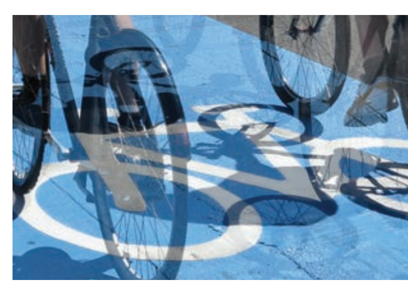
International Transport Forum

Cycling, Health and Safety



Research Report

DECADE OF ACTION FOR ROAD SAFETY 2011-2020

OECD

Cycling, Health and Safety

Research Report

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The International Transport Forum was created under a Declaration issued by the Council of Ministers of the ECMT (European Conference of Ministers of Transport) at its Ministerial Session in May 2006 under the legal authority of the Protocol of the ECMT, signed in Brussels on 17 October 1953, and legal instruments of the OECD.

The Members of the Forum are: Albania, Armenia, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Canada, Chile, China, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, FYROM, Georgia, Germany, Greece, Hungary, Iceland, India, Ireland, Italy, Japan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Moldova, Montenegro, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom and the United States.

The International Transport Forum's Research Centre gathers statistics and conducts co-operative research programmes addressing all modes of transport. Its findings are widely disseminated and support policymaking in Member countries as well as contributing to the annual summit.

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Organisation of this report

This report reviews recent research findings and presents evidence derived from surveys of International Transport Forum-OECD countries relating to bicycle safety.

Chapter 1 addresses the key issues relating to cycling safety and links them to a greater discussion of health, safety and cycling. The deleterious impact of crashes on cyclists' health is only one part of the health impacts of cycling – the health benefits of cycling are often overlooked in policy discussions. This chapter examines the full range of health impacts and discusses critical elements necessary for cycling policy evaluation. It also suggests a way forward for framing cycling and road safety policy such that health benefits are maximised.

Chapter 2 looks at how national and regional/local authorities are developing, facilitating or guiding cycling policy. Based on a questionnaire of International Transport Forum members, this chapter inventories national cycle plans and discusses their key features. It also reviews the different national legal frameworks and rules surrounding bicycles and cycling and presents some findings relating to the funding of bicycle infrastructure and programmes to promote cycling.

Chapter 3 reviews trends relating to cycling safety as reported and vetted by ITF members via a questionnaire. This information is complemented by different national and regional sources of information. Trends relating to fatalities, injuries and crash rates are presented alongside international data on levels of cycling. Where possible, exposure-adjusted safety figures are given and some of the underlying factors contributing to observed trends are discussed.

Chapter 4 presents detailed analysis of bicycle crash characteristics across a range of countries based on a detailed questionnaire and other sources of national information. It provides an up-to-date comparison of factors relating to bicycle crashes among responding countries and discusses the policy implications that emerge.

Chapter 5 discusses the efficacy of a range of measures typically deployed to decrease bicycle crash rates and severity or increase cycling levels.

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Boxes

01. Separate Linear Infrastructure

Cycle track

Separated cycle lane, Separated cycle track, Segregated cycle facility, Bicycle track, Cycle path alongside the road, Kerbed bicycle lane

A cycle track is a reserved space specificly for cyclists and provided along a road. The track is physically (vegetation, fence, curb, …) separated from vehicle travel lanes, parking lanes and sidewalks. Cycle tracks can be either one-way or two-way, on one or both sides of a road.

Photo credit: Authors

01. Separate Linear Infrastructure

Cycle lane

Marked cycle track, Bicycle lane

A cycle lane is a legally reserved driving space for cyclists on the road, separated from motor traffic by marking.

Photo credit: Authors

01. Separate Linear Infrastructure

Combined cycle-pedestrian track

Shared track

A combined cycle-pedestrian track is a reserved space (one- or two-way) for cyclists and pedestrians provided along a road. The track is either **mixed** cycle-pedestrian allowing both cyclists and pedestrians to use its full width, or **separated** cycle-pedestrian with a visual separation (marking) or differentiation (pavement) between the two groups of users on the same track.

Photo credit: Authors

01. Separate Linear Infrastructure

Greenway

Cycle path off road, Cycle trail, Solitary cycle track

Greenways are connecting trails, used for non-motorised traffic. Greenways are normaly bi-directional.

Photo credit: Gene Bisbee

02. Mixed Linear Infrastructure

Suggested cycle lane

Non-compulsory lane, Suggestion lane, Schutzstreifen, Suggestiestrook, Bande cyclable suggérée, Voie centrale banalisée, Sharrow

Technically and legally an advisory lane is not a cycle lane at all. A part of the carriageway is marked as a suggested space for cyclists, without being exclusively reserved for their use.

Photo credit: Eric Fischer

02. Mixed Linear Infrastructure

Cycle street

Cycleway, Bicycle boulevard

A cycle street is a road designed that cyclists dominate visually and motorised traffic is tolerated exceptionally (e.g. for residents), if it is allowed at all.

Photo credit: Authors

02. Mixed Linear Infrastructure

Central traffic lane

Chaussée à voie centrale banalisée, Kantstroken, Kernfahrbahn

The carriageway is divided into one central lane for motor traffic and two side lanes for cyclists and pedestrians. Motor traffic uses the lateral band only to pass or cross vehicles.

Photo credit: Authors

02. Mixed Linear Infrastructure

Combined bus-cycle lane

Bus-lane

A combined bus-cycle lane is facility where cyclists and buses share a reserved lane.

Photo credit: Authors

02. Mixed Linear Infrastructure

Contra-flow cycling

Double sens cyclable, Contre sens cyclable en sens unique, Sens Unique Limité (SUL)

Contra-flow cycling is when cyclists are allowed to ride against the flow of one-way streets.

Photo credit: Authors

03. Point Infrastructure

Cyclist signals

Photo credit: Authors

At crossroads comprising a cycle lane or a cycle track (for example), some signals are installed for cyclists only. In some cases (e.g. in Denmark) an early green stage is included in the signal cycle to release cyclists before motorists. In other cases, the signals are controlled so as to allow cyclists to turn nearside during the red stage.

0.3 Point Infrastructure

Advanced stop line

Stopline for cyclist (on a cycle track or cycle lane) placed some meters ahead of stopline for motor vehicles in a signalised junction.

Photo credit: Authors

0.3 Point Infrastructure

Cycle box

Cycle stacking lane, Zone avancée pour cyclistes, Sas vélo

This reserved space for cyclists makes them more visible on the approach to crossroads with traffic signals.

Photo credit: Authors

Key messages and recommendations

I. Setting the Groundwork for Safe Cycling

Bicycles belong in the urban mobility mix

Bicycles are an essential part of the urban mobility mix. They use no fossil energy, deliver important health benefits, and improve the liveability of cities. In low income regions the bicycle offers perhaps the only affordable way of getting to work, to earn income and to access basic living needs. In high income urban areas the bicycle is becoming more popular or returning to popularity. In some cases cycling dominates the urban traffic mix.

The attraction of the bicycle resides in its ability to provide an affordable and seamless door-to-door mobility service – it is as versatile as walking but can cover greater distances at higher speeds. It represents an alternative to cars and allows for greater freedom of movement than scheduled public transport services. Bicycles are well suited to the great number of short trips that are typical for urban mobility. Beyond public bike sharing systems, there are a number of pro-cycling policies and frameworks that are being implemented throughout ITF countries.

Cyclists are vulnerable road users.

Road traffic is inherently unsafe. Traffic infrastructure is seldom designed with safety as a starting point and though efforts are made to accommodate the wide range of behaviours displayed by road users, errors and unpredictable or impaired actions often lead to crashes. The kinetic forces involved resulting from the differences in mass and velocity of crash opponents largely dictates the severity of the outcomes. Crash outcomes are especially severe for vulnerable road users such as pedestrians and cyclists who lack the level of protection mandated for, and offered to, car and other vehicle occupants. Single bicycle crashes are also a source of injuries through falls and collisions with obstacles and can result in serious injuries, especially for elderly cyclists and those unprotected by helmets. Studies investigating the comparative risk of injury for cyclists versus car occupants find significantly higher risks per unit of exposure for cyclists.

Cyclists are often forgotten in the design of the road traffic system

Cyclists are at risk in traffic because the road system has, with some notable exceptions, not been designed for cyclists. More precisely, the road system has not been designed for mixing well-protected, heavy and high velocity vehicles with unprotected, lightweight and slower road users. Furthermore, the traffic system does not typically account for the specific characteristics of cyclists and bicycles. Cyclists are highly flexible and sometimes unpredictable road users, riders display very different abilities, cyclists seek to minimise energy expenditure, bicycles can be easily de-stabilised and are relatively difficult to see because of their size (in daytime) and relatively poor or absent night-time lighting. Though cycling is an important component of urban mobility, cyclists are often seen as intruders in the road system.

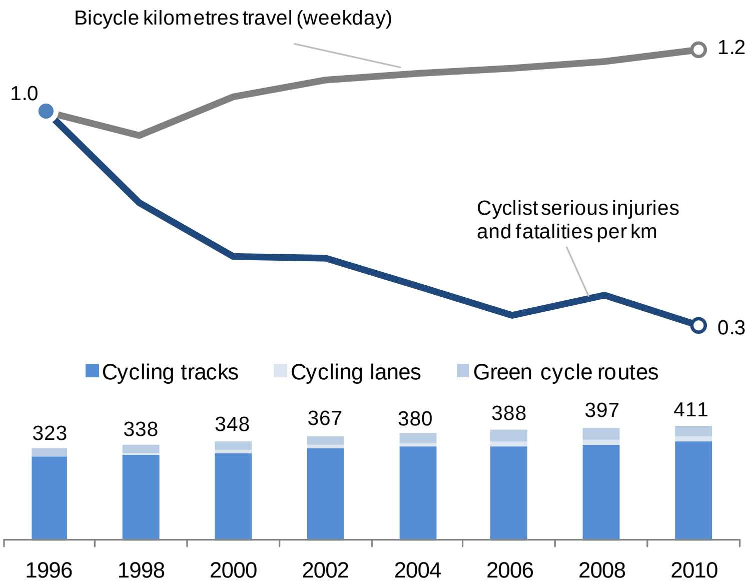
Do policies that increase the number of cyclists contribute to more crashes?

This is an important question because if cyclists are vulnerable and the road system is not designed for cycling, then pro-cycling policies could conceivably expose a greater number of people to potentially dangerous conditions. The short answer to this question is that when the number of cyclists increase, the *number* of crashes, both fatal and non-fatal, may increase as well – *but not necessarily so* if attention is paid to good policy design. Furthermore, the *rate* of cycling crashes may decrease, *especially if accompanying safety-improving policies are implemented.* Thus while the number of crashes may increase, cycling safety -- measured by the number of crashes per some measure of exposure (e.g. trips, cyclists, time cycling, distance travelled) -- may improve though it should be noted that any absolute increase in serious or fatal cycling crashes is clearly an outcome to be avoided.

Sustained, well-designed and targeted policies can increase both cycling *and* safety

Where pro-cycling and pro-safety policies are deployed hand-in-hand, an increase in ridership can be accompanied by a concomitant reduction of injury risk. For example, in Copenhagen, bicycle travel has increased by 20% from 1996 to 2010 while at the same time police-reported fatalities and serious injuries have dropped by 70% (Figure I.I). These findings are significant and, in the context of the expansion of well-designed bicycle facilities over the same period, indicate that targeted policies can simultaneously increase cycling and safety.

Figure I.I **Index of bicycle travel and per-kilometre cyclist casualties for Copenhagen (Police-reported, 1996-2010) and kilometres of cycling infrastructure.**



Source: City of Copenhagen

Cycling, safety and health are indissociably linked

A discussion of the impact of cycling on road safety should not be isolated from a broader discussion of the overall health impacts of cycling. Indeed, if we are concerned that increasing the number of cyclists may increase crash numbers or risks, it is because of the deleterious effects of crashes on cyclists' health. Crashes, however, are not the only factors that affect cyclists' health – exposure to air pollution can negatively impact cyclists' health just as cycling-related exercise can (greatly) improve cyclists' health. Pursuing *increased safety* for cycling makes sense no matter what the balance of positive/negative health outcomes but accounting for overall health impacts is essential in helping frame efforts to *increase cycling*.

Cycling significantly improves health

The most important point to retain is that cycling, as a form of moderate exercise, can greatly reduce clinical health risks linked to cardiovascular disease, obesity, Type-2 diabetes, certain forms of cancer, osteoporosis and depression. Taken separately and even more so when effects are cumulative, these conditions exact a high human and economic cost on society. This health improving-effect is robust across different studies and in different geographic contexts and is greatest when moving from largely sedentary lifestyle patterns to more active ones. There is evidence that the range of morbidity-reducing effects is even greater than that of mortality-reducing effects – not only does cycling reduce disease-related *deaths* but it also contributes to substantially better *health*.

Cyclists register higher doses of particulate matter than car drivers

On the other hand, cyclists' health is negatively impacted by exposure to air pollution – especially fine particulates and ozone. This risk, at least when compared to other urban travellers (car, bus, metro), has often been downplayed by the finding that average concentrations of suspended particulate matter (especially fine particulate matter) are rarely significantly different between cyclists and car drivers – and slightly higher on average for car occupants. However, this finding ignores a crucial variable – ventilation. Cyclists breathe more often and more deeply than car occupants. Thus while ambient levels of particulate matter may be similar, actual particulate deposition within the lungs of cyclists is much higher – by several orders of magnitude. In some cases, the mortality effects from exposure to air pollution are greater than the mortality effects stemming from crashes. Cyclists' health could be improved by locating bicycle facilities away from road traffic where feasible – especially for sections where cars are accelerating (hills, long straightaways).

Recommendation 1:

Where it does not reduce the quality of cycling networks, bicycle facilities should be located away from road traffic when feasible – especially for sections where cars are accelerating (hills, long straightaways).

On balance, the positive health impacts of cycling far outweigh negative health impacts

Reviewing evidence from studies looking at the full spectrum of cyclist health impacts (including crash-related injuries and air pollution) while controlling for exposure and crash under-reporting indicates that the estimated health benefits of cycling are several orders of magnitude greater than the health dis-benefits of cycling. Promoting cycling makes sense from a societal and whole of government perspective though this may challenge those transport authorities who constrain their analysis to relative crash risks only.

Monetisation of incommensurate health impacts allows for comparison of these along a common scale. For large European cities, (Rabl and de Nazelle, 2009) find that on average the positive health gains for an individual resulting from a switch from car to bicycle commuting add up to €1343 per year. They find the negative health impacts, including those linked to crash-related mortality, result in a loss of €72/year – or 19 times less than the benefits. The principal finding that the health benefits from cycling dwarf all other variables is robust to a range of assumptions regarding specific variables and monetary values.

Considering *morbidity* in addition to *mortality* would likely increase the numbers for individual and societal air pollution-related impacts by approximately 50% and increase the number for the health gain from cycling by more than 50%. At the same time, costs related to non-fatal bicycle accidents would be significantly higher (estimated, for instance by to be €0.125/km in Belgium).

