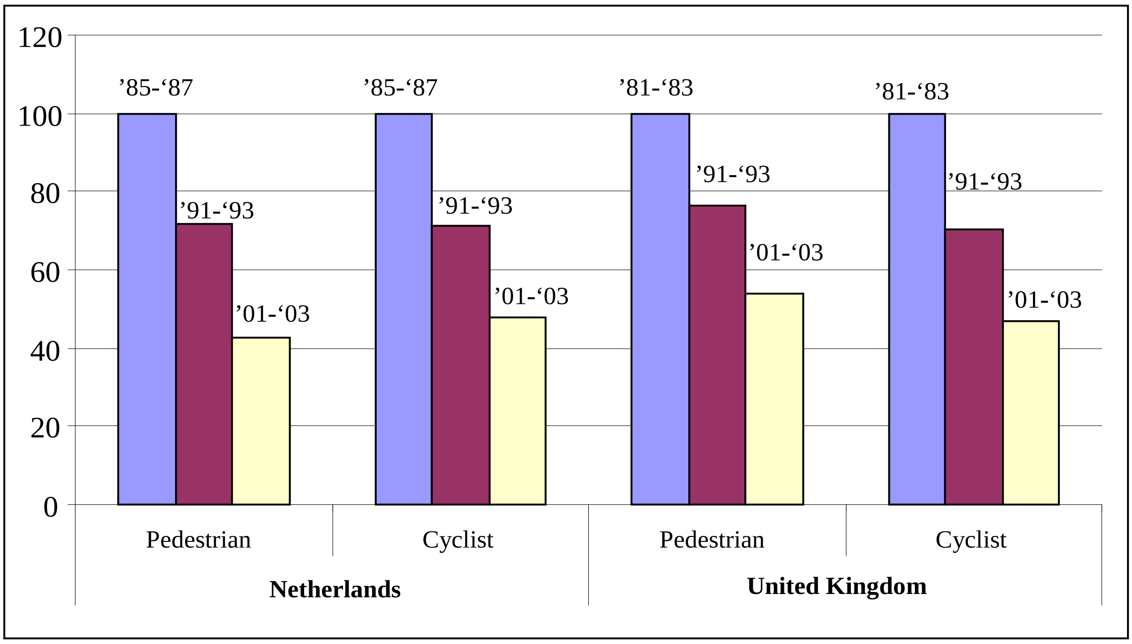
		1981-1983*	1991-1993	2001-2003
Pedestrians	UK	27.5	26	21.3
	Netherlands	10.7	11.7	13.3
Cyclists	UK	5.0	4.8	4.4
	Netherlands	2.7	2.9	3.3

* For the Netherlands, 1985-1987 data are used

Source: SUNflower +6 (Lynam et al., 2005)

Since exposure data are available for only a few countries, the question remains whether the reduction in fatalities were caused by a reduction in kilometrage (exposure to danger) or by an increase in safety per walking kilometre. Exposure data from Table 5, Figure 6 shows that in 2003 compared to the 1980s, the numbers of pedestrian fatalities per kilometre travelled and cyclist fatalities per kilometre travelled were reduced to about 50%.

Figure 6: Index of pedestrian fatalaties and cyclist fatalaties per kilometre walked and cycled respectively for the Netherlands and United Kingdom



Source: SUNflower +6 (Lynam et al., 2005)

3.3 Age groups most involved in fatal crashes

In the EU, the proportion of killed pedestrians of all road fatalities per age group is high for children, but is the highest for pedestrians for the eldest pedestrians 80 years of age and older. The proportion of killed pedestrians of all road fatalities starts to increase after age 50 (see the already mentioned 'Traffic Safety Basic Facts' for pedestrians of 2010). Age groups that have the highest percentage of *pedestrian* fatalities are children younger than 10 years of age and adults aged 65 and above. About 35 to 40% of the fatalities in these age groups were pedestrian fatalities; twice as much as the average percentage for all age. The youngest age groups, those younger than 10 years of age, also have the highest percentage of pedestrian casualties: 30-40% of the casualties in these age groups were pedestrian casualties.

Cyclist fatalities have the highest share among children between 6 and 14 years of age. About 14% of the fatalities in this age group were cyclist fatalities; twice as much as the average percentage for all age groups. Children between 10 and 14 years of age also have the highest percentage of cyclist casualties: 30% of the casualties in this age group were cyclist casualties.

3.3.1 Young pedestrians and cyclists

Most crashes involving children occur in the late afternoon, when they are either walking back home or playing outside. Several British studies have shown that most of the pedestrian fatalities were connected to running or not paying attention at the time of the crash (Sentinella & Keigan,2005; Carole Miller Research, 1998; Tight et al., 1996). In the Netherlands, fatal crashes with children are nearly always with a motor vehicle. The impacting vehicles are typically: cars for young pedestrians, and heavy vehicles (vans and lorries) for young cyclists. Collisions between cyclists and heavy goods vehicles include the common crash scenario where the cyclist is in the blind spot of a lorry turning right (or turning left in left-hand side driving countries).

A study of children's exposure to risk as pedestrians and their rate of involvement in crashes in three European countries found a higher fatality rate among children in Britain than among children in France and the Netherlands, although children in Britain spent marginally less time in traffic as pedestrians and crossed the road less frequently than children in the other two countries (Bly et al., 1999). This study found that these exposure rates alone do not explain the increased fatality rate. It was determined that children in Britain spend more time on main roads and busy streets than children in the other two countries, that they cross roads between rather than at intersections, and that they are more likely to be accompanied by other children than by adults. These specific examples of exposure are, in turn, connected with the country's residential and traffic infrastructure and, not least, with typical national habits such as adults accompanying children to school (OECD, 2004).

While all children are vulnerable, some children are more at risk than others. There is some evidence of a gender correlation between road safety behaviour and crash involvement. In the United Kingdom, crash patterns for pedestrians reveal a consistently higher rate of incidence for boys than for girls under age 12. In the 5-11 age group, twice as many boys are likely to be killed or severely injured than girls. In the Netherlands, 64% of the traffic victims under 14 are boys. Teenage male bicyclist fatalities exhibit a similar pattern. Teenage female pedestrians may be at particularly high risk once their exposure is taken into account (Ward, 1994), (OECD, 2004).

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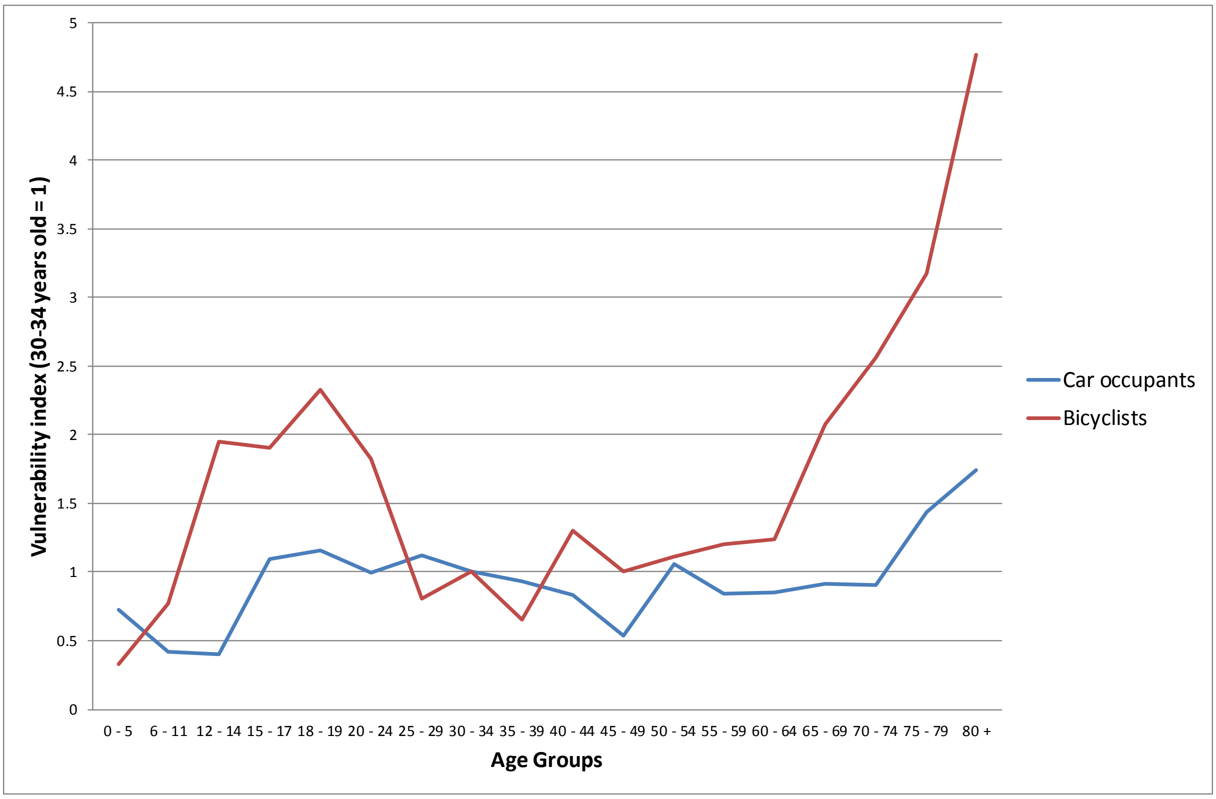
3.3.2 *Elderly pedestrians and cyclists*

An important cause of the high fatality rate of older cyclists and pedestrians is the physical vulnerability of elderly people. Since their bones are more brittle and their soft tissue less elastic, they are at higher risk of severe injury, even if the crash forces are the same. If it is assumed that cyclists of all ages have about the same speed (around 16 km/h) when they fall, the number of fatalities divided by the number seriously injured provides an indication of the vulnerability of the cyclists. The smaller the figure for a particular age group, the less vulnerable are the cyclists in this age group. In Figure 7 the rate between fatalities and seriously injured bicyclists and the rate between fatalities and seriously injured car drivers of 30-34 years of age is indexed as 1. The figure shows the vulnerability index by age group for bicyclists and car drivers in the Netherlands.