"Safety in Numbers": Cyclist safety is linked to the number of cyclists in traffic but causation is uncertain.

Many researchers and observers have noted a correlation between cyclists' numbers and increased safety expressed as a decrease of the incidence rate of severe/fatal crashes involving cyclists. The "safety in numbers" effect has been cited widely but *correlation* does not imply *causality* and there are numerous possible explanations for the observed effect. At the centre of the phenomenon is the observation of non-linearity of risk: an increase in exposure (numbers, volumes, etc.) results in a less than proportional increase in the number of crashes. This implies that if the number of vehicles increases, crash rates will go down. The risks to cyclists are also non-linear, that is to say an increase in numbers results in a non-proportional increase of crashes.

"Expectancy" is one way of explaining this non-linearity. That is to say: if a road user expects the presence of another road user, or can predict the behaviour of that other road user, one may expect lower risks. Another possible explanation is that large groups of cyclists benefit from cumulative danger awareness – when one cyclist detects and avoids a dangerous situation, others in proximity benefit and can take protective action as well. In this respect, it may be more precise to re-cast "safety in numbers" as "awareness in numbers". An alternative explanation for the "safety in numbers" phenomenon is that cycle-safe traffic systems attract large numbers of cyclists – large numbers of cyclists in countries such as the Netherlands, Denmark and Germany are associated with high densities of bicycle facilities. There is no solid evidence that low fatality rates can only be explained by 'numbers' alone. Critically, if policy simply adds more cyclists to the system without other risk-reducing measures, then those cyclists may be exposed to significant crash risks.

Recommendation 2

Insufficient evidence supports causality for the "safety in numbers" phenomenon – policies increasing the number of cyclists should be accompanied by risk-reduction actions.

Most authorities lack the factual basis with which to assess cycling safety or the impact of "safety-improving" policies

In the course of this review of cycling safety, it has become clear that most national authorities and many regional/municipal authorities lack the basis on which to assess both cyclists' safety and the impact of safety policies. At the core of safety assessment is the calculation of crash incidence rates (typically split into fatal crashes and others of varying degrees of severity). Schematically; safety (expressed as the crash incidence rate) is the quotient of the number of crashes divided by a measure of exposure or bicycle usage.

$$\textit{Safety (incidence rate)} = \frac{\textit{Number of crashes, fatalities or injuries)}}{\textit{Measure of exposure (trips, km, hrs)}}$$

In many cases both numerator and denominator are inadequately measured or may be missing altogether.

Cycling crashes are significantly under-reported

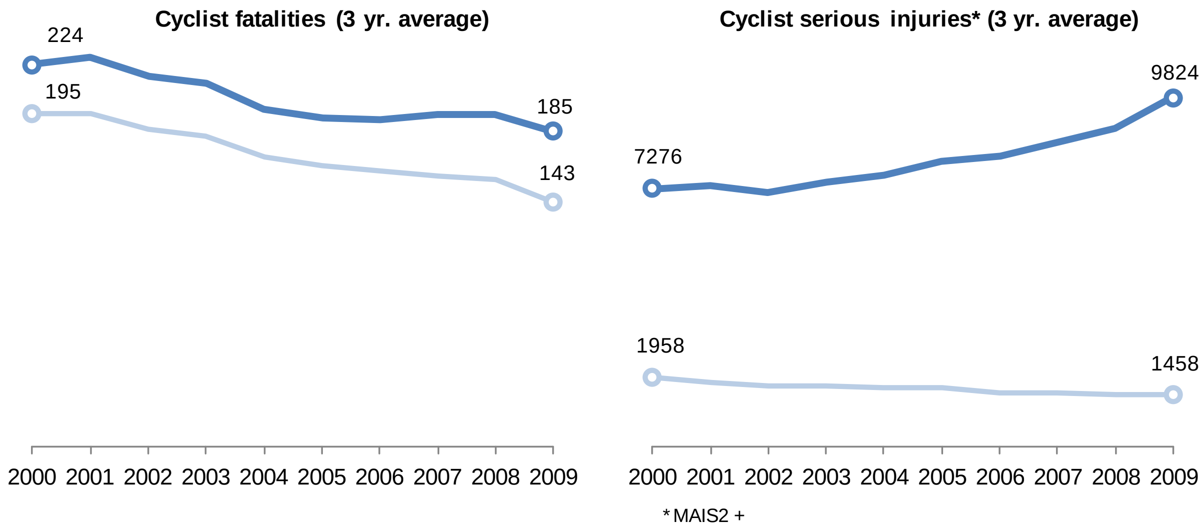
Under-recording of cycling accidents is an essential problem for bicycle safety analysis. The underlying reason of under-recording is that personal injury accidents are not systematically registered. It should be kept in mind that the analysis that follows in this report is based largely on data of recorded bicycle accidents. Under-recording is not limited to bicycle accidents or certain countries, it concerns all types of vehicles and all countries. Under-reporting is less prevalent when considering *fatal* crashes involving cyclists though there are discrepancies in criteria for attributing post-crash deaths to specific traffic incidents. Poor coordination between police and hospital record-keeping also contribute to inexact crash-related fatality data. Furthermore, while there is convergence in many countries towards common terminology and definitions for injury severity, important differences remain that may hinder cross-country analysis of trends – greater convergence along the lines of terminology defined by the IRTAD International Traffic Safety Data and Analysis Group would simplify safety analysis.

Recommendation 3

Efforts must be made to harmonise definitions of terminology so as to be able to make reliable international comparisons of cyclist safety.

Under-reporting of *non-fatal* cycle crash related injuries is much more prevalent and hampers cycling safety assessments. Under-reporting complicates the analysis of long-term trends and poor or biased recording hides the true picture of cycle safety. For instance, police-reported data on serious bicycle crash injuries in the Netherlands gives a completely misleading view of the real evolution of these injuries when accounting for hospital-recorded data (Figure I.II). In this context, reported data misinforms policy-making both to the scope and scale of crash rates. In the absence of an objective point of reference and comparison, it is also difficult to set quantified goals for reducing the number of cycling crash victims. There is evidence that among all road crash victims, cyclists are the least recorded. There are numerous reasons for this. When there are no seriously injured persons or immediate physical complications, parties involved generally do not inform the police or, when informed, the police do not always find it necessary to respond. When only vulnerable road users such as cyclists are involved, it is less probable that the police intervene than for car crashes. Another reason for under-recording is that the fewer people involved in a non-severe crash, the smaller the likelihood of records being filed.

Figure I.II **Actual vs. Registered number of fatalities (30 days) and serious injuries (MAIS 2+) in the Netherlands 2000-2009 (3 year rolling average)**



Source: Netherlands Road Safety database, SWOV

How severe is under-reporting of cycling crashes? One assessment for Europe finds that police records only capture 50% of hospital admissions for traffic-related cycling injuries. In Austria, police records only account for 15% of all bicycle crash-related injuries. Another assessment for the United States finds this figure to be only 10%. An in-depth prospective cohort-based study for Belgium confirms strong underreporting of non-fatal crash-related injuries finding that only 7% of non-severe bicycle crashes were recorded in police statistics – a low figure confirmed in other studies. Further, authorities lack information on the year-on-year pattern and consistency of under-reporting complicating efforts to systematically correct for this phenomenon

Recommendation 4

National authorities should set standards for and collect or otherwise facilitate the collection of data on non-fatal cycling crashes based on police reports linked, in either a systematic or periodic way, to hospital records.

Lack of bicycle usage and exposure data hinders safety assessment

Most countries and/or cities are ill-equipped to assess cycling safety because of a lack of accurate and detailed information on actual bicycle usage. This lack of exposure data is a real hindrance to understanding the current status of cycling safety and complicates the assessment of the impact of transport policies on cycling safety. This makes it difficult to answer questions such as how safe is cycling, and how does cycling compare to other modes of travel? Without information about distances cycled in different countries it is difficult to compare the safety of the cycling systems in those countries. Crucially, exposure-based injury rates allow authorities to understand if policies improve safety by *reducing exposure* (e.g. by decreasing bicycle use) which, given the benefits of cycling would be a bad thing or if they increase safety by decreasing crash-related injuries for a same level of usage.

Arguably, the best measures of cycling exposure are distance or time cycled. In the absence of this information, proxy exposure measures can be used but these are far less accurate. For example, length of cycling infrastructure in a particular country might give an indication of how much cycling occurs in that country. However, it is possible that a country has a great deal of cycling infrastructure without this infrastructure necessarily being used much. Other proxy measures include number of bicycles owned (some of which go unused) and population (many of whom don’t cycle). Rates calculated using the less accurate indicators of exposure should be treated with caution.

Recommendation 5:

National authorities should set standards for and collect or otherwise facilitate the collection of accurate, frequent and comparable data on bicycle usage.

II. What approach for increased cycling safety?

Apply “Safe system” principles for cycle safety

Authorities have often approached cycling safety (often all traffic safety) in a piecemeal way – focusing on cyclists and rarely on the entire traffic system. Reaching high levels of safety for cyclists (and for other traffic participants as well) requires a different approach that seeks to design (or re-design) the system to accommodate cyclists and to account for their characteristics. If the system is unsafe for cyclists, policy should focus on changing the system, not simply on marginal improvements for cyclists in an inherently unsafe system. The “Safe System” approach extends beyond cyclists and is recommended as a general safety planning approach for all traffic classes. In a Safe System Approach the road transport system is designed to accommodate human error and incorporate a full range of strategies for better management of crash forces, addressing infrastructure design, road user behaviour, enforcement and the design of vehicles,

Recommendation 6:

Authorities seeking to improve cyclists’ safety should adopt the Safe System approach -- policy should focus on improving the inherent safety of the traffic system, not simply on securing marginal improvements for cyclists in an inherently unsafe system.

At the heart of the Safe System approach are 4 key principles:

- **Functionality**: It is important to ensure that the actual use of the roads conforms to their design and intended use. This implies a functional definition according to traffic levels, speed and purpose, e.g. through roads, distributor roads, and (residential) access roads. Ideally, each road or street is should have only one function -- for example, a distributor road should not have any direct dwelling access.

- **Homogeneity**: Large differences in speed, direction, and mass should be avoided by separating traffic types. In certain configurations where separation is neither possible nor desirable, traffic speed differentials between non-motorised and motorised vehicles can be reduced by slowing the latter. Based on this principle, bicycles should be physically separated from motorised traffic unless motorised traffic speeds are quite low.

- **Predictability**: Road users should know what to expect from others and what is expected of themselves in specific traffic situations and contexts. Road design, including all of its surroundings, should be easily recognisable and predictable for all traffic participants, including cyclists. Dangerous traffic situations can thus be detected and avoided in time.

- **Forgivingness**: Finally, if a crash cannot be avoided, crash outcomes should be minimised. This may be achieved via the development and deployment of cyclist-friendly vehicle designs or promoting the use of protective equipment by cyclists.

Safety measures are not all transferable or applicable in different environments

Municipalities and regions differ in the share of cycling in the modal split. They also differ in the degree to which they provide facilities for cyclists. The type of cycle facilities offered should depend on the share of cycling -- the more cycling, the more bicycle facilities. Facilities typical for a high share of cycling do not fit in a traffic environment with a low share, while facilities adapted to a low cycling share are not compatible with a high bicycle share. Setting facilities within their context can help avoid "over" or "under" investing in safety.

III. Lessons from national and regional cycling safety policies.

National-level commitment to cycling and to cycling safety is important to set a common framework for action

National-level commitment, or at a minimum, regional-level commitment, is important in setting the right legal, regulatory and financial framework so that successful implementation of cycling strategies can take place. Not all countries address cycling safety at the national level but those that do either establish plans focusing on improving cycling (or road) safety specifically or plans addressing transport, spatial, environmental and health planning more generally. The first approach is more direct though the second approach may impact the cycling environment and thus indirectly impact safety.

Top-level coordination between cycling and other policies helps deliver more cycling and better safety

Cycling is affected by and in turn impacts a number of other government policies, e.g. health and land-use, alongside transport. In addition to developing national plans, some administrations assign a person or institution responsibility for coordinating cycling policy across all of government. This practice has the benefit of ensuring consistent policy action in favour of cycling. In particular, since health improvement accounts for the majority of the benefits resulting from (increased) cycling, such an approach ensures that critical links are made between transport and health policies and that critical objectives for the latter are accounted for in the former.

Recommendation 7:

Authorities should establish top-level plans for cycling and cycling safety and should ensure high-level coordination among relevant government agencies to ensure that cycling grows without aggravating safety performance.

Training all road users to cycle safety on both roads and bicycle facilities reduces potential crash-causing conflicts.

Authorities in many high-cycling countries/regions ensure that all citizens (not just cyclists) receive adequate training regarding cycling skills. This training covers rules relating to the use of cycling infrastructure and governing the interaction between cyclists and motorised traffic at junctions and other points of conflict. Ensuring that both motorists and cyclists expect and understand each others' likely behaviour in critical situations (e.g. junctions) can reduce potential crash-causing conflicts.

Recommendation 8:

Authorities should ensure that all road users receive cycling training covering riding skills and use of both roads and bicycle-specific facilities. This training can be part of a broader safety training programme that many authorities have put in place targeting children and young adults.

IV. Review of evidence on cycle safety status and trends - What do the numbers tell us?

The Working group collected data from countries on cycle crash statistics in order to assess the status and evolution of cycle safety in those countries. However, it is important to recognise that data were returned by a fairly restricted number of member countries. Several of these respondent countries are recognized as providing an excellent cycling environment, while even the worst of them are fairly good. Given this and the caveats on underreporting and lack of accurate exposure data noted above, we can say the following based on the working group's scan of cycling safety amongst working group countries.