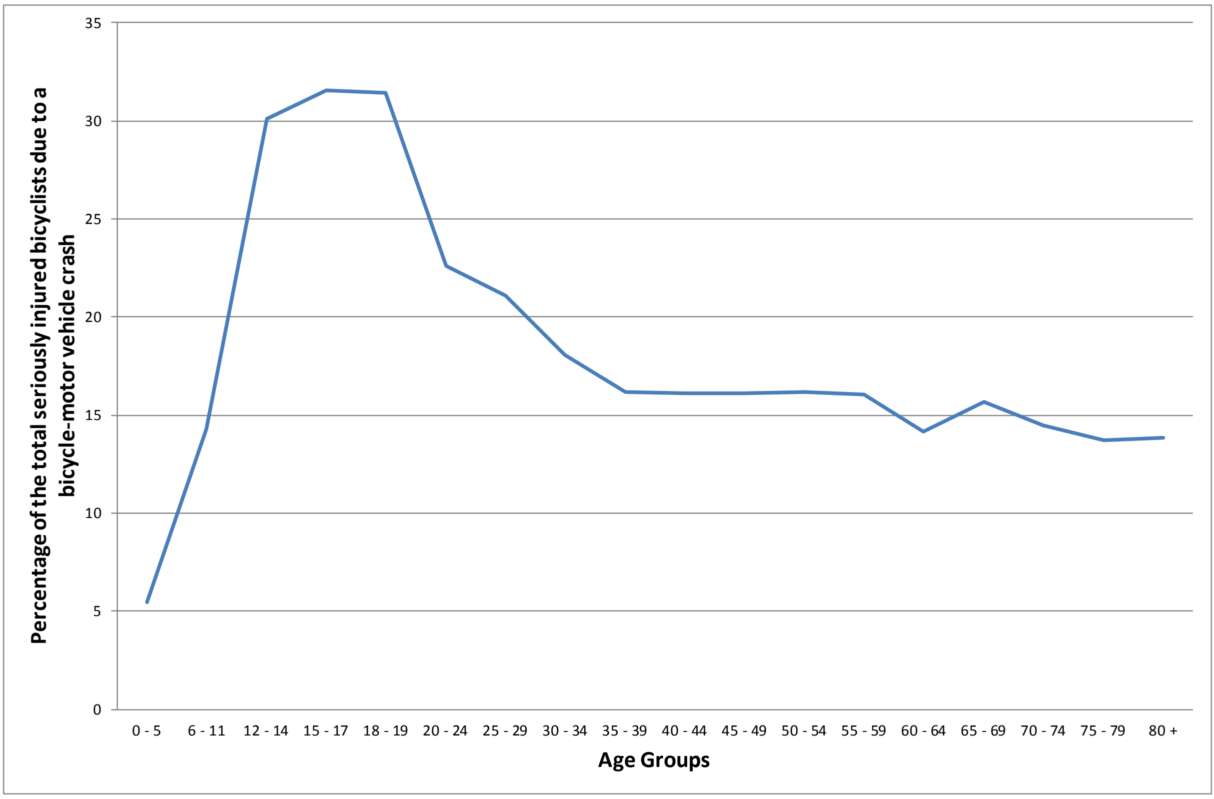
Figure 7: Vulnerability index: the number of fatalities divided by the number of seriously injured per age group for bicyclists and car occupants in the Netherlands (2007-2009) with the vulnerability of the 30-34 years old indexed as 1



Source: Ministry of Infrastructure and Environment

Figure 7 indicates that older cyclists are much more vulnerable than middle-aged cyclists and that older cyclists are much more vulnerable than older car occupants. Teenage bicyclists also have a relatively high vulnerability. This is remarkable as, in general, they are physically strong and in good health. It was assumed that when bicyclists of all ages have a crash, This is apparently not true. Figure 7 indicates that the kinetic impact of a crash is not the same for all and shows the percentages of cyclist-motor vehicle crashes of all the cycle crashes (including the single vehicle crashes) resulting in serious injury.

Figure 8: Percentage seriously injured bicyclists of the total number of seriously injured bicyclists per age group due to a bicycle-motor vehicle crash in the Netherlands (2007-2009).



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Source: Ministry of Infrastructure and Environment.

Figure 8 shows that teenage cyclists are more seriously injured due in a crash with another vehicle than middle-aged bicyclists and older bicyclists. As the kinetic impact of a crash in general will be stronger than a fall, the peak for teenage bicyclists in Figure 7 is self-evident. Figure 8 indicates that the peak in Figure 7 for young bicyclists is caused by the fact that they less often fall and more often collide with other motor vehicles than bicyclists in other age groups.

The elderly have a higher chance of being involved in a crash because people become more vulnerable when they grow older but also because locomotive functions deteriorate with increasing years. This deterioration generally consists of slower movement; a decrease of muscular tone, a decrease in fine coordination, and a particularly strong decrease in the ability to adapt to sudden changes in posture (keeping balance). This latter aspect is particularly important for cyclists and pedestrians, but also for public transport users. See ERSO web text on Older Drivers .

Older pedestrians are over-represented in crashes at intersections, particularly those without traffic signals, and being struck by a turning vehicle. Older pedestrians are also over-represented in crashes when they are crossing mid-block sections of roads, particularly on wide multi-lane roads, in busy bi-directional traffic (Oxley et al., 2004). Pedestrian crashes in which no moving vehicle is involved also occur more frequently among older pedestrians. However, these are not included in the UNECE definition of a road accident and are, therefore, heavily under-reported or not included in crash databases at all. These include falls when boarding or exiting public transport, falls on footpaths, when stepping off kerbs, and while crossing the road (without being struck by a vehicle). Although injuries resulting from pedestrian falls and other non-collision events are generally not as severe as those where a vehicle is involved, they nevertheless represent a significant cause of trauma for older pedestrians (Oxley et al., 2004).

According to Dutch studies (Goldenbeld, 1992), when older cyclists crash with a passenger car, the cyclist often had to cross a multi-lane road. Such incidents (63% of all crashes) occurred particularly inside urban areas (50%), at intersections (19%), and at T-junctions (15%). The latter crashes most often occurred at intersections and T-junctions which were controlled by traffic signs (25%). The difficulties experienced by older cyclists related primarily to manoeuvres such as crossing or turning against the traffic at the intersection. In the majority of these cases, the passenger car was driving on a main road while the cyclist approached from a side road. This crash type resembles the crash type that is over-represented among older car drivers: while turning, the older driver collides with oncoming traffic with right of way on the main road (see ERSO Older Drivers web text). Negotiating an intersection clearly represents a “testing of the limits” type of task; it requires a host of age-sensitive functions while simultaneously limiting the usefulness of normal safe driving strategies such as anticipating upcoming events.

3.4 Collision partners

The more severe the consequences of a traffic crash, the more that the crash will be a collision between a motor vehicle and a pedestrian or cyclist. Table 6 shows the average annual number of fatally, seriously and slightly injured pedestrians per million inhabitants in the Netherlands as a result of a collision with another road user and as a result of a fall not involving other road users.

Table 6: Average number of victims over the years 2003-2007 per million inhabitants in the Netherlands.