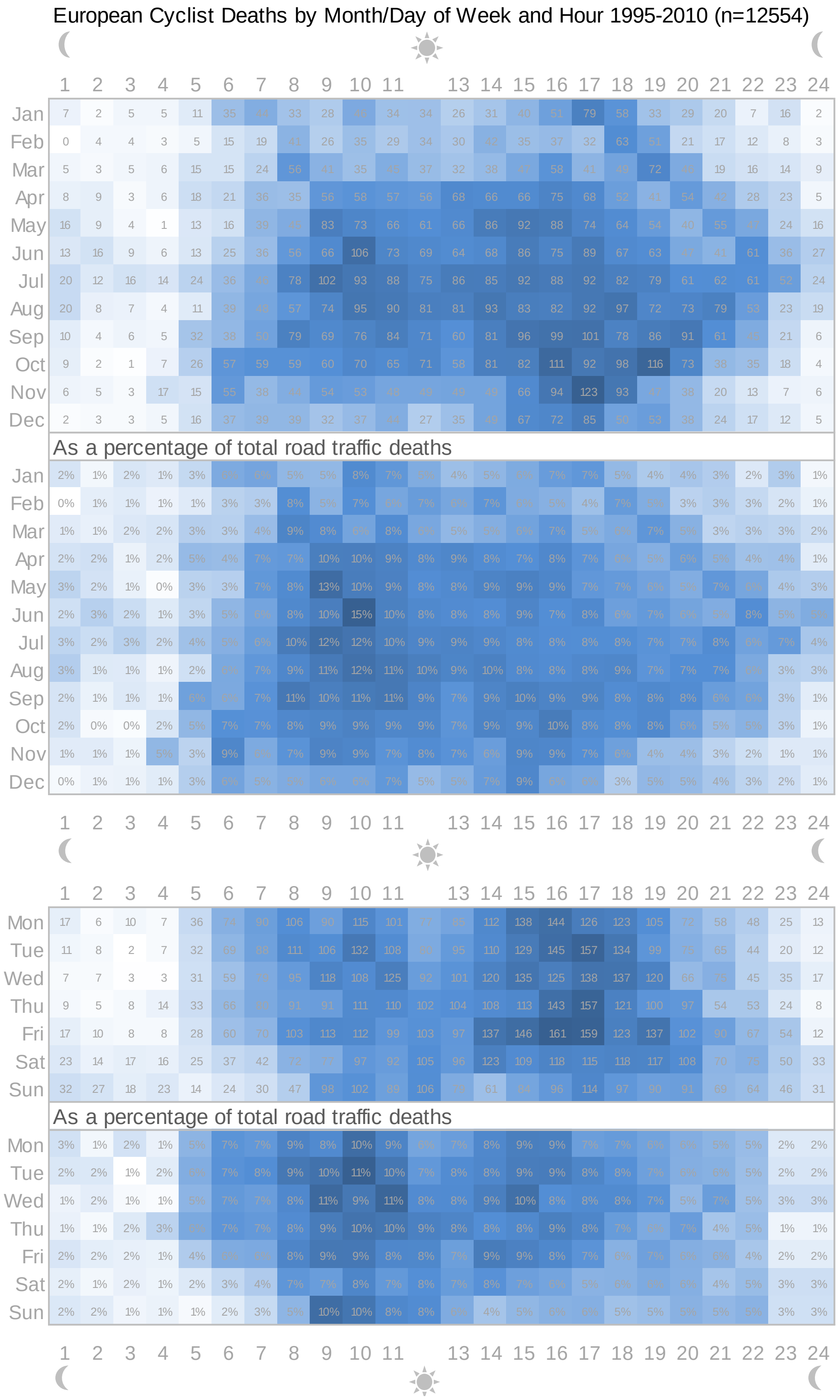
Most countries report decreasing bicycle crash numbers though cycling safety improvements lag behind other modes.

Two thirds of the countries responding to our survey report fewer bicycle injury crashes in 2009 than in 2000 and a minority show a deep and constant improvement. What is not clear is the extent to which these trends are linked to changes in the safety of cycling or changes in the volume of travel by bicycle. Countries that track travel by bicycle and safety (e.g. the Netherlands and Denmark) indicate that per kilometre fatality risk may be decreasing but report divergent trends on the evolution of per kilometre risk for serious injuries – it is not clear the role under-reporting of crashes plays in explaining these differences. While most countries report a decrease in both injury and fatal bicycle crashes, in most countries the decrease of bicycle injury and fatal crashes is slower than the decrease in overall injury and fatal crashes. The safety performance of cycling continues to lag behind overall transport safety performance.

Crashes are most likely when exposure is greatest, severe crashes are most likely when traffic speeds are above 40 km/hr and at night.

Crashes involving cyclists seem to be relatively constant over time according to the working group member survey results but the rates differ greatly from country to country. Cycling crashes are most likely when exposure is greatest: during peak travel periods (in the morning, middle of the day, and afternoon), during the week in countries where cycling is a typical mode of transport (and otherwise on the weekend), during seasons when the weather is most conducive to cycling or when the cycling surface is dry (Figure I.III.). That most cycling takes place at these times is most likely simply a reflection that those times and surface conditions are most suitable for cycling.

Figure I.III **Cyclist traffic fatalities by month or day of week and by time of day, EU**



Source: EU CARE database, EU27 countries, Norway and Switzerland, 2005-2010

The general pattern was for most fatal and injury crashes to occur in low speed limit zones, which is likely to reflect greater cycling exposure in built-up areas. For fatal crashes in particular, there was a second peak in 70-80kmph zones, presumably reflecting higher chance of fatality for crashes occurring at higher speeds. The impact of traffic speed on cycle crash risk and severity highlights the value of speed management as "hidden infrastructure" that protects cyclists.

Recommendation 9:

Speed management acts as “hidden infrastructure” protecting cyclists and should be included as an integral part of cycling safety strategies.

Though there is likely to be relatively little cycling at night, a fairly high percentage of fatal crashes occur at night in several countries. Further, there is a noticeable spike in crashes just as night falls in many countries. Thus, there is an argument for directing resources to improve cycling safety not only in peak periods but also at night.

The very young and the very old are disproportionately represented in serious crash-related injuries across a number of countries – with fatal crash rates for the latter reaching alarming proportions in some countries.

The distribution of cyclist traffic fatalities by age group is similar for most countries and follows a u-shaped curve though some countries display a flatter distribution than others Generally those over 65 years old represent a significantly large proportion of cyclist fatalities. Korea and Japan, two countries with a significant share of older people, are especially confronted with bicycle crash fatalities and injuries among the old – e.g. in Korea 65% of bicycle fatalities were aged over 60 (2009) and in Japan, 70% of bicycle fatalities were aged over 60 (average 2005-2010)

One explanation for the over-representation of the elderly in fatal cycle crashes is the more severe consequences of crashes due to the sometimes lessoned physical condition of many older people. In particular the combination of more brittle bones, less elastic soft tissue weakened locomotive functions including reaction times results in more crashes for this population group and more severe crash outcomes. For children, a combination of factors may be at play: a greater propensity to expose themselves to crash risk and the location of crash contact points between motor vehicles and their bodies (head and upper body)

Collisions appear to more common than single bicycle crashes for serious and fatal injuries but this finding may reflect reporting bias.

For crashes resulting in serious and fatal injuries, collisions appear to be more common than falls, and collisions with motor vehicles most common of all. Although this is may partly reflect a sampling bias in the police-recorded data, because collisions with motor vehicles are likely to have the most serious outcomes and thus warrant police attention. Indeed, one study finds that for non-fatal minor accidents recorded in a prospective cohort study of Belgian cyclists, “slipping” represents 33% of all crashes and 36% of injuries (with collisions with cars represent only 11% of crashes and 19% of injuries). This is consistent with that study’s conclusion that such minor crashes are underreported in police records. Another study of cyclists reporting to emergency departments in California, New York, and North Carolina found that 70% of the bicycle injury events did not involve a motor vehicle, and 31% occurred in non-roadway locations (such as sidewalks, parking lots, or off-road trails), although bicyclists struck by motor vehicles in the roadway tended to be the most seriously injured. Spain appears to have a particular issue with collisions with trains – which appear to almost always be fatal. In counties with high bicycle traffic (Belgium and Denmark) crashes with other cycles account for 5% of injury crashes (but fewer fatal crashes).

While cars remain (by far) the most common crash opponent for cyclists, crash outcomes with heavy goods vehicles are disproportionately serious and warrant special measures.

Cars represent the most common crash opponent for cyclists in serious injury and fatal crashes. Heavy goods vehicles were the most common crash opponent following passenger cars for most countries reporting this data. Comparing the involvement of trucks in fatal versus serious injury crashes reveals the disproportionate risk of death for cyclists in truck-bicycle collisions and the need to address these types of crashes. Light goods vehicles and motorised two wheelers are also significant crash opponents in some countries, in some cases figuring more frequently than heavy goods vehicles.

Recommendation 10:

Safety policy should target crashes between Heavy Goods Vehicle and Bicycles crashes due to the especially serious consequences of these crashes and their (relative) frequency.

Drawing broad conclusions regarding cyclist versus motorist fault in serious injury and fatal cycle crashes is challenging though evidence indicates that cyclists are not predominantly (and in many cases, principally) at fault.

It is difficult to draw a general conclusion regarding cyclist vs. motorist "fault" in fatal and serious injury bicycle crashes across countries due to the limited amount of available and comparable data. It seems plausible that for fatal crashes, the fact that the cyclist cannot provide input regarding crash causation may bias outcomes. Having clearly defined right-of-way rules may better frame the operationalisation and reporting of "fault" – this is the case for some countries such as Denmark.

Recommendation 11:

Cyclists should not be the only target of cycling safety policies – motorists are at least as important to target.

Metropolitan areas dominate in terms of crash numbers; rural crashes are disproportionately fatal or severe in several countries.

Fatal and serious injury crashes are typically more common in metropolitan than in non-metropolitan areas. This may be because most cycling takes place in urban areas in most countries. For fatal crashes, a minority of countries demonstrated a reversal in this pattern, whereas crashes were roughly evenly distributed across metropolitan and non-metropolitan or more common in non-metropolitan areas. For injury crashes all respondent countries adhered to the general pattern, although some countries, such as Belgium and Spain, have relatively more injury crashes in non-metropolitan areas than other countries. These patterns are likely to reflect where the most cycling occurs, in combination with the density and speed of traffic in these areas. Thus, in Belgium and Spain may have a greater amount of cycling in non-metropolitan areas than other countries, and crashes in these areas might often be fatal due to high traffic speed. For example, in Denmark, Germany, the Netherlands and the United Kingdom, urban areas accounted for 84%, 81%, 79% and 86%, respectively, of combined *killed and seriously injured* cyclists whereas non-urban areas accounted for a disproportionate 36%, 41%, 37% and 40%, respectively, of all *killed* cyclists.

Crashes are generally less common on cycling-specific infrastructure than on infrastructure that is not cycling-specific.

Where it is reported, police-reported crashes are less common on cycling-specific infrastructure than on infrastructure that is not cycling-specific – although arguably the cycling-specific infrastructure carries more cycle traffic, particularly in some countries. Presumably this reflects a safety benefit conferred by various aspects of cycling-specific infrastructure – such as separation from traffic, lower speeds and speed differentials. Another possibility untested by the working group is that this finding may also reflect a bias in the police-reported data. For example, in Australia, crashes are only reported to police if they occur on a road (including a bicycle lane on a road). It is noteworthy that in Denmark injury crashes are more common on on-road bicycle lanes than on roads not marked with bicycle lanes – perhaps reflecting exposure.

Junctions account for a disproportionate share of fatal and serious injury cycling crashes given the amount of time that cyclists spend crossing them.

About one-quarter of all fatal crashes occurred within junctions for European countries reporting this data though there is great variability amongst countries. Korea and the United States report higher shares of junction-related crashes. Figures from Australia are lower perhaps reflecting the greater share of fatal bicycle crashes in non-metropolitan areas where there are presumably fewer junctions. Given that cyclists spend a great deal more of their time cycling *not at a junction*, these percentages indicate the risk posed by junctions and the need for care when designing junctions to be “readable” by all traffic participants and cycling-friendly.

Bicycle crashes outside of junctions tend to have more severe outcomes than junction-related crashes.

For Europe, non-junction areas account for a proportionately greater share of fatal (64%) than serious injury bicycle crashes (40%). Likewise junctions account for a smaller percentage of fatal (29%) versus serious injury (41%) bicycle crashes. One possible explanation for this is that motor vehicle speeds are typically higher outside junctions than in junctions and thus when non-junction crashes occur, the consequences are likely to be more serious for cyclists.

Recommendation 12:

Cycle safety policies should pay close attention to junction design – visibility, predictability and speed reduction should be incorporated as key design principles.

V. Review of Bicycle Safety Measures: Lessons for Policy

Policies must account for cyclist heterogeneity

User or cyclist heterogeneity is important to account-for as well when planning safety interventions. There is no single type of cyclist - there are old and very young cyclists, experienced and inexperienced cyclists, commuting and recreational cyclists, etc. High impact safety policies should be tailored to reach as many types of cyclists as possible or, alternatively, seek to target specific cycling publics. Furthermore safety policies seeking to attract new cyclists may have to be different in scope and content as those aiming to improve the safety of those who already ride bicycles.

Recommendation 13:

Authorities should match investments in cycle safety to local contexts, including levels of bicycle usage and account for cyclist heterogeneity.

Dual but interlinked goals: increase safety and increase perceived safety.

Cities are simultaneously seeking to entice citizens to start cycling while at the same time keeping those already cycling safe. Policy seeking to increase cycling and improve safety must approach safety with two interlinked objectives: reducing actual crash rates and their severity and, crucially, increasing the perception of safety for potential cyclists. If citizens don´t feel safe cycling – then they will not ride if there is an alternative they perceive as safer. If on the other hand citizens feel confident that risks are managed along cycling routes the road traffic system is designed with their safety in mind, then they are likely to take up or increase their bicycle travel. Addressing both objective and perceived safety improvements will require slightly different but necessarily coordinated approaches.

Recommendation 14:

Cycle safety plans should address safety improvement and the improvement of *perceived* safety.

Non-infrastructure measures can improve safety, but they should not be the sole focus of policy.

Safety measures for cycling can be broadly categorised as those measures seeking to reduce the negative outcomes of crashes (e.g. vehicle design and helmets) and those that seek to avoid crashes. These are not incompatible but implementing the latter is likely a necessary pre-condition for increasing cycling levels. This report reviews a number of non-infrastructure-related safety measures. Some of these have documented safety effects on crash reduction (e.g. night-time lights and reflective devices for cyclists), others have less documented evidence or unclear findings even though they intuitively would seem to reduce crash risk (e.g. convex mirrors covering lorry drivers' blind spots). More robust investigation of the crash-reduction effect of certain polices is called for.

Helmet usage reduces the severity of head injuries from cycle crashes but may lead to compensating behaviour that otherwise erodes safety gains.

One area that has received vigorous research focus is on the safety impact of bicycle helmet usage and helmet-wearing mandates. As discussed below, these two must be treated separately.

Studies addressing the safety impact of helmets can generally be split into two groups: those that focus on the way in which bicycle helmets change the injury risk for *individual* cyclists in case of a crash and those that focuses on the generalised safety effect of introducing measures (typically campaigns and/or legislation) to increase helmet usage among cyclist. The first group generally finds that wearing a bicycle helmet reduces the risk of sustaining a head injury in a crash and may slightly increase the risk of neck or facial injuries (head injuries are among the most severe outcomes of cycle crashes) though recent re-analysis of previous studies suggests that this effect is less than previously thought. To be clear -- these studies indicate reduced risk of head injury for a *single* cyclist in case of a crash. The effects must not be mistaken for the safety effects of mandatory helmet legislation or other measures to enhance helmet usage.

The safety effect of mandatory helmet legislation as such has been evaluated in far fewer studies. The safety effect of mandatory helmet legislation is a result of a series of factors:

- reduced **injury risk** (due to increased helmet usage)
- increased **crash risk** (due to an often claimed change in behaviour amongst cyclists who take up wearing a helmet)
- **less cycling** (leading to a reduced number of accidents and injuries, but also to a higher accident risk for those who still bike)

Whether bicyclists change behaviour, when they start to use a bicycle helmet seems very uncertain (and difficult to prove), but it is evident that mandatory helmet use might reduce the total number of bicyclists. It is also possible that cyclists who continue to bike might represent a behaviour which is different from the behaviour of those who stop biking. In the end this could very well lead to an overall change in behaviour.

Infrastructure-related measures help resolve issues linked to the visibility of cyclists, predictability at junctions and differences in traffic speed, especially when broadly and consistently deployed.

This report reviews evidence on the safety-improving effect of different type of cycle infrastructure and infrastructure treatment (e.g. lane painting). Adequate infrastructure that matches levels of cycle use is a pre-condition for improving cycle safety in the Safe System approach. Cycle infrastructure (just as any road infrastructure) must meet minimum requirements for sight distances for both cyclists and motorists. The aggregate safety effects of an extensive segregated bicycle infrastructure network may contradict the evidence of the safety performance of its component parts. Why this should be is not clearly evident from the study of the safety impacts of individual measures but it has been the experience of many countries that the coordinated, targeted and network-wide deployment of many bicycle safety measures along with sustained policy support and training of all road users contributes to high levels of bicycle safety.

Adequate maintenance and enforcement of access rules ensures that the benefits of well-designed bicycle infrastructure are achieved.

The effectiveness of safety-improving infrastructure treatments relies on ensuring that these operate as intended. In order to do so, bicycle infrastructure must be maintained to a standard such that the condition of the infrastructure does not contribute to crashes. This also requires that rules and regulations regarding motor vehicle encroachment on bicycle facilities and governing bicycle-motor vehicle interactions are enforced.

Recommendation 15:

The deployment of cycling infrastructure should be accompanied by adequate levels of maintenance and enforcement of access rules.

Traffic speed management should be deployed where appropriate to increase cycling safety.

Where appropriate (e.g. where authorities wish to increase cycling densities, where cycle traffic is concentrated and in distributor road networks in urban areas) speeds should set to 30km/hr and lower for mixed bicycle-motor vehicle carriageways. • In speed-control or traffic-calmed areas, care should be given to the design of speed-control devices (humps, bollards, signage, etc.) as these may constitute hazards to cyclists.

Recommendation 16:

Where appropriate, traffic speeds should be limited to less than 30km/hr where bicycles and motorised traffic mix but care should be taken so that speed control devices do not create hazards for cyclists.

Separation of bicycles from other traffic can also be effective where volumes or speeds warrant.

Another fundamental design consideration is whether to separate cycle traffic from other road traffic. In this matter motor vehicle speed is a decisive factor. According to the Safe System Approach, bicycles should never cross motor vehicle traffic, where motor vehicle speed exceeds 30 km/h. In most countries the situation on the road network is very far from this scenario, and for most road authorities a full implementation of the Safe System Approach will only be possible to achieve incrementally. Emphasis should be put on separating bicycles from motor vehicles on the roads with the highest speed levels and the highest traffic volumes, and slowing down traffic speed at junctions in areas where policy seeks to retain or increase cycling.

Recommendation 17:

Where speeds cannot be lowered, or where justified by traffic densities, authorities should seek to separate bicycle and motor traffic whenever feasible.

Bicycle tracks reduce crashes and crash severity and are generally perceived as safe but may generate increased crash risks at junctions.

Separated bicycle tracks are an attractive option in that they generally produce fewer and less severe crashes in their linear sections – however this safety effect is often compromised at junctions, which may lead to an increased number of crashes and injuries.

Crash risk at bicycle track/road interfaces is exacerbated by poor sight lines, un-conspicuity of cyclists to motorists and the difficulty motorists experience in anticipating the behaviour of cyclists and vice-versa. Proper design of junctions that eliminates obstacles along lines of sight, clearly signal likely cyclist behaviour (e.g. cross-junction bicycle markings), physically demarcate cycling space (e.g. continuous raised cycle track across side roads), separate and give priority to cyclists at junctions (advanced stop line, bike boxes) or harmonise behavioural expectations (e.g. truncated bicycle track) all contribute to lower crash risk.

Junction design and treatment is perhaps the most important infrastructure-related safety intervention. Ensuring that all traffic participants are visible, engage in predictable manoeuvres and that differences in traffic speeds are minimised are key elements of good junction design.

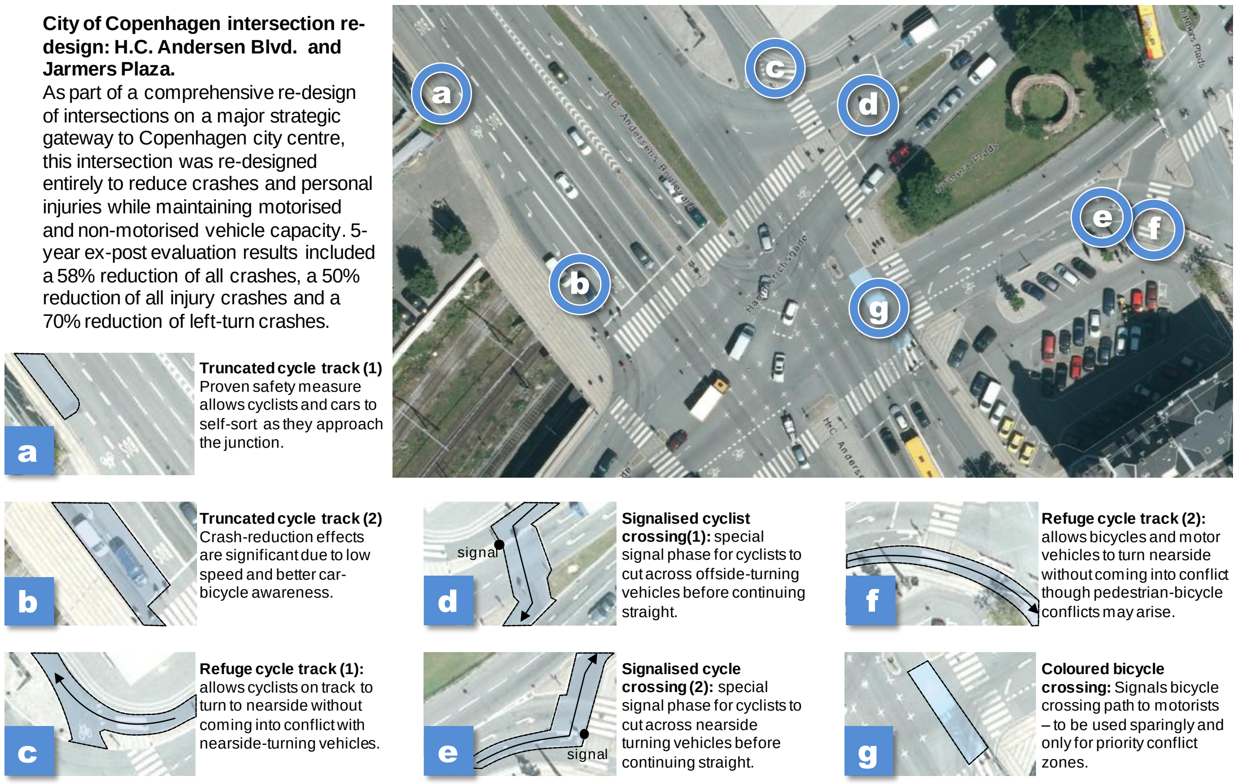
Recommendation 18:

Authorities must critically examine bicycle facility junction design and deploy known safety-improving measures to decrease crash risks.

Safety impacts of individual measures are not necessarily additive and require site-specific diagnosis.

The safety impacts of individual measures are not necessarily additive – the ultimate safety effect of multiple measures deployed on one site will largely depend on site-specific interactions. The selection and implementation of bicycle safety measures should be based on a site-specific diagnosis and identification of the safety problems to be treated. Bicycle safety audits as can be helpful in this respect.

Figure I.IV. **Safety improvement from complete re-design of complex junction (Copenhagen)**



Source: City of Copenhagen

Cycling infrastructure is important, targeted design and coordinated policies even more so.

Countries and cities that have successfully improved bicycle safety have done so via a coordinated set of policies and measures at both the tactical (design of specific safety interventions) and strategic ("safe system" approach) levels. Success requires coordinating both of these approaches in a supportive regulatory environment. On the tactical level, diagnosis of safety improvement targets must be built on crash and traffic monitoring so that effective responses may be designed and implemented. Rarely will isolated safety interventions satisfactorily improve safety and in some cases, uncoordinated responses might make things worse. Figure I.IV illustrates how safety improvements may result from wholesale re-design of critical elements of the traffic environment – in this case, a series of complete junction re-designs along a major thoroughfare entering the Copenhagen city centre. Here only one of several treated junctions is shown but similar results were found for other junction re-designs in the project – e.g. 39-64% reduction for all crashes, 39-78% reduction for all injury crashes and 64-76% reduction in offside-turning crashes.

New or improved infrastructure can also spur more cycling - and stimulate public demand for more and better solutions. Ultimately, specific interventions should be matched to specific safety shortcomings. Improving bicycle safety requires building on proven interventions and adapting them to local conditions. The trouble-shooting table that follows (Table I.I) is based on the findings detailed in the report and should be seen as an indicative guide to potential infrastructure-related solutions for commonly found bicycle safety problems. These are not prescriptive (indeed, they could not be given that implementing all of these would lead to conflicting traffic situations) but serve as a guide to understanding possible solutions for particular, oftentimes site-specific, bicycle safety hotspots.

Table I.I **Trouble-shooting table : Infrastructure measures and bicycle safety**

Accident problem	Hypothesis	Possible solutions
Road sections		
Accidents with bicyclists being run over from behind	Speeds are too high	Speed reducing measures Narrowing of lanes with edge line
	Narrow, dense traffic	Bicycle lanes/bicycle and pedestrian path
	Darkness, moist weather	Road lighting Campaigns on the use of bicycle lights
	Road side parking	Prohibit parking/stopping
Accidents with bicyclists hitting parked cars	Narrow roads	Markings (parking lane) Prohibit parking
Accidents with bicyclists hitting pedestrians	Accidents concentrated	Refuge/verge Raised pedestrian crossing
	Wide street, accidents spread out	Center island
Entrances to private properties		
Bicyclists on bicycle path are hit by cars from the entrance	Sight distance from stop position not enough	Close entrance Improve sight distance
	Bicyclists are overlooked/lack of attention because of dense and fast traffic	Close entrance Speed reducing measures, reduce number of lanes
	Bicyclists go in the wrong direction	Sight distance improved in both directions
Nearside turning cars/lorries hit bicyclists going straight ahead on bicycle path	No sight distance in mirrors	Prohibit nearside turn Prohibit stopping Remove trees and other obstacles from verge Remove or narrow verge Close entrance

Priority junctions in general		
Accidents with offside turning vehicles hitting bicycles driving straight on bicycle path	Sight distance; check parked cars along bicycle path	Sight distance along bicycle path improved Prohibit offside turn Prohibit stopping
	Insufficient orientation	Blue bicycle markings Speed reducing measures
Roundabouts		
Bicyclists are hit by entering vehicles	Too high speeds	More narrow design
	Problem with sight distance/Signs and other obstacles are blocking view	Improve sight distance Replace signs and obstacles
	Bicyclists are overlooked	Bicycle markings on road Change of roundabout design/priority
Bicyclists are hit by vehicles leaving the roundabout	Too high speeds	More narrow design
	Problem with sight distance/Signs and other obstacles are blocking view	Improve sight distance by removing verge Replace signs and obstacles
		Bicycle markings on road Change of roundabout design/priority
Signalised intersections		
Turning cars hit bicyclists	Bicyclists are overlooked	Cross-junction bicycle markings Avoid pre-green for nearside turning vehicles
Right-angle collisions in far end of big junctions	Insufficient clearance phase for slow bicyclists	Increase amber phase
Bicyclists turn offside in front of straight going traffic	No waiting area or signal for cyclists	Establish waiting area Separate signal/phase for bicyclists
Bicyclists cross on red	Long waiting time	Retime signal
Nearside turning cars/lorries hit straight going bicyclists	Not sufficient sight in mirrors	Staggered stop line for cars Remove verge Cut back bicycle track
	Sight OK, but insufficient orientation	Separate regulation Cut back bicycle track Pre-green stage for cyclists Avoid pre-green for nearside turning cars

1. Cycling, safety, health and policy – necessary linkages, suggested approaches

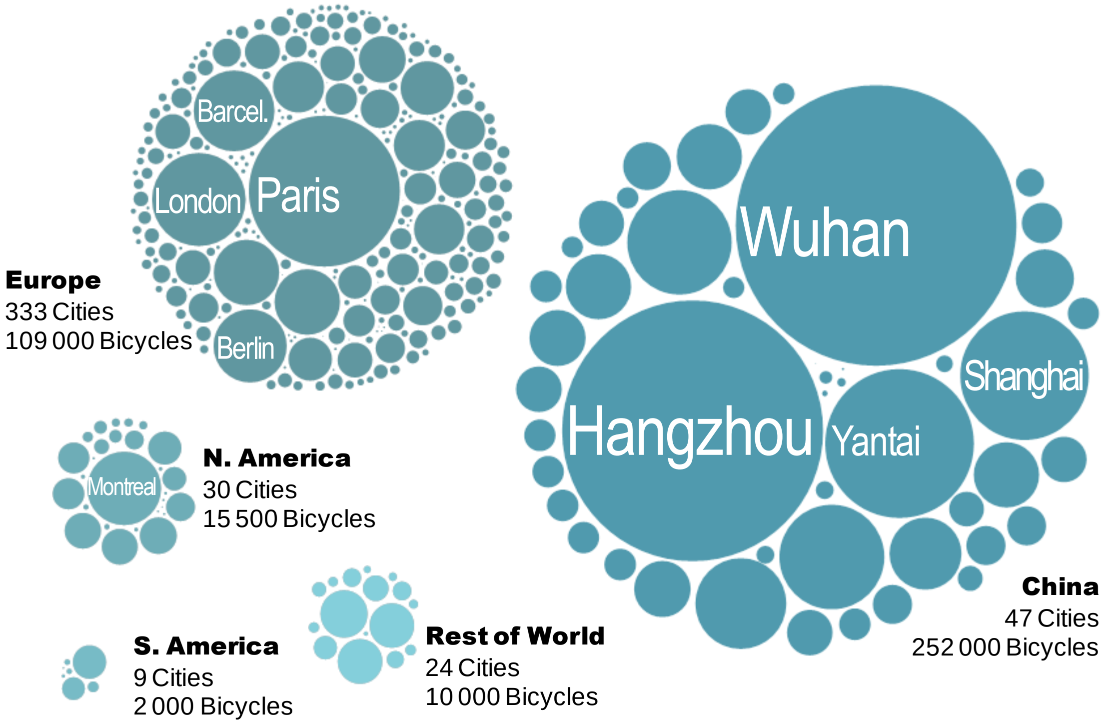
Many countries are promoting cycling as a way to improve health and quality of life while reducing the negative impacts of transport in terms of congestion and pollution. Safety, however, is a key concern since cyclists are relatively unprotected road users. This chapter addresses the key issues relating to cycling safety and links them to a greater discussion of health, safety and cycling. The deleterious impact of crashes on cyclists' health is only one part of the health impacts of cycling – and it is often overvalued in policy discussions. This chapter examines the full range of health impacts and discusses critical elements necessary for cycling policy evaluation. It also suggests a way forward for framing cycling and road safety policy such that health benefits are maximised.