	Deaths	Serious injury	Minor injury	Total
Pedestrians	9.2	319	3050	3375
Involving no other road users	2.8	245	2815	3070
Involving other road users	6.4	74	235	305
Bicyclists	13.5	466	3695	4170
Involving no other road users	3.1	368	2915	3280
Involving other road users	10.4	98	780	890
Other means of transport	36.5	503	2950	3495
Total	59.2	1288	9695	11040

Source: Methorst (2010)

3.5 Road types

Most injuries (all severities) to pedestrians and cyclists occur in urban areas. However, in rural areas, the percentage of fatalities is higher than the percentage of slight injuries (OECD, 1998). This means that crash severity is higher in rural areas. Higher vehicle speeds in such areas is a key factor but factors include: the absence of pedestrian facilities e.g. footpaths, a more acute visibility problem, the increased negative effects of drink driving etc. (ECMT, 2000). Although this general tendency is observed (i.e., most casualties occurring in urban areas), in France and Spain there are more fatalities of cyclists in rural areas than in urban areas. In addition, in Spain more pedestrian fatalities occur in rural areas than in urban areas (OECD, 1998).

3.6 Crossing facilities

Crashes involving pedestrians and cyclists occur frequently at facilities designed for pedestrians and cyclists such as pedestrian crossings, cycle tracks, and cycle lanes. This means that these facilities are not necessarily safe enough to prevent crashes (OECD, 1998). However, pedestrian crossings probably also are those locations at which roads are most often crossed.

In the United Kingdom, over 20% of crashes happen at places where people should be safe, such as on the pavement or at a pedestrian crossing. In Denmark, half of the crashes with cyclists occur at facilities for cyclists such as cycle tracks or cycle lanes (OECD, 1998).

Pedestrian crashes occur most often whilst crossing the roadway, especially for older pedestrians. In the Netherlands, 25% of the pedestrians who died as a result of a crash while crossing the road, were crossing at a zebra or other kinds of pedestrian crossing. Among the elderly, 75% of pedestrians who died as a result of a crash did so whilst crossing the road. Of these, 38% were crossing the road at a pedestrian crossing.

Pedestrian crashes often occur when people are trying to cross the street on links off pedestrian crossings, viz. where no pedestrian crossings exist. One of the causes is the driver's difficulty in perceiving pedestrians because of darkness and/or parked cars. In the United Kingdom, nearly 90% of the injury accidents with older pedestrians which are caused by motor vehicles happen under such conditions. In over 10% of the cases the drivers cannot see pedestrians because of parked cars. 67% of pedestrians in the United Kingdom were killed or injured whilst crossing the road more than 50 metres away from a pedestrian crossing (OECD, 1998).

3.7 Contributory factors

There are various causes why motor vehicles collide with pedestrians and cyclists. Drivers may drive too fast and may not notice pedestrians and cyclists. It could also be that drivers do not expect pedestrians and cyclists from certain directions (Summala et al., 1996) or do not expect that in certain circumstances pedestrians and bicyclists may start to act dangerously (e.g. a pedestrian who suddenly may cross the road, because he wants to catch his bus that has stopped on the other side of the road). It could also be that drivers have adequate hazard perception skills, but underestimate the risks and/or overestimate their own capabilities to avert a crash. Not only drivers, but also pedestrians and bicyclists may lack hazard perception skills and/or take too much risk. Lack of hazard perception skills (both by drivers and pedestrians and bicyclists) and the tendency to take too much risk (both by drivers and pedestrians and bicyclists) is influenced by factors such as experience, age, training and gender. There are also temporally factors such as the influence of psychoactive substances (alcohol, illicit drugs and medicines), fatigue, inattention/distraction and emotions.
Drivers may not notice pedestrians and bicyclist because they are poorly visible. This is aggravated at dusk, dawn, and night, especially when public lighting is absent or weak. The most serious problem for cyclists seems to be detection of them by drivers approaching alongside or from behind. The limited physical visibility of cyclists (linked to their vehicle - car drivers are seeking for vehicles as big as theirs) is reinforced, at least in countries when cycling is not very common, by their lack of 'social visibility': car drivers do not see cyclists because they do not expect to see any (PROMISING, 2001b).

The influence of technical defects of the bicycle, the quality of the road surface, and the presence of protective devices (such as cycle seats and wheel spoke covers) has been analysed in the Netherlands. A technical cycle defect was cited as the principal cause of the crash by 7% of cyclists aged twelve years and older. In most cases, the condition of the brakes was poor (Schoon, 1996).

The increase of crash risk with the amount of alcohol consumed is about the same for drivers and bicyclists, but increases steeper for pedestrians (Olkkonen & Honkanen, 1990).

4 Measures to reduce crash numbers and injury severity

Long-term planning is needed to create the fundamental changes that will improve the safety and mobility of vulnerable road users. Measures require a framework that takes the various needs of vulnerable road users into account. Concepts like Sustainably Safe Traffic and Zero Vision provide the framework that long-term planning requires. These concepts stop defining road fatalities as a negative but largely accepted side-effect of the road transport system. Rather, road fatalities can and should be avoided, and the probability of crashes can be reduced drastically by means of the infrastructure design. Where crashes still do occur, the process which determines the severity of these crashes should be influenced in such a manner that the possibility of severe injury is virtually eliminated.

The Dutch Sustainably Safe Traffic system is currently characterised by:
A structure that is adapted to the limitations of human capacity through proper design, and in which streets and roads have a neatly appointed function, as a result of which improper use is prevented.
Vehicles which are fitted with facilities to simplify the driver’s tasks and which are designed to protect the vulnerable human being as effectively as possible.
Road users, who are adequately educated, informed and, where necessary, guided and restricted.

A road safety system based on this framework can be combined with transport policies that honestly consider walking and cycling as a mode of transport, such as the one written down in UK’s White Paper on *A new Deal for transport: better for everyone* (Wittink, 2001).

The main consequences of the necessary framework and new concepts for road planning and design are:

- Motorised traffic with a flow or distribution function must be segregated from non-motorised transport.
- A network of main traffic routes must be created for pedestrians and cyclists.
- A fair balance between motorised and non-motorised traffic for priority facilities at crossings should be achieved.
- The maximum speed of motorised traffic should be limited on roads where it mixes with non-motorised traffic (Wittink, 2001).