1.1. Pro-cycling Policies and Safety

Bicycles are an essential part of the urban mobility mix. They use no fossil energy, deliver important health benefits, and can improve the liveability of cities. The attraction of the bicycle resides in its ability to provide an affordable and seamless door-to-door mobility option. Cycling is as versatile as walking but can cover greater distances at higher speeds. It represents an alternative to cars and allows for greater freedom of movement than scheduled public transport services. When combined with the latter, bicycles can also extend the range and attractiveness of public transport. Bicycles may decrease pollution and congestion if they successfully replace automobile traffic[1]. Bicycles are well suited to respond to the great number of short to medium distance trips that are typical of urban travel. While powered two-wheelers offer similar advantages, they also impose greater societal costs linked to crash frequency and outcomes as well as air pollution.

That many cities are introducing advanced public bike systems is a clear indication that bicycling is becoming a central part of the mobility solution in many urban settings (see Figure 1.1). Beyond public bike sharing systems, there are a number of pro-cycling policies and frameworks that are being implemented throughout International Transport Forum member countries[2]. Crucially, however, while there are many reasons to promote cycling, safety *per se* is not foremost among them in most countries. In fact, the *improvement* of cyclists' safety is a central element of many pro-cycling policies since evidence points to vulnerability of cyclists in road traffic.

Figure 1.1 **Example of pro-cycling policies: Public Bicycle sharing systems worldwide in 2012**



Source: ITF, data from Data from MetroBike, LLC (http://www.MetroBike.net, accessed 12 December, 2012)

How dangerous is cycling compared to other modes? Statistics (see Table 1) and studies detailing the comparative risk of injury or death for cyclists versus car occupants find significantly higher risks per unit of exposure for cyclists: e.g. 7.5 times higher injury risk and 6 times more fatality risk per kilometre in Norway (Elvik, 2009) (Vegdirektoratet, et al 2009), 6 times higher fatality risk per kilometre for the Netherlands (IRTAD, 2011)(SWOV, 2011), 15 times more injury/fatality risk per hour of travel in New Zealand (Tin Tin, Woodward and Ameratunga 2010). In a meta-analysis of data from Denmark, Great Britain, The Netherlands, Norway and Sweden (Elvik, Høye, et al. 2009) find that cyclists face 9.4 times the risk of being injured per kilometre as car occupants. Part of this disproportionate risk may stem from a bias in the data; an important share of car travel is comprised of relatively "safe" motorway kilometres. One Dutch study compared risks of fatal crashes for motorists and cyclists (including the risk to other traffic participants) *excluding* relatively "safe" motorway travel and found relatively similar mortality rates for cyclists and car occupants (21.0 and 20.8 deaths per million kilometres travelled respectively)(Dekoster and Schollaert 1999). Another Belgian study found that the relative risk of getting killed while cycling versus car travel dropped by 20%[3] if controlling for motorway travel(Hubert and Toint 2002). Whether these finding hold for other countries or regions is unclear and requires further study.

An additional element to consider when assessing the relative safety of cycling versus other modes is the selection of the exposure variable. We discuss issues related to lack of availability of exposure data further on but note here that the type of exposure variable selected (risk per trip, per distance or per duration) is not without consequence. For instance, the United Kingdom's 2007 Road Casualties Annual Report found that cyclists faced 13 times more fatalities than car occupants per 100 million kilometres of travel but only 4 times more fatalities per 100 million hours of travel or trips (Department for Transport 2008).

It is not clear that changing the exposure variable results in a consistently different relative risk level – for instance, (Martensen and Nuyttens 2009) finds that fatality risk per minute travelled is essentially the same for cyclists and motorists in Belgium whereas this is not the case for New Zealand (Tin Tin, Woodward and Ameratunga 2010) (though the latter looks at both serious injury and fatality risk).

Table 1.1 **Relative risk for cyclists vs. other modes, selected countries (index, car driver=1)**

Below are indicators of relative risk of death and/or serious injury for a selection of countries reporting safety and kilometre-, trip- or duration-based exposure statistics for cyclists. Note that because of differences in reporting methodologies and coverage, especially for non-fatal injuries, the figures below should not be used to compare relative risk between countries, but rather to evaluate relative risk between modes within one country.

	Cycling	Walking	Moped	Motorcycle	Car (driver)	Car (pass.)
Netherlands[a] : *Annual number of **killed** per billion **kilometres** of travel, 2007-2009*	5.9	9.1	30.0	30.0	1.0	
Switzerland [b]: *Annual number of **killed** per billion **kilometres** of travel, 2010*	11.2	9.1		18.0	1.0	
Norway[f] : *Annual number of **killed** per billion **kilometres** of travel, 1998-2002*	5.9	8.4		10.2	1.0	
United Kingdom[g] : *Annual number of **killed** per billion **kilometres** of travel, 2008-2011*	14.4	16.9		51.3	1.0	
Denmark[a] : *Annual number of **casualties (killed and injured)** per billion **kilometres** of travel, 2010*	10.6	10.2	148.9	44.1	1.0	
United States[c] : *Annual number of **killed** per billion **trips**, 1999-2003*	2.3	1.5		58.3	1.0	
Belgium[d] : *Annual number of **killed** per billion **minutes** spent travelling, 2005*	1.2	0.8	12.9		1.0	
New Zealand[e] : *Annual number of injuries resulting in **death or hospitalisation** per million **hours** spent travelling, 2003-2007*	14.6	1.1	..	51.2	1.0	1.4

Sources:
a. (IRTAD 2011),
b. Swiss Federal Statistics Office (www.bfms.admin.ch), accessed October 15, 2012
c. (Beck, Dellinger and O'Neil 2007),
d. (Martensen and Nuyttens 2009),
e. (Tin Tin, Woodward and Ameratunga 2010),
f. (Vegdirektoratet, et al 2009),
g. UKDFT Road Safety Annual Report – Table RAS53001.

Box 1.1 **Crash Risk Factors and Cycling**

Participating in traffic is an inherently dangerous activity given the combination of multiple direct and indirect risk factors. Though much has been accomplished to reduce these risk factors or to reduce the likelihood of these risks resulting in injury crashes, they still persist. Below, we outline principal crash risk factors and discuss their relevance for cycling.

Fundamental Risk Factors

Speed: Evidence indicates that speed (absolute speed and relative speed differences among traffic participants) is positively correlated to an exponential increase in crash risk. Speed is also correlated to crash severity as it is an important component of kinetic energy which, in crashes involving bicycles, is directly released onto unprotected soft body tissue and skeletal systems.

Mass and Protection: Mass is the other component of kinetic energy. At constant speed, the larger the mass, the greater the amount of kinetic energy released. For cyclist crashes with heavier opponents (motor vehicles) the mass differential can be extreme thus contributing to increased severity of crash outcomes for cyclists. Protection can help absorb some of the crash-released kinetic energy but motor vehicles offer very much greater levels of protective engineering than cycling equipment (typically limited only to helmets, if worn).

Contributory Factors from Road Users

Lack of experience: For cycling, there is a difference between knowing *how* to cycle and knowing how to cycle *in a road environment*. Both may be addressed by early education but in cases of late adoption of cycling, special training might be desirable for adult cyclists since experience from motor vehicle driving may not be directly transferable to cycling. In addition, late adoptees of cycling may require fundamental training on the use of a bicycle.

Impaired use (Drugs and Alcohol): Use of drugs or alcohol, or both, significantly increases risk for road users. Single bike crash severity for cyclists may be lower than single motor vehicle crash severity (largely due to speed and mass differences) but risk-taking by impaired cyclists could expose them to greater involvement in motor vehicle-bicycle crashes (with largely detrimental outcomes for the cyclist). It may be that impaired people opt to use a bicycle rather than a motor vehicle in order to reduce their crash risk and in some jurisdictions, cyclists face lower blood alcohol limits than motorists (e.g. in Germany, the blood alcohol limit for car use is set at 0.05%, whereas for cycling it is 0.16%) (Juhra, et al., 2011). This is a practice worth re-assessing using available evidence on alcohol use and bicycle injury crashes.

Illnesses or Ailments: Visual or auditory impairment can be a contributing factor in bicycle crashes. The latter especially may be a factor in crashes resulting from overtaking. Wearing headphones may mimic this risk.

Emotion and Aggression: Anecdotally, crash risk exacerbation from aggressive behavior in traffic seems to be mainly attributable to motorists. This is not to say that aggressive behavior on the part of cyclists does not contribute to crashes – especially when it is combined with risk-taking behavior vis-à-vis other cyclists and pedestrians.

Fatigue and Distraction: Fatigue increases the risk of crash involvement. Cyclists may be even more prone to fatigue since cycling requires energy expenditure further complicating an already fatigued state. On the other hand, fatigued people may avoid cycling altogether or may find themselves becoming less tired as they cycle because of the beneficial impact of physical activity. Distraction may also be a contributing factor to crash risk for cyclists – especially for those using mobile phones or other electronic devices. The latter is an area where more research can help guide safety policy, especially as use of mobile ICT devices is increasing (Scheppers 2007).

Source: Adapted from (Wegman and Aarts 2006)

The majority of trips are made in view of travelling from point to point, not for travelling during a set amount of time. Because of this *distance-based* exposure variables have (when available) typically been seen as a superior measure of relative risk for *equivalent* trips. In reality, trips by bicycle and by car are not necessarily equivalent and travellers may adjust mode choice according to a wide range of factors (availability of parking, exposure to congestion, amenities at the destination, ease of linking with other modes, etc). For instance, although average trip lengths are greater for cars than for bicycles in Belgium, average per-trip travel time is roughly equivalent (Martensen and Nuyttens 2009). International data is lacking to estimate comparative risks of cycling per travel duration but this indicator may be lower than relative risk indicators based on travel distance. (Van Hout 2007) found that the relative risk of death per hour of travel was roughly equal between cyclists and car occupants in Belgium in 1999. Duration-based indicators of relative risk may be appropriate in instances where the duration of cycling and car trips is nearly the same — for example, in congested urban areas where cycling speeds are equal to, if not greater, than car speed.

Part of the "built-in" lack of safety of cycling is that the road system has, with some notable exceptions, not been designed for cyclists. More precisely, the road system has not been designed for mixing well-protected, heavy and high velocity vehicles with unprotected, lightweight and slower road users. Furthermore, the traffic system does not typically account for the specific characteristics of cyclists and bicycles. Cyclists are highly flexible and sometimes unpredictable road users, riders display very different abilities, cyclists seek to minimise energy expenditure, bicycles can be easily de-stabilised and are relatively difficult to see because of their size (in daytime) and their poor or lack of night-time lighting. Cyclists are also often seen by motorists as intruders in the road system.

Given the vulnerability of cyclists in traffic, those seeking to promote cycling must address a fundamental question: *do policies that increase the number of cyclists contribute to less safety and more crashes?*

This is an important question because if cyclists are vulnerable and the road system is not designed for cycling, then pro-cycling policies could conceivably expose a greater number of people to potentially dangerous conditions. The short answer to this question is that when the number of cyclists increase, the *number* of crashes, both fatal and non-fatal, may increase as well – *but not necessarily so* if attention is paid to good policy design. Furthermore, the incidence *rate* of cycling crashes may decrease, *especially if accompanying safety-improving policies are implemented.* Thus while the number of crashes may increase, cycling safety -- measured by the number of crashes per some measure of exposure (e.g. trips, cyclists, time cycling, distance travelled) -- may improve. A fuller answer to this question must address four crucial factors whose understanding is essential in the cycling safety debate:

- The linkage between cycling, safety and health
- The safety in numbers effect
- The strong under-reporting bias in cycling crash statistics
- The lack of adequate exposure data

1.2. Linkages between Cycling, Safety and Health

A discussion of the impact of cycling on road safety should not be isolated from a broader discussion of the overall health impacts of cycling. Indeed, if we are concerned that increasing the number of cyclists may increase crash numbers or risks, it is because of the deleterious effects of crash-induced injuries on cyclists' health. Injuries from crashes, however, are not the only health endpoint from cycling – exposure to air pollution can negatively impact cyclists' health just as cycling-related exercise can (greatly) improve cyclists' health. Pursuing *increased safety* for cycling (e.g. reducing crash risk and the severity of crash outcomes) makes sense no matter what the balance of positive/negative health outcomes from cycling since these policies expressly reduce the negative outcomes linked to crashes. Understanding the balance of positive/negative *health* outcomes from cycling, however, is essential in helping frame efforts to *increase cycling*.

Health benefits of cycling: Physical Activity

The World Health Organization recommends that adults participate in at least 30 minutes of moderate exercise 5 days a week and more intensive training a few times every week. Cycling, as a moderate physical activity, can significantly reduce clinical health risks linked to cardiovascular disease, obesity, Type-2 diabetes, certain forms of cancer, osteoporosis and depression. Taken separately and even more so when effects are cumulative, these conditions exact a high human and economic cost on society. This health improving-effect is robust across different studies and in different geographic contexts (Tables 1.2 and 1.3). There is evidence that the range of morbidity-reducing effects are significant as well – not only does cycling reduce disease-related *deaths* for cyclists but it also contributes to substantially better *health* (Rabl and de Nazelle 2012).

Health Impacts of Physical Inactivity

"Physical inactivity is one of the most important health challenges of the 21st century because of its influence on the most deadly chronic diseases, contributing worldwide to 21.5% of ischemic heart disease, 11% of ischemic stroke, 14% of diabetes, 16% of colon cancer and 10% of breast cancer (Bull, et al. 2004). The World Health Organization (WHO) recently estimated overweight and obesity to be responsible for 2.8 million deaths annually; physical inactivity is (separately) responsible for an additional 3.2 million deaths."

Source: (de Nazelle, et al. 2011)

Table 1.2 **Quantified relative risk of all-cause mortality for cyclists compared to non-cyclists**

Relative risk expressed as a ratio of *all cause mortality of cyclists* compared to non-cyclists after controlling for confounding factors (age, gender, education, etc.) – e.g. a relative risk result of 0.70 indicates that a cyclist has a 30% reduction in risk of death compared to a similar non-cyclist.

Location	Relative mortality risk (cycling/non-cycling)	Confidence interval	Study
Copenhagen, DK	**0.72**	0.57-0.91	Anderson *et al*, 2000
China	**0.79**	0.61-1.01	Matthews *et al*, 2007
China (high activity)	**0.66**	0.40-1.07	Matthews *et al*, 2007
Finland	**0.78**	0.65-0.92	Hu *et al*, 2004
Finland (high activity)	**0.69**	0.57-0.84	Hu *et al*, 2004

Evidence suggests that this health-improving effect is not linear – that is, the greatest benefit for a sedentary person occurs simply from becoming active and further health benefits reduce with each additional increment of moderate activity (US DHHS 2008). Evidence of the non-linearity of benefits (e.g. the dose-response relationship) varies according to pathology and for some pathologies the relationship is unclear. Nonetheless, the evidence suggests that the health benefits of cyclists are greatest for those who were previously sedentary or displayed modest levels of exercise. It also appears that the health gains from physical activity are greater for frequent and recurrent bouts of moderate exercise as opposed to occasional periods of higher-intensity exercise (Praznoczy 2012). Successfully attracting non-cyclists or otherwise inactive people will deliver the greatest health benefits from physical activity but will require a good understanding of their perceptions of safety (see Chapter 4) and of the specific safety challenges posed by inexperienced cyclists.

Table 1.3 **Quantified relative risk estimates for *selected diseases* from 2.5 hours per week of moderate physical activity***

Disease	Relative risk (exercise vs. sedentary) – Square root model	Study
Cardiovascular disease	**0.82**	(Hamer and Chida, 2008).
Colon cancer (men)	**0.87**	(Harriss, et al. 2009)
Colon cancer (women)	**0.91**	(Harriss, et al. 2009)
Breast cancer**	**0.87**	(Harriss, et al. 2009)
Dementia	**0.82**	(Hamer and Chida 2009)
Depression	**0.86**	(Paffenbarger, Lee and Leung 1994)
Diabetes	**0.82**	(Jeon, et al. 2007)

* RR normalised to 2.5 hrs moderate physical activity in (Woodcock, et al. 2009)

** Linear model

Health benefits of cycling: Reduced air pollution

Some researchers suggest that a secondary health benefit from cycling (not just for cyclists) may be the improvement of local air quality due to bicycle traffic replacing other, mostly car-based, travel. Replacing short car trips with cycling or walking could result in a disproportionate reduction of volatile organic compounds (VOCs) and fine particulate matter emissions since a large share of these emissions are emitted in the first few minutes of motor vehicle operation (e.g. cold-start emissions) and thus over distances easily replaced by bike trips (Grabow, et al. 2012).

While the potential for air quality-related health improvement is important, the extent to which this benefit is realised depends on how successfully pro-bike policies reduce a significant share of car travel. The realisation of this potential also depends on the emissions profile of cars whose trips are susceptible to being replaced.

With the exception of the Netherlands and Denmark, and some specific urban areas, it is not clear that pro-cycling policies have led to a significant reduction of car traffic, at least at present. One reason for this is that, at least initially, new cyclists seem to switch not from cars but from public transport and walking. For instance, (Börjesson and Eliasson 2011) find in a survey in Stockholm that only 13% of cyclists identified the car as their second-best travel alternative. Likewise, only 10% of Barcelona's Bicing users, 5%.of Lyon's Vélo'v users and 2%[4] of Montréal's Bixi users would have used a car absent bikesharing (Ajuntament di Barcelona 2007) (Beroud 2010).(Bachand-Marleau, Larsen and El-Geneidy 2011). The initial potential for mode shift seems low – in central Lyon and Villeurbanne, the public bicycle system Vélo'v was found to have replaced less than 0.01% of all car travel. However, it should be noted that car-bicycle replacement might be greater if measures are taken that reduce average trip distances (e.g. by increasing density) with a correspondingly larger health impact.

Air pollution health benefits from car trip reduction could potentially be more significant in areas with fewer walking and public transport opportunities (though these areas may be ill-suited for cycling as well). In areas undergoing rapid motorisation, air quality benefits from retaining cycling and walking shares could be high -- (Shaheen, et al. 2011) find that 16% of users of Huangzhou's bikesharing system replaced car trips (78% for users from car owning households) and that 37% state they have postponed buying a car. Over time, if pro-cycling policies are sustained, new cyclists may indeed switch from cars. If that is the case, the health-improving impact from reduced air pollution may be positive but lagged though evidence is lacking on this point[5].

To be clear, reductions of pollutant levels (especially those of fine particulate matter, ozone (O_3) and NO_2) from automobiles and other motorised traffic[6] have been shown to have significant beneficial health impacts. What is less clear is the extent to which uptake of cycling will lead to strong enough reductions in motorised traffic such that these benefits are realised and research suggests that this is not the case (van Kempen, et al., 2010). As a general rule, it may be more appropriate to take into account air pollution impacts from switches from *public transport and walking* (rather than from mainly cars) to cycling when assessing the *initial* health impacts of pro-cycling policies.

Another factor to consider is the relationship between pollutant emissions and exposure to pollutants. Pro-cycling measures are often comprised of (or accompanied by) policies seeking to calm traffic, increase urban densities or mix land uses such that longer trips by car are replaced with shorter trips by foot, bicycle or public transport. When successful, overall pollutant emissions may decrease whereas exposure to pollutants may paradoxically increase. This is because of a shift in proximity between emission sources and people due to densification and from the configuration of high-density urban settings (e.g. increased incidence of "canyon" streets[7]).

Should pro-cycling urban design policies increase the incidence of stop-and-go traffic, local pollutant concentrations may also increase as a result of repeated engine acceleration. Evidence from a study in Vancouver confirms the paradox of higher density, more polluted neighbourhoods (under current traffic regimes) – dense, multi-use neighbourhoods (e.g. "walkable" or bicycle-friendly neighbourhoods) were found to have high levels of primary traffic-related pollution (NO) though secondary pollutants such as ozone were found to be lower[8] (Marshall, Brauer and Frank 2009). In these instances, the balance of overall health impacts may see the individual physical activity-linked health gain *for cyclists* be eroded by a collective air-pollution linked decrease in health for all other *inactive local residents* remaining in high density and relatively more polluted neighbourhoods. This of course is a sub-optimal outcome of urban policies and underscores the need to manage traffic volumes proactively and tackle pollutant emissions alongside urban policies seeking to increase density or shorten trips.

Where pro-cycling policies replace car trips, the air quality health benefit will be proportionate to the amount of displaced air pollution. New automobiles emit fewer and fewer air pollutants and considerable progress has been made to reduce disproportionately more polluting “cold-start” emissions. At the same time, ultra-low emission technologies, mainly in the form of hybrid drivetrains (and some battery electric vehicles), are penetrating many national fleets. This would seem to suggest that the marginal air pollution reduction benefit from car-bicycle trip replacement will decrease over time. However, if pro-bicycle policies successfully lead to the replacement of car travel by the most polluting and older vehicles in the fleet, the air pollution reduction benefit could be significant. There seems to be insufficient evidence at this time to quantify this potential impact.

Other health Benefits of cycling

Other potential benefits from increased cycling include a reduction in traffic noise and a reduction of crash injuries from modes previously used by new cyclists.

Noise is an important environmental stressor increasing the risk of ischaemic heart disease, contributing to cognitive impairment in children and disrupting sleep patterns (WHO 2011). Traffic noise is a significant contributor to overall noise levels and some have postulated that pro-cycling policies may reduce overall traffic noise. Not many studies have sought to quantify this effect -- one study that has undertaken this analysis has found the health benefits of reduced noise due to a shift from cars to cycling are minimal (van Kempen, et al., 2010). For the reasons exposed earlier it seems highly optimistic to expect that cycling will decrease ambient traffic noise levels such that there is a city-wide positive health impact – though localised noise reduction is entirely likely.

An additional health impact could result from a reduction in the number of crash-related injuries and deaths due to people switching from other modes to cycling. The sign and scale of this benefit is related to the crash rate for those modes and the severity of injuries incurred. It is also related to the risk profile of those making the switch. For instance, a switch from public transport to cycling is not likely to generate any benefit due to reduced crashes given that the former is typically safer than the latter. A switch from cars to cycling, on the other hand, would reduce fatalities linked to car crashes, especially if one includes pedestrians and cyclists hit by cars in addition to victims of car-only crashes. A study in the greater Paris region has sought to quantify this effect under various mode shift scenarios. It finds that a modest increase of cycling to 4% of trips from its current level of 2%, assuming that only 5% of new trips were previously made by car, would result in 0.4 fewer deaths per year compared to 5 new bicycle crash-related deaths. However, at a 8% mode share for cycling (comparable to the cycling mode share of several other European cities) and assuming 38% of new bicycle trips were previously made by car, avoided car-crash deaths would break even with new bicycle-crash deaths (Praznoczy 2012). This finding helps frame the eventual crash fatality impact of long-term pro-bicycle policies – at some point, avoided car crash deaths will outstrip newly generated bicycle crash deaths, *all else equal*. In reality, pro-bicycle policies should seek to reduce *all* crash deaths and so these findings should hopefully only serve to indicate that there is a dynamic and positive safety impact of switching bicycle traffic for car traffic.

Risk profiles matter as well as seen in data from the Netherlands in Table 1.4. Eighteen to twenty-four year-olds switching from cars to bikes would decrease their risk exposure for fatal crashes, at least in the Netherlands. An early estimate of the overall health impact (including crash risk and exposure to air pollution) from shifting from car travel to cycling also found that young males benefit most – largely because of their car crash risk profile (van Kempen, *et* al, 2010). On the other hand, sixty-plus year old drivers switching to cycling would greatly increase their risk exposure, all else held equal.

Table 1.4 **Average number of killed per 1 billion vehicular kilometres in the Netherlands from 2007 to 2009 and relative risk**

Age	18 - 24	25 - 29	30 - 39	40 - 49	50 - 59	60 - 74	75+
Cyclists	7.4	3.7	3.7	6.6	9.6	23.7	164.0
Car occupants	9.6	3.7	2.1	1.2	1.5	2.1	13.2
Relative risk, cycling vs. car	-0.23	-0.01	0.74	4.65	5.44	10.18	11.40

Source: SWOV, 2012

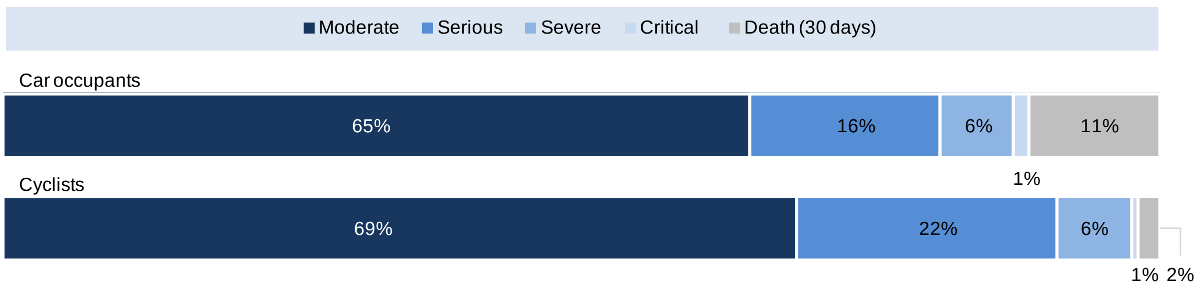
Health risks of cycling: Crash-related injuries for cyclists

Traffic infrastructure is seldom designed with safety as a starting point and though efforts are made to accommodate the wide range of behaviours displayed by road users, errors and unpredictable or impaired actions often lead to crashes. The kinetic forces involved resulting from the differences in mass and velocity of crash opponents largely dictates the severity of outcomes. Crash outcomes with cars are especially severe for vulnerable road users such as pedestrians and cyclists who by far lack the same level of protection mandated for, and offered to, car and other vehicle occupants.

The distribution of crash outcomes by severity varies across countries given the heterogeneity of cycling environments. For example, the share of killed and serious injuries (greater than MAIS 2 – or moderate injuries) is greater for cars than for cyclists in the Netherlands (Figure 1.2), principally because of a smaller share of deaths resulting from cycling-related crashes. In the UK, the opposite is true with those killed or seriously injured representing 16% of crash outcomes for cyclists versus 8% for car occupants[9].

The very young and the very old are disproportionately represented in serious crash-related injuries across a number of countries (see Chapter 4). Korea and Japan, two countries with a significant share of older people, are especially confronted with bicycle crash fatalities and injuries among the old – e.g. in Korea 65% of bicycle fatalities were aged over 60 (2009) and in Japan, 70% of bicycle fatalities were aged over 60 (average 2005-2010) – these figures are likely exacerbated by relatively low rates of car use and high rates of cycling (and walking) among these populations. For comparison, in the Netherlands, 55% of police-recorded bicycle fatalities were aged 60 and older (average 2005-2009) and in the United Kingdom, this figure was as low as 21% of all police-registered bicycle fatalities (2005-2010).

Figure 1.2 **Traffic injuries by severity in the Netherlands, Average 2007-2009**



Source: SWOV, 2012

Crashes between cyclists and other cyclists or pedestrians also are a source of injuries. Official German accident statistics indicate that in 2010 3 300 injury accidents occurred involving a cyclist and a pedestrian, and about 4 400 injury accidents occurred involving two bicycles. These types of crashes, because of their lessened severity, are often under-recorded . Nevertheless, such crashes appear to be a real issue in certain countries. In Japan, for instance, the Ministry of Land, Infrastructure and Transport decided in 2007 to reconsider their approach to cycling facilities in urban cores (where a large share of cycling occurs on sidewalks). Indeed, since 2000 a strong increase in crashes between cyclists and pedestrians had been noted leading transport authorities to start to develop separated one-way cycling tracks as a rule in urban cores.

Few studies have looked specifically at the crash-related injury burden among modes using metrics relating to overall lifetime health. Evidence from one study (in high cycling environments in Belgium) using disability-adjusted life years (DALYs)[10] finds that DALYs per 1 billion kilometres of travel was lowest for cars (113), followed by pedestrians (1359), cyclists (1724) and motorcyclists (6365). However, the relative contributions to lifetime health of years lost due to *disability* (YLD) versus *lost life* years (e.g. deaths or YLL) were found to be diametrically opposed for cyclists and car occupants. The majority of the health burden for cyclists was found to stem from *disability* (75% of DALYs) whereas *lost life* years represented 67% of the crash-related health burden for car occupants (Dhondt, et al. 2012).

Injuries to cyclists that do not require hospitalisation often do not appear in national or regional safety statistics and yet represent the majority of all cyclist injuries. Minor crashes, exact a high cumulative cost, when considering health care expenditures, absenteeism and lost productivity (B. de Geus, et al. 2012) (Aertsens, et al. 2010).

Few studies have looked specifically at the incidence rate of minor versus major crash outcomes for cyclists but evidence indicates that un-recorded minor injuries represent the overwhelming majority of cycle crash outcomes. One cohort study of bicycle commuters in Portland, Oregon found that 80% of all injury-causing crashes were classified as “minor”, e.g. requiring no medical attention. That study found the incident rate for minor versus serious (e.g. requiring medical attention) injuries was found to be 0.093 and 0.024, respectively, per 1000 kilometres (Hoffman, et al. 2010). Another cohort-based study from the Netherlands found an even greater share of “minor” crash outcomes – 97% of the total[11] – though this result cannot be compared to the Portland case given that a “minor” incident was defined as one requiring less than 24 hours hospitalisation. Corresponding incident rates for minor versus serious injuries per 1000 kilometres was found to be 0.046 and 0.001, respectively (B. de Geus, et al. 2012). (Aertsens, et al. 2010) find the cost of these accidents to be significant in Belgium – 0.125 euro per kilometre with productivity losses dominating.