Specific measures that are needed to realize the above mentioned traffic system, relate to road and traffic planning, and road design. In addition, there are other measures that could improve the safety of pedestrians and cyclists, such as the improvement of the visibility of pedestrians and cyclists; pedestrian- and cyclist-friendly design of cars and heavy vehicles bicycle helmets, and education and training.

4.1 Land use planning

Pedestrian safety measures that are the most comprehensive and most closely associated with urban planning and policy philosophies are:

- Area-wide speed reduction or traffic calming schemes, and
- Provision of an integrated walking network.
- These are two complementary measures, which can be implemented together without conflicting. Not only do they apply to different parts of the urban fabric, but they also address different objectives. Area-wide schemes (the most widespread of which is the 30 km/h zone) are aimed at reducing vehicle speeds and thus at allowing for a safer mingling of pedestrians with motor traffic. Integrated walking networks (usually centred around a downtown pedestrian zone) serve to remove and/or reduce conflicts between pedestrians and vehicles and to provide or improve crossing points (Wittink, 2001; PROMISING, 2001a).

The same basic planning principles that apply for pedestrians apply for cyclists. Because cycling is suitable for travelling over greater distances than walking, it is necessary to distinguish a flow and an access function. As is the case with motorised traffic, a network for the flow function is required. However, this network cannot follow the network for through-motor traffic easily, since the mesh of the routes of the cycling network is smaller. Provisions for cycling should therefore not simply be seen as additional features of the traffic structure for motor traffic. Rather, they require a network of their own (Wittink, 2001; PROMISING, 2001b).

When facilities for cyclists are being designed, five criteria are important if their needs are to be met (CROW, 2007):
Safety*:* for large parts of the population in Europe (the perception of) road safety problems is a key reason for not cycling. Improvement of the safety of cyclists on the road is therefore a precondition for promotion of cycling.
Coherence*:* continuity, consistency of quality, recognisability and completeness. It is obvious that cycling will be restricted if the cycle network is not complete or coherent. These are mainly features at network level.
Directness*:* mean travel time, detours and delays should be avoided.
Comfort*:* smoothness of road surface, curves, gradients, number of stops between starting point and destination, complexity of rider's task.
Attractiveness*:* visual quality of the road, variety of environment and social safety.

4.2 Road design

Road design measures that assure a pedestrian-friendly and cyclist-friendly infrastructure, relate to:area-wide speed reduction, safe walking routes , cycling networks and crossing facilities. The next four sections give a general overview of what they entail. More detailed information can be found in the ADONIS-manual (Dijkstra, 1998) and in Design manual for bicycle traffic (CROW, 2007).

4.2.1 Pedestrian-friendly networks: area-wide speed reduction and safe walking routes

Area-wide speed reduction
At collision speeds below 30 km/h, encounters between motorised vehicles and pedestrians do not usually result in a fatality. A *Safe System* principle is that:where pedestrians and motorised vehicles meet, driving speeds of the latter must be reduced to 30 km/h. See ERSO Speeding web text).

Area-wide reduction of driving speed in the short-term will be provided by traffic engineering and infrastructural measures. Creating zones by road signs alone does not discourage drivers from driving faster than 30 km/h. Physical measures such as speed humps can force speed reduction (Schoon, 2004), but can meet with opposition from bus and emergency vehicle drivers as well as from residents if extensive ground vibrations occur. In several countries, 30 km/h zones are implemented in residential areas or school zones. A Dutch evaluation of the effectiveness of these zones indicated that the introduction of these zones led to a reduction of about 10% in the number of fatalities per km road length and a reduction of 60% in the number of in-patients per km road length (Wegman et al., 2005).

In the medium term, intelligent use of area-wide speed cameras might provide an alternative means of enforcement in some areas. In the longer term, extensive implementation of Intelligent Speed Adaptation should result in more direct compliance with speed limits.

Safe walking routes
'Kid routes' are special corridors of safe routes for guiding children for example to schools, play areas and sport facilities. These kid routes can mainly be found in busy residential areas. Since 2006 Delft and Amsterdam are the first municipalities in the Netherlands where children can use kid routes. The special child-friendly routes have a playful layout in which recognizable markings and boards lead children to their destination (Jager, de, et al., 2005).

4.2.2 Cycling networks

Although cycle lanes have been found to be effective safety measures on road sections - provided the width of the track is sufficient and measures have been taken to prevent crashes with vehicles parking - there is evidence that they tend to create safety problems at intersections. Particular attention has to be given to the design of cycle routes at these locations. Crossings between cycle tracks and streets do not always seem well understood by drivers, in particular, when environmental features do not clearly reflect the right-of-way, thus creating confusion among drivers and cyclists alike (PROMISING, 2001b). Additional facilities are necessary at intersections in order to reduce the speed differences between cyclists and other traffic as much as possible. Priority regulations, speed humps, and raised intersections are suitable to achieve this (SWOV, 2004).

4.2.3 Crossing facilities

The introduction of crossing facilities does not necessarily reduce pedestrian and cyclist casualties. They need to be carefully designed and appropriately sited if they are to improve safety. Crossings at inappropriate sites can lead to confusion and unsafe behaviour by both motorists and pedestrians (Lynam et al., 2005; Wittink, 2001).

Feelings of mutual respect can be promoted by right-of-way regulations, speed reduction measures and improved visibility. Examples of speed reduction measures at cyclist crossings are raised cycle crossings, humps, refuges in crossings, and mini roundabouts. Important features for improvement of visibility are: truncated cycle tracks, advanced stop lines at signalised intersections, and parking regulations (Wittink, 2001).