Single bicycle crashes (e.g. crashes with no crash opponent) are also a significant source of injuries though they tend to go unreported in national statistics due to their lessened severity. Single bicycle crash outcomes involving falls and collisions with obstacles can result in especially serious injuries for elderly cyclists. Studies compiling hospital and police records reveal that, at least in countries with a high share of cyclists, single-bicycle crashes represent a majority of cyclist crashes and a significant share of overall traffic crash victims. e.g. three quarters of all cyclist crash victims in the Netherlands (P. Schepers 2012) (Schepers and Klein Wolt 2012), 87% of cycle crash victim in Flanders and Brussels (Dhondt, et al. 2012) based on hospital data and 73% of crash injuries in a prospective cohort study in Belgium(B. de Geus, et al. 2012).

Do countries with lower cycling shares display the same level of single bicycle crashes? Evidence looking beyond police-reported statistics is sparse on this point though one prospective cohort study in North America reports that 62% of injury-causing cycling crashes involved neither a motor vehicle or another cyclist (Hoffman, et al. 2010).

Health risks of cycling: Crash-related injuries caused by cyclists

While cyclists tend to fare badly in motor-vehicle crashes, cyclists themselves can injure other non-motorised crash opponents. The bulk of these crashes may have minor outcomes and go unreported but there is evidence that for certain crash opponents, especially elderly pedestrians and cyclists, outcomes are more serious (Chong, et al. 2009).

Health risks of cycling: Air pollution

Cyclists' are exposed to a wide spectrum of potentially health-damaging pollutants while riding. Foremost among these are constituents and products of motor vehicle exhaust -- especially particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), ultrafine particulate matter (UFP) of less than 1 micron in diameter, NO_2 and O_3. Exposure to these pollutants are associated with heart disease, respiratory ailments and disease, lung cancer and mortality (Marshall, Brauer and Frank 2009) (Knibbs, Cole-Hunter and Morowska 2011). The dose-response relationship has been found to be linear (e.g. there are no threshold effects) with adverse health outcomes reported for long both long-term and short-term exposure (Marshall, Brauer and Frank 2009) (Weichenthal, et al. 2011) (Int Panis, Meeusen, et al. 2011). However, many studies have found that adverse impacts of air pollution in relation to mortality fall disproportionately on already-weakened populations such as the elderly or those with pre-existing cardiovascular conditions (Int Panis and de Hartog 2011). If the cycling population is largely drawn from younger and healthier subjects, then mortality-related impacts due to exposure to air pollution are likely to be smaller than those suggested by many studies. This would suggest that the health disbenefits from exposure to air pollution for cyclists may be overestimated in current analyses.

Box 1.2 **Electric Bicycles, Safety and Health**

Electrically-assisted bicycles and light scooters are not specifically addressed in this report, largely because national crash and injury data do not typically keep separate statistics for these vehicle classes. Nonetheless sales of electrically-assisted bicycles are growing rapidly in many countries. More than 32 million electric bicycles were sold in 2011, 31 million of them in China (and most of these were not strictly "pedelecs" as described below). In Europe and Switzerland over 750 000 electric bicycles were sold in 2011 with market shares of total bicycle sales reaching 15% in the Netherlands, 9% in Austria and 8% in Germany. Upwards of 350 000 electric bicycles were also sold in Japan in 2011 surpassing moped sales. The rate of uptake of electric bicycles and their continued penetration within national fleets warrants some discussion of their safety and health aspects.

The electric bicycle market can be broken into two broad categories. "Pedelecs" represent the first category and are characterised by low-power motors that operate only with pedal input up to speeds of ~25 km/hr at which motor assistance cuts out. They cannot be powered by the motor alone and in most jurisdictions are treated as traditional pedal-powered bicycles. The second category consists of pedal vehicles with more powerful electric motors, higher top-end speeds and, in many instances, the ability to operate solely on electric power (e.g. with no pedal input from the rider). The regulatory framework for these vehicles is disparate among countries and, in some cases, within countries. Some jusrisdictions (e.g. the EU) classify these types of electric "bicycles" as light motorcycles or mopeds triggering more stringent licensing, operating age and helmet use rules. Certain other jurisdictions are in the process of revising the regulatory framework governing these vehicles (as in the case of China). Below, we discuss safety and considerations in relation to *pedelecs* only.

Research on pedelec use is limited but the following characteristics can be summarised from the litterature; average per-trip travel distances tend to be longer than for traditional bicycles, average travel speeds tend to be higher and pedelecs tend to be used predominantly by those 50 and older and by commuters (Roetynck 2010) (Hendriksen, et al. 2008) (Lenten and Stockmann 2010). What do these findings imply as far as safety is concerned?

Increased speeds will translate into higher crash-related kinetic forces. This suggests that pedelec use may lead to more severe injuries than crashes involving a traditional bicycle. Available evidence supports this hypothesis (Lenten and Stockmann 2010) (GDV 2011) (Feng, et al. 2010). Higher speeds may also increase the severity of single-bicycle crashes and crashes involving bicycle and pedestrian opponents. The finding that older cyclists tend to be disproportionately represented among pedelec users also implies that crash outcomes will be more severe given the vulnerability of these cyclists in relation to the general cycling population. Crashes may also be more frequent for this class of user due to the combination of lower psycho-motor function and elevated travel speeds. The impact of speed on the frequency and severity of pedelec crashes could also be exacerbated should pedelecs attract new (and older) cyclists with little riding experience. Pedelec and electric bicle kilometres travelled are likely less safe than bicycle kilometres travelled, all things equal, and this should be accounted-for in policy.

What can be said about the health benefits of pedelecs? Again, this is an area where little research has been undertaken but there is evidence to support the following statements. Pedelecs require some physical effort and therefore can contribute to beneficial levels of physical activity. How much depends on the speed at which pedelecs are operated. At typical operating speeds (22+km/hr for pedelecs, 15km/hr for traditional bicycles) metabolic effort is roughly similar (Lenten and Stockmann 2010). If pedelecs are operated at traditional bicycle speeds (~15km/hr), then the metabolic effort for pedelecs is lower than a traditional bicycle and so too are the health benefits from physical activity. However, air pollutant intake is also lower at lower rates of metabolic effort.

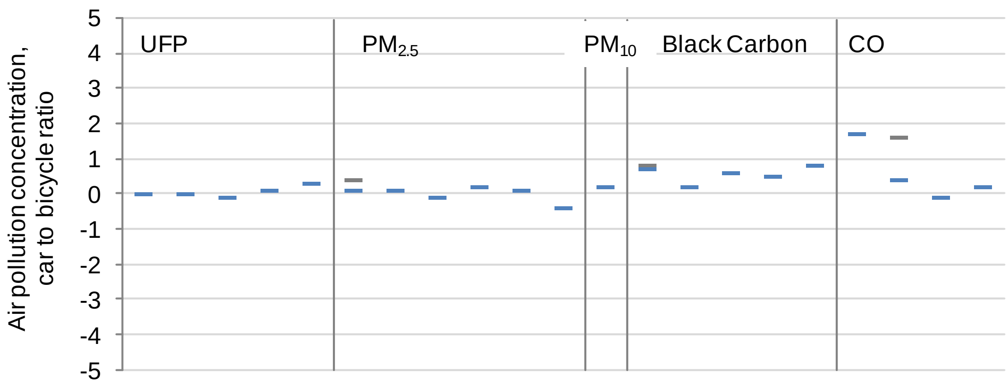
It would seem that increasing pedelec numbers is not neutral from a safety perspective and will require targeted action (possible strategies could include adapting bicycle infrastructure design, rider awareness campaigns , protective equipment) as well as more research. One may broadly conclude that pedelec riders face increased crash risk and increased risk of severe injuries as compared to traditional cyclists. Nonetheless, if pedelec riders were previously sedentary, the adverse health outcomes from crashes may be more than compensated-for by the health benefit of increased activity. A fundamental question remains as to the safety and health balance of pedelec use by older riders which should be a targeted research area in the future.

Are cyclists disproportionately at risk compared to other populations? Three variables come into play when evaluating this relative risk which is necessary to evaluate the health impact of shifting traffic to cycling. These variables are:

- ambient pollutant *concentrations* measured on or near the road,
- *exposure* to pollutants for on-road and near-road populations and
- the ultimate *dose* experienced by cyclists and other road users.

Most studies evaluating the health impact of traffic pollution are based on measurements of ambient pollutant levels in the roadside environment. One major reason for this is the relative ease and low cost of collecting this data. As a result, health risks to cyclists from exposure to $PM_{2.5}$ and UFP have often been downplayed in light of consistent findings that differences in average concentrations faced by cyclists and car drivers in traffic are rarely significant (and even slightly higher for car occupants, see Figure 1.3). Average concentrations do not serve, however, as a perfect proxy for gauging exposure or deposition.

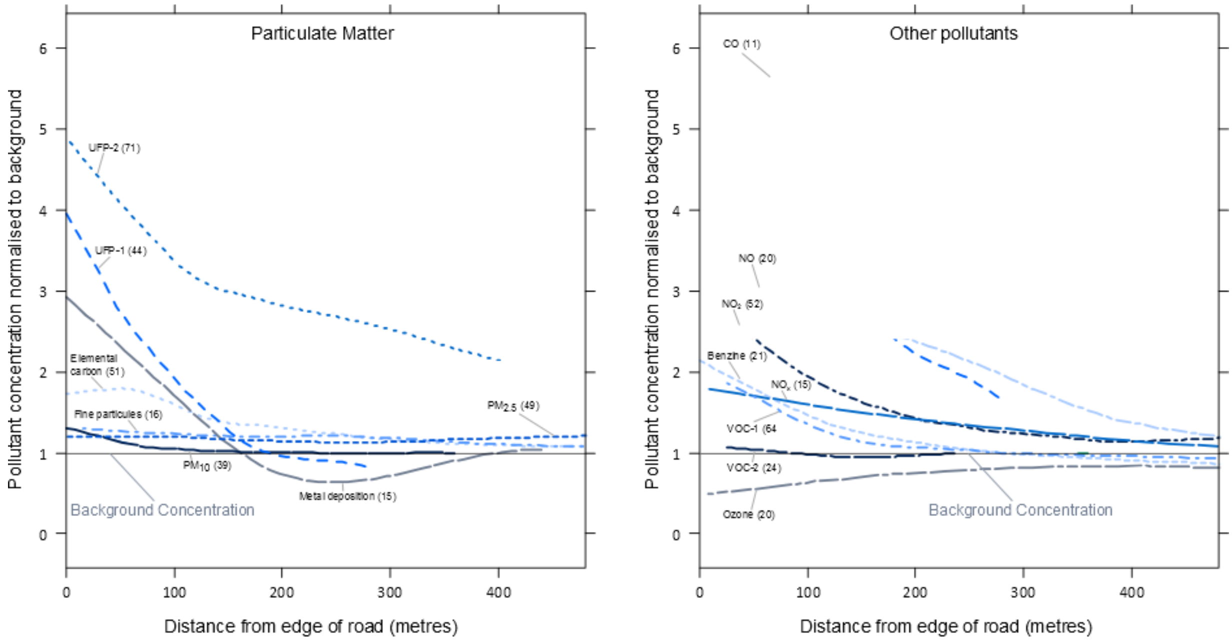
Figure 1.3 **Summary of car vs. cyclist pollutant concentration ratios, 13 studies, 21 findings**



Source: Compiled from (Brauer and Cole 2012)

Studies have confirmed a distance-based concentration gradient for several pollutant species that have significant adverse health impacts. The slope of this gradient is highly dependent on local conditions, fleet composition and meteorology but a recent review controlling for many of these factors has found that concentration-distance gradients for several toxic pollutants are relatively steep with highly dangerous ultrafine particulate matter and carbon monoxide degrading especially rapidly (Karner, Eisinger and Niemeir 2010)(Figure 1.4). This would suggest that dangerous pollutant concentrations faced by cyclists on near-road but separate facilities may be less on average than those faced by cyclists and motorists in the traffic stream.

Figure 1.4 **Pollutant concentration gradient from roadside – Local regression of background normalised concentrations on distance**



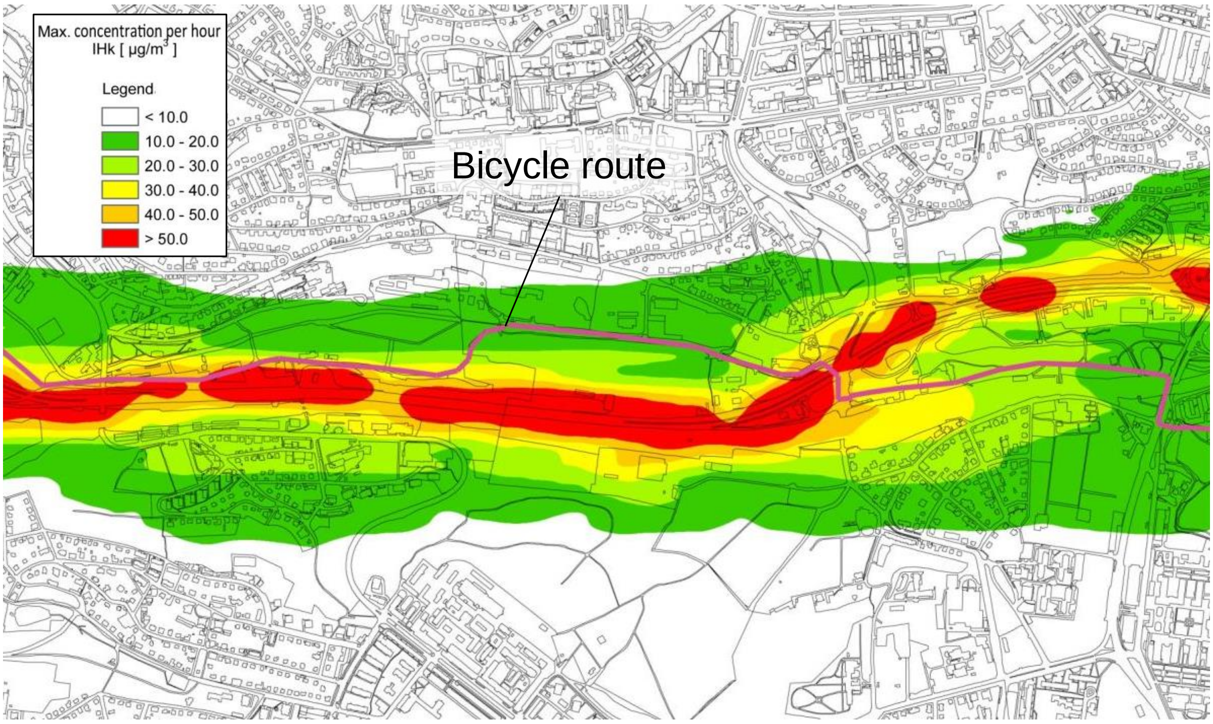
Regression sample for each pollutant in parentheses

Source: (Karner, Eisinger and Niemeir 2010).

This intuitive finding is supported by micro-scale studies looking at pollutant concentrations measured within very close distances to the roadway. For instance, (Kendrick, et al. 2011) found that displacing cyclists 1 to 2 metres away from motor traffic (in the context of a cycle lane to cycle track conversion) led to an 8-38% reduction in UFP concentrations depending on the day and location monitored. The particular configuration of the cycle track (separated from traffic by a row of parked cars and a small buffer zone) is likely to have played a role in the lower concentrations measured for cyclists in addition to the horizontal separation from motorised traffic.