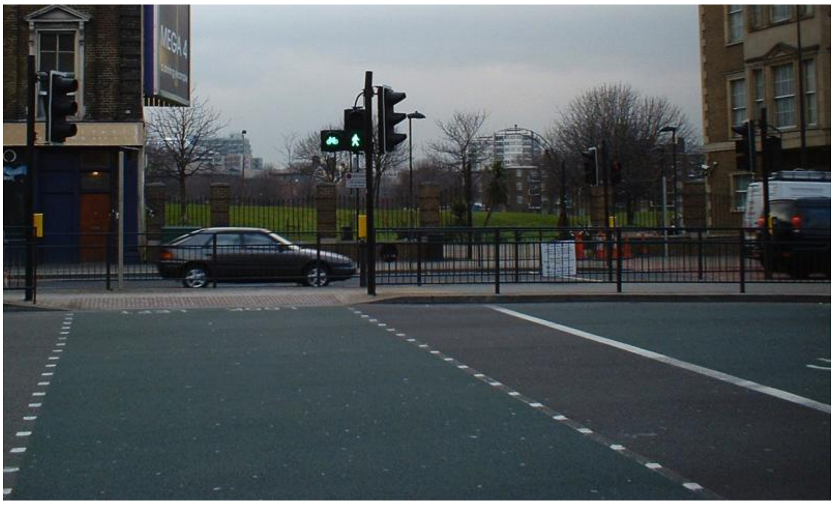
Features of safer pedestrian crossings, in particular to allow for the specific limitations of many elderly pedestrians, include:

- reducing the distance to be crossed by means of a median island and/or by sidewalk extensions;
- equipping more pedestrian crossings with traffic lights;
- allowing for the slower walking speed of the elderly when setting the traffic lights cycle;
- reducing the speed of other traffic or banishing motorised vehicles completely in areas with many pedestrians (SWOV, 2006a).

At facilities used by both pedestrians and cyclists there must be one rule: either both have priority, neither have priority, or both have traffic lights. Where they have priority, this can be indicated by triangular priority marking just in front of the crossing facility, combined with an extended speed hump to ensure a low approaching speed. An extended-length speed hump in would increase motorists' comfort because they can position the whole vehicle on the speed hump just in front of the crossing facility (SWOV, 2005).

Combining crossing facilities for pedestrians and cyclists can be effective since a greater number of people crossing at one time reduces risk. One method is the ‘Toucan crossing’ currently used in Britain (Ryley, Halliday & Emmerson, 1998) (see Figure 9). This crossing facility is named Toucan because both pedestrians and cyclists can use the same facility (‘two can cross’). The advantage of a combined crossing is that it is more visible for fast-moving traffic travelling on the major road. In addition, Toucans can detect the numbers of crossing pedestrians and cyclists. These systems enable a fairer distribution of waiting times for fast and slow traffic, and they often establish shorter waiting cycles.

Figure 9 Toucan crossing.



Source: C. Ford

4.3 Visibility: lighting and reflecting devices

Both child pedestrians and cyclists benefit from conspicuity aids and the use of light-coloured and retro-reflective clothing. Designers and manufacturers of children's clothing and accessories are well-positioned to incorporate retro-reflective materials into product lines. Parents, as well as public health and safety officials should encourage them to do so, as one component of an ongoing campaign for protecting children in traffic. Dangle tags, armbands, strips on school bags, and use of bicycle lamps are all recommended (OECD, 2004; OECD, 1998).

To ensure the visibility of cyclists, a bicycle should be equipped with a red reflecting device at the rear, devices ensuring that the bicycle can show white or selective yellow light in front, and red lights on the rear. In some countries, reflectors are also compulsory on the wheels, at the front, and on the pedal. However, not all bicycles meet those legal norms. A Dutch survey showed that 37% of cyclists did not have their lights on during darkness (AVV, 2005). Similar results were found in a Scandinavian survey: 35% of the cyclists did not have correct lighting (Hansen, 1995).

4.4. Vehicle design of crash opponents

Injuries to cyclists and pedestrians can be reduced by better design of cars and heavy vehicles. Design measures include crash-friendly car fronts, and side-under-run protection on lorries (Wittink, 2001).

For pedestrians and cyclists, the provision of safer car fronts for pedestrians is now required by EU legislation and is addressed in consumer safety rating. See ERSO Vehicle Safety web text and Euro NCAP (www.euroncap.com). While Euro NCAP testing is state of the art, the legislative test requirements are not as comprehensive (ETSC, 2003), and they do not take sufficient account of cyclists who strike the car front in different places from pedestrians.

Lorries could be made much safer for third parties by the application of adequate protection around the vehicle. Such protection prevents the dangerous underrun of, for instance, cyclists and other two-wheeled vehicles. In 35-50% of the crashes between heavy goods vehicles and two-wheelers, injury severity can be limited by side-underrun protection. Moreover, this facility prevents a road user involved in a collision from being run over, in addition. The number of traffic fatalities in urban areas due to crashes of this type could be reduced by 10% (Goudswaard & Janssen, 1990). For moped riders, cyclists and pedestrians, closed side-underrun protection on lorries is more effective than open protection. Both open and closed side-underrun protection appear in the top ten of relevant and cost-effective measures to reduce the number of casualties as a result of crashes involving lorries (Kampen, van & Schoon, 1999), (see PROMISING , 2001c) for a cost-benefit analysis).

4.5 Protective devices: helmets

In the Netherlands cycling is very popular, but apart from racing cyclists and children, only a few bicyclists wear a helmet. Of the cyclists admitted to hospital following a crash with motorized traffic, approximately one third in the Netherlands has head and brain injuries. Of the single bicycle crashes (the falls not involving other road users), about a quarter has head or brain injuries (Ormel, 2009). In Europe the use of bicycle helmets is currently mandatory in Finland for all cycle use, Spain (outside built-up areas), the Czech Republic (children < 16 years), Iceland (children < 15 years), and Sweden (children < 15 years). Outside Europe, wearing bicycle helmets is compulsory in Australia, New Zealand, in twenty states of the USA, and in a number of Canadian provinces. For these countries the legislation usually applies to children and young people. The use of helmets is currently being promoted in a number of other (European) countries.

A good indication of the (maximum) effect of a bicycle helmet can be gained from case-control studies. Here the injuries of cycling casualties with and without helmets are compared, including correcting for differences in other characteristics of the cyclists (such as gender and age), and the crash circumstances. Table 7 shows the results of a recent meta-analysis of case-control studies (Elvik, 2011). This meta-analysis is a re-analysis of an earlier meta-analysis (Attewell et al., 2001) in which is adjusted for the effect of publication bias and includes more studies than in the original meta-analysis.

Table 7: Overview of the results of a meta-analysis about the effects of bicycle helmet use on reduction/increase of injuries.

Type of Injury	Number of estimates	95% confidence interval of the effect	Best estimate of the reduction in injuries
Head injury	23	-55% to – 25%	-42%
Brain injury	9	-71% to -25%	-53%**
Facial injury	13	-33% to + 3%	-17%
Neck injury	4	+1% to +72%	+32%*
Head, facial or neck injury	40	-26% to -2%	-15%
Too few estimates (4) to allow for correction on publication bias ** Values derived from table 1 in Elvik (2011), the other values are from table 2			

Source: Elvik (2011)

According to Table 7, wearing a bicycle helmet would then result in a reduction of the risk of receiving a head injury with around 42% and with around 53% sustaining brain injury. However, wearing an helmet increases the risk of a neck injury by around 32%. Of all the injury types taken together, current designs of cycling helmets reduce the risk of getting injured on head, brain or neck injury by15%.

A study resembling a case-control study was carried out in Norway (mentioned in (Erke & Elvik, 2007). The voluntary use of helmets is relatively high in Norway. In 2006, 63% of children up to the age of 12, 25% of young people aged 12 to 17, and 34% of adults wore helmets. An analysis showed that the risk of sustaining fatal or severe injury is reduced by 25% when a helmet is worn.

That helmets prevent head injury in general does not imply that mandatory wearing of bicycle helmets for all cyclists is necessarily an effective public health measure. Normal (helmets that comply with the European standard EN-1078) bicycle helmets offer too little protection in bicycle-motor vehicle crashes when cars hit the bicyclist at higher speeds. The car drivers can adapt their behaviour when they see a bicyclist with a helmet and the bicyclists adapt their behaviour when they wear a helmet. Car drivers pass bicyclists at a closer distance when they wear a helmet than when they do not wear a helmet (Walker, 2007). Bicyclists ride faster when they wear a helmet than when they not wear a helmet (Philips et al., 2011). As helmets are considered as inconvenient, less people cycle when they have to wear a helmet. In some studies a strong decline in bicycle use after the introduction of mandatory helmet use is reported and in others it is not. Robinson (2006) refers to the data of large-scale counts in

Australia (Melbourne and New South Wales), which show an unmistakable decline in the use of bicycles after the introduction of compulsory helmet use. This applied particularly to children and young people. In the first year after the use of helmets was made compulsory, 42% fewer children and young people were using their bicycles, and 36% less in the second year compared to before compulsory helmet use. Amongst adults there was a decline of 29% and 5% respectively. Robinson also reports a decline in the use of bicycles in the Canadian province of Nova Scotia after the introduction of compulsory bicycle helmet use, but adds that it was not easy to compare the research methods applied before and after the introduction of compulsory helmet use. On the other hand, Macpherson et al. (2001) found that in the Canadian province of Ontario, the use of bicycles by children aged 5 to 14 was not affected as a result of compulsory helmet use. The long-term effects are unknown.

All things considered, bicycle helmets are an effective means of protecting cyclists against head and brain injury, but consideration of mandatory helmet use for all age groups need to take into account other effects in weighing up the potential positive and negative effects of mandating helmet use.

4.6 Education and training

Education supports a comprehensive approach to road safety and mobility. Crucial factors for safe behaviour are (Wittink, 2001):

- Control of the vehicle through handling skills and defensive behaviour,
- Control of situations through understanding of road conditions
- Understanding and communication among road users, and
- Behavioural patterns.

Some examples are described concerning road safety education for children. Education should, however, also be directed at other types of road users, such as motorists.

4.6.1 Road safety education for children

Young child pedestrians learn best at the roadside or a close approximation. From there, with experience, they develop conceptual understanding. This supports the promotion of practical skills training for pedestrians, cyclists, and drivers in connection with reflections on emerging ideas and understanding. In addition to skills acquisition, improvement of knowledge and attitudes is implicit in most of the recently developed behavioural programmes (OECD, 2004).

There is general consensus in the research and among practitioners that ad hoc activities, such as visits from experts and road safety enthusiasts, may have mass appeal but are relatively unsuccessful. Road safety education needs to be planned and progressive. Bailey (1995) promotes integrated road safety education that spans several curriculum areas and this approach is also supported by the Good Practice Guidelines for Road Safety Education in Schools (www.dft.gov.uk) which identify and provide examples of road safety education across the curriculum and recommend that road safety professionals support teachers in delivering a progressive programme of road safety education rather than occasional talks on road safety (OECD, 2004).

Duperrrex, Bunn and Roberts (2002) reviewed the literature on the education of pedestrians for injury prevention. They identified 15 studies of sufficient quality (i.e. random assignment to the treatment group, and the use of a control group). Of these studies, 14 were aimed at children. None of the studies looked at the effect of safety education on the occurrence of pedestrian injury, but six assessed its effect on behaviour. The effects varied considerably across studies and outcomes, indicating that impact of programmes differ. Evaluation studies may encourage programme developers to enhance the effectiveness of programmes aimed at improving behaviour.

4.6.2 Education for other road users

Pedestrian and cyclists need to learn by formal and informal education how to walk and cycle safely. Other road users such as car drivers, have to learn how they can safely interact with pedestrians and bicyclists. One way of doing this is to incorporate hazard anticipation training with the emphasis on vulnerable road users in basic driver training and to include a hazard anticipation test in the driving test (Vlakveld, 2011).

5 Promoting walking and cycling: changes to expect

Walking and cycling is good for the environment, is good for one's health and is cheap. It reduces congestion on the roads and is noise-free. However, walking and cycling are not safe means of transport (see Table 3). Improving pedestrian safety is key to achieving a *Safe System* and reducing serious health loss in through road use by child and older users in particular. Although the effects on health and environment seem to outweigh the costs related to crashes involving bicyclists (Kempen, van et al., 2010), it is also important to improve cycling safety as much as possible.

5.1 Effects on crash rates

Replacing short car trips -around 10% of all car trips is shorter than 1km- by walking or cycling should also be beneficial from a safety point of view for all age groups. This is not the case at this moment. When in the Netherlands, young road users replace short car trips by cycling trips this will result in fewer victims. However, when older road users replace short car trips by cycling trips this will result in more victims (Stipdonk & Reurings, 2010).

5.2 Effects on health

The beneficial effects of cycling on health have been assessed in terms of prevention of cardiovascular risk. In a study of 9,400 men in sedentary occupations (executive grade civil servants), 70% cycled at least one hour a week to work or did at least 25 miles of other cycling a week. They were found to have an incidence of coronary heart disease of 2.5 per 1000 man years. This compares with 5.6 for non-cycling civil servants. Those cycling less kilometres had a rate of 4.5 (Morris 1990 in Edwards, 1998) This health aspect is 5 to 10 times more important than the safety aspect. ECF (1998) cites Hillman (1993), who calculated that years of life gained by cycling outweigh years of life lost in crashes by 20 to 1 (PROMISING, 2001b).

5.3 Environmental effects

Motorised forms of transport cause pollution through noise and exhaust emissions. Cycling and walking do not produce such emissions. The table below gives some estimated effects of replacing car kilometres with cycle kilometres.

Estimated effects of a one-third reduction in the number of car trips from 44% to 30% of all trips in a city:

- 30% less traffic jams,
- 25% reduction in pollution from motor vehicles (all types),
- 36% reduction in carbon monoxide (CO) emissions,
- 37% reduction in hydrocarbon emissions (CH) by private cars only,
- 56% reduction in nitrogen dioxide (NO_2) emission,
- 25% reduction in petrol consumption (cars only),
- 9% reduction in the number of people suffering from noise pollution,
- 42% reduction of the barrier effect of major highways.

Source: The above figures are estimations in the 1980s of the effects of a pro-bicycle policy in Graz, Austria (252,000 inhabitants; cited by EC DGXI, 1999).

A Cyclists' Public Affairs Group study (Edwards, 1998) has demonstrated that modest increases in cycling could readily reduce transport sector emissions by 6% of the total in Great Britain, while at Dutch levels there would be a 20% reduction.

Car traffic is moreover the major source of noise in towns. In France, since 1 January 1998 any renovation or construction of urban thoroughfares must include provision for cyclists. In addition, all conglomerations in France with more than 100,000 inhabitants had to adopt an urban mobility plan. The purpose of this is to reduce pollution-producing town traffic (PROMISING, 2001B).

Energy savings would also be an important benefit of increased level of cycling. The space consumption of a cyclist was calculated to be only 8% of the space consumption of a car UPI report Heidelberg 1989, cited by EC DGXI (1999).

5.4 Cost-benefit analysis of mode switching

Cycling does not impose the same external costs on society as car driving does. The major external costs of car driving include: air pollution, traffic noise, traffic congestion, and injury crashes.

The major external costs of cycling are the costs of injuries. However, contrary to car driving, cycling may also generate benefits for society. These may include, for example, savings in public health care as a result of improved physical fitness.

In the PROMISING project (PROMISING, 2001c), a cost-benefit analysis was carried out of switching from driving a private car to cycling. External costs that were included in the calculation were air pollution, traffic noise, 40% of the costs of crashes, and savings from reduced absence from work. The researchers concluded that despite the fact that crash costs of cycling are higher than those of car driving, the total social costs of cycling are lower than those of driving a car.

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Best practice to promote cycling and walking (Dijkstra et al., 1998)

Dijkstra et al. (1998) contains information about measures which are intended to stimulate cycling and walking so that the number of short car trips will be reduced. In general, two kinds of measures are presented: technical and non-technical measures which are friendly for pedestrians and cyclists. Examples of the first category are good cycle tracks and good crossing facilities. The second kind of measures concern rules and regulations, traffic signals, and public information and education. Each description of a measure is accompanied by illustrations: photos, diagrams of layout designs or other road elements, or illustrations of public information material. Infrastructure measures are sometimes provided with dimensions as well. Next, the advantages and disadvantages of the measures in terms of comfort, costs, safety, and social safety are described in as much detail as possible. Also discussed are the advantages and disadvantages for road users other than pedestrians and cyclists. If possible, a cost estimate is provided. Finally, the names of publications or organisations are listed as sources for more information.

Dijkstra et al. (1998) is one of the reports of the ADONIS research project. The original title of the project is: Analysis and Development Of New Insight into Substitution of short car trips by cycling and walking. The ADONIS project was commissioned by European Commission as part of the Fourth Framework Programme, and ran from 1 may 1996 until end of 1997.

Design manual for bicycle traffic (CROW, 2007)

This design manual replaces 'Sign up for the bike' (CROW, 1993). It offers road designers and other interested parties extensive data on how to attain a bicycle-friendly infrastructure. A bicycle-friendly infrastructure is one that allows direct and comfortable cycling in a safe and attractive traffic environment. Only then is it possible to compete with the car. High quality bicycle infrastructures lead to a larger share of bicycles in the modal split. This design manual describes the steps required to achieve such an infrastructure, from the policy plan to promote cycling to the physical implementation of a bicycle-friendly infrastructure.