Likewise, a monitoring study of a major roadway in Prague highlighted the distance-decay effect for road traffic pollutants (Bendl 2011). A cycling path running parallel, but not always adjacent, to the roadway registered levels of PM10 running from less than 10µg/m³ to higher than 40µg/m³ (Figure 1.5). These findings suggest that locating bicycle facilities even slightly further away from traffic may reduce pollutant concentrations faced by cyclists – especially if physical barriers help block pollutant dispersion (e.g. parked cars or planted barriers).

Figure 1.5 **Map of PM10 concentrations alongside a main road with 110 000 vehicles/day, Prague**



Source: (Bendl 2011)

Exposure to air pollutants is the product of ambient *concentrations* and *duration*. Holding concentration and distance equal, and assuming typical average speeds, cyclists experience greater exposure than car occupants since they require longer in order to travel the same distance. If traffic is congested however, cyclists may be as fast or faster than motor vehicles and thus cyclists' exposure, holding concentrations equal, may be lower. In reality, cyclists typically will, if possible, select lower trafficked routes that *de facto* reduce *exposure* due to lower pollutant concentrations despite sometimes longer travel times. In some cases, the exposition to harmful air pollutants is quite significantly reduced on low versus high traffic routes (Zuurbier, et al. 2010), (Cole-Hunter, et al. 2012).

The ultimate health impact of air pollutants on cyclists is closely related to intake and thus, ultimate deposition of pollutants in the lungs, especially in the alveoli where pollutants enter the bloodstream. Intake is a product of both *exposure* and, critically for cyclist, *ventilatory effort* since cyclists breathe more often and more deeply than occupants of motorised vehicles. Studies looking at ventilation-adjusted pollutant intake among cyclists and other road users find much higher doses for cyclists. Controlling for real measured ventilatory effort, one study found that cyclists inhaled 5.9 to 8 times more $PM_{2.5}$ (μg) than car drivers on the same route in the same traffic and meteorological conditions (Int Panis, Meeusen, et al. 2011). Another study found smaller but still significant differences with cyclists inhaling 1.9 times as much $PM_{2.5}$ (μg) as car drivers on the same route (Zuurbier, et al. 2010). Part of the difference between the two findings can be explained by the travel speed (and therefore ventilatory frequency and effort) of the cyclists – e.g. 12 km/hr in the former study versus 15/hr (for women) to 19km/hr (for men) in the latter. In Dublin, (McNabola, Broderick and Gill 2008) similarly find that cyclists register 1.4 times more intake of $PM_{2.5}$ than car occupants (and 1.3 times more than pedestrians but only slightly more than bus occupants) though their intake of volatile organic compounds is slightly less than car occupants (but more than pedestrians and bus occupants).

The three above-mentioned studies were undertaken in northern European settings (Netherlands, Belgium and Ireland) – do their findings hold for other geographical contexts? Cross-mode comparisons of pollutant exposure and intake including cyclists are not common, but two recent studies examine evidence from Spain and China. (de Nazelle, Fruin, et al. 2012) find in a pairwise analysis of travel along two commuter routes by various transport modes in central Barcelona that cyclists were *exposed* to 0.6 times fewer ultrafine particles as cars and about the same concentration of $PM_{2.5}$ (Table 1.5). Accounting for ventilatory effort (2.1 times as high for cyclists as for car occupants) but faster trip times for bicycles, they found that cyclists *inhaled* 1.7 times as much $PM_{2.5}$ as cars but about the same amount of ultrafine particles. They also find lower inhaled doses of black carbon and carbon monoxide for cyclists as compared to car drivers. Compared to bus occupants, cyclists registered *larger* inhaled doses for all pollutants considered while cyclists registered *lower* inhaled doses of all pollutants when compared to pedestrians.

Table 1.5 **Inhalation, travel time, air pollutant concentration and calculated inhaled dose: Pairwise analysis of two commuter routes in Barcelona**

			Ultrafine particles		$PM_{2.5}$		Black Carbon		CO	
	Inhalation Rate	Trip time	Concentration (arithmetic mean)	Inhaled dose per trip	Concentration (arithmetic mean)	Inhaled dose per trip	Concentration (arithmetic mean)	Inhaled dose per trip	Concentration (arithmetic mean)	Inhaled dose per trip
unit	*(L min^{-1})*	*(min)*	*(# cm^{-3})*	*(# x 10^{9})*	*(µg m^{-3})*	*(µg)*	*(µg m^{-3})*	*(µg)*	*(ppm)*	*(µg)*
Walk	34.1	49	52700	89.8	21.6	35.1	6.31	10.7	1.31	7
Bike	41	25	77500	75.6	35	32.8	9.53	8.7	1.64	3.2
Bus	20	34	55200	39.8	25.9	18	7.58	5.3	2.14	3
Car	19.9	28	123000	75.6	35.5	19.7	19.5	10.4	7.33	8.9
Background			*19200*		*15.6*		*1.74*		*0.3*	
bike to car ratio	2.1	0.9	0.6	1.0	1.0	1.7	0.5	0.8	0.2	0.4
bike to bus ratio	2.1	0.7	1.4	1.9	1.4	1.8	1.3	1.6	0.8	1.1
bike to walk ratio	1.2	0.5	1.5	0.8	1.6	0.9	1.5	0.8	1.3	0.5
bike to background	..	..	4.0	..	2.2	..	5.5	..	5.5	..

172 trips, route length 4.7 and 3.1 km, 60% peak hour traffic, 40% off peak

Source: (de Nazelle, Fruin, et al. 2012)

Another recent study has looked at pollutant intake across various modes in Shanghai. It found that cyclists register a disproportionate pollutant intake compared to other travellers – peak hour inhalation doses of PM_1 for cyclists ranged from 2 times as great as for bus occupants and 4.25 times as great as for car occupants (using taxis as a proxy). Another finding was that absolute concentrations of particulate matter were substantially more elevated than those found in other studies in North American or European contexts (Yu, et al. 2012).

Overall, evidence on the concentration-exposure-deposition relationship suggests that cyclists' health could be improved by locating bicycle facilities away from road traffic where indicated – especially for sections where emissions are highest (motor vehicle acceleration on hills, long straightaways and in congested traffic) or where cyclist effort is greatest (e.g. hills). It also underscores the more elevated air pollution-related health risk faced by cyclists in highly polluted locales. Finally, when estimating air quality-related health benefits/disbenefits from a switch towards cycling, care should be taken to control for air pollution intake by mode as these can be quite different.

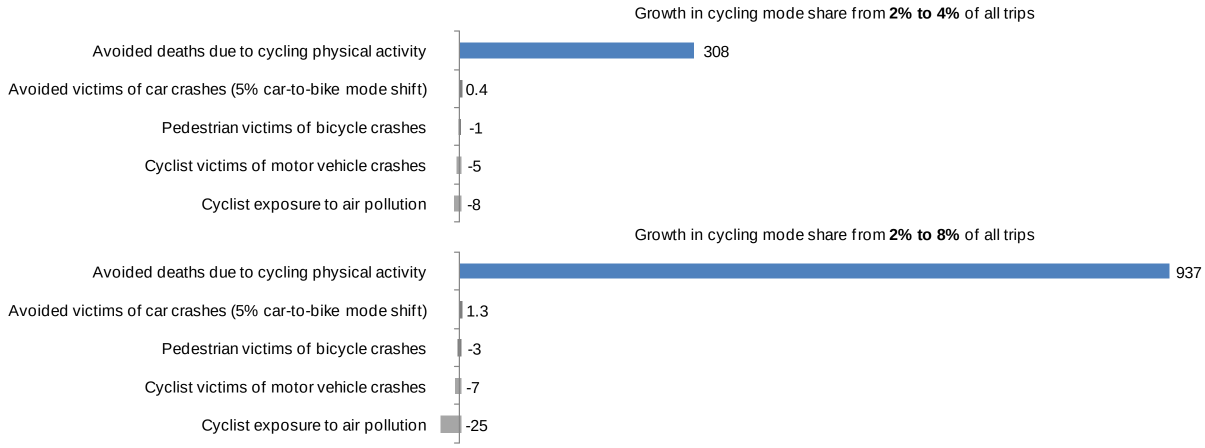
The balance of health and safety risks for cycling

Based on the wide range of research evidence highlighted in the previous sections, what can be said about the overall *balance* of health and safety risks for cycling? In particular, do the health benefits identified compensate for the injury risks linked to crashes and exposure to air pollution and noise? This is a particularly important question for cost-benefit analysis of cycling projects (see Box 3).

Several researchers have sought to answer these questions recently – (Praznoczy 2012),(Rabl and de Nazelle 2012), (de Nazelle, Niewenhuijsen, et al. 2011), (Teschke, et al. 2012), (Int Panis, Meeusen, et al. 2011), (Rojas-Rueda, et al. 2011),(de Hartog, et al. 2010), (van Kempen, et al., 2010). Controlling for exposure (and sometimes for crash under-reporting), these studies find that the health benefits of cycling are on average substantially larger than the disbenefits resulting from cycling crashes and exposure to air pollution.

In a comprehensive health and safety evaluation of cycling in the greater Paris region, (Praznoczy 2012) finds that the health impact of bicycle crashes impacts (in terms of fatalities) are particularly over-estimated by most actors whereas the health impact of air pollution is significantly underestimated. Crucially, however, the health benefits of regular exercise via cycling is several orders of magnitude higher than the health disbenefits outlined above and is fundamentally underestimated by authorities.

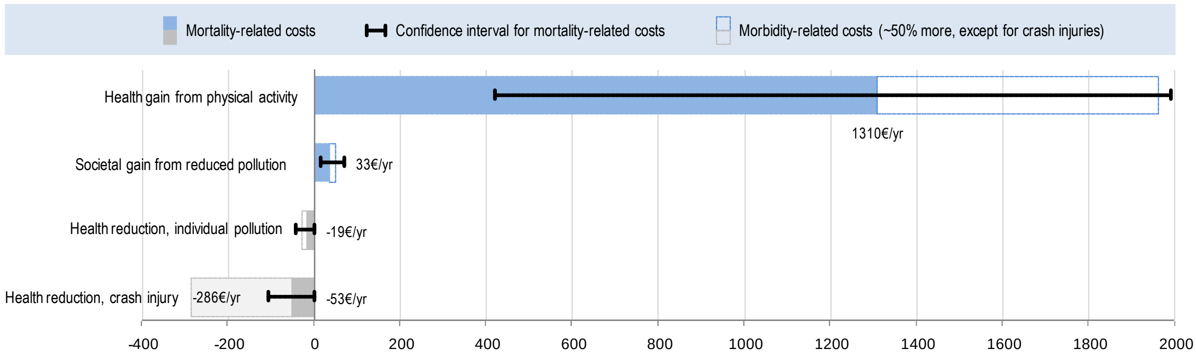
Figure 1.6 **Estimated mortality impacts due to an increase in cycle mode share in the Greater Paris region (annual deaths avoided/induced in 2020)**



Source: (Praznoczy, 2012)

Figure 1.6 summarises the findings of (Praznoczy 2012). Using conservative estimates[12] the study finds a benefit-to-risk ratio of 19 for an increase of cycling mode share in the Paris region from current levels to 4%, in line with recent growth rates. Should pro-cycling and other policies increase cycling mode share to levels found in many other French and European cities (8%), that ratio increases to 24. Under a more extreme scenario, but one in line with bicycle mode shares observed in some other (smaller) cities, that ratio could reach 27. As with other studies, it is the beneficial health impact from physical activity that by far outpaces other positive impacts and outstrips negative impacts. Unlike some other studies, and perhaps due to the high levels of suspended particulate matter in Paris, the author finds that the health impacts from cyclists' exposure to air pollution are greater than the crash risk cyclists face, at least in terms of fatalities.

Figure 1.7 **Estimated mortality (and morbidity) costs and benefits per individual switching from car to bicycle for work trips* in large European cities**



* 2x5km daily roundtrip, 5 days per week, 46 weeks per year

Error bars represent upper and lower (95% confidence intervals.

Source: Rabl and de Nazelle, 2012

Another study looking only at the monetised impact of switching from car to bicycle travel in large European cities (Rabl and de Nazelle 2012) finds that the positive health gains for an individual resulting from a switch from car to bicycle commuting add up to €1343 per year on average (Figure 1.7). It finds the negative health impacts, including those linked to crash-related mortality, result in a loss of €72/year – or 19 times less than the benefits. The study's principal finding that the health benefits from cycling surpass by several orders of magnitude other adverse health impacts linked to crashes and air pollution is robust to a range of assumptions regarding specific variables and monetary values. One reason is that physical activity has a beneficial impact on a much wider range of endpoints than air pollution and crashes. They note that considering *morbidity* in addition to *mortality* would likely increase individual and societal air pollution-related impacts by approximately 50% and increase the health gain from cycling by more than 50%. At the same time however, the burden from non-fatal bicycle accidents would also rise to €286/yr – or 5.5 times more than in the scenario outlined in Figure 1 using per kilometre costs from (Aertsens, et al. 2010).

While the studies cited above find that the health benefits of cycling far outweigh the disbenefits of increased crash risk – the crucial question remains "*which health benefits for whom?*"

Many of the studies cited above investigate primarily the *individual* health gains experienced by cyclists making the switch from *car use*. As noted previously, however, there is strong evidence that pro-cycling policies, at least initially, attract people that previously walked or used public transport rather than car users. There may be a point where the number of car users attracted to cycling significantly increases (evidence from countries with long-standing pro-cycling policies supports this) but it is unclear if, when and how many car users will make the switch as this is influenced not only by local policies but by local conditions as well. Suffice to say that at least the initial health impacts of pro-cycling policies will be largely based on of the uptake of cycling by pedestrians and public transport users rather than car occupants alone.

Box 1.3 **Accounting for cycling safety and health in cost-benefit analysis**

The use of cost-benefit accounting (CBA) in transport helps to guide investment decisions such that they maximize societal outcomes. Investments in cycling and the development of pro-cycling policies should ideally be subject to cost-benefit exercises, especially in a context of constrained budgets and a desire for maximum value. (Cavill, et al. 2008) review 16 CBA exercises that include or focus on cycling. Controlling for study methodology and quality, they find a range of largely positive benefit-to-cost ratios (BCR) in favour of cycling projects in 16 studies ranging from a BCR of 1.5:1 to a BCR of 32.5:1 with one slightly negative BCR. The median BCR for the studies examined was 5:1 which, for illustration, is much higher than the threshold 2:1 BCR required for infrastructure planning in the UK. Health benefits make up a significant contribution to the elevated cycling BCRs for cycling and walking projects in the studies examined. The authors note that the multiplicity of methods and variables considered as well as sometimes obscure assumptions included in the CBAs examined no not lend themselves to elucidating a clear view on the scale of cycling benefits. They also note the difficulty in observing levels of total physical activity for the populations considered (which would help to better gauge the health improvement impact for cycling) – though one study did control for leisure time activity (Rutter 2006). At a minimum, it would seem that more transparency is required regarding methodologies and assumptions in cycling-related CBA.

Given the preponderance of health benefits in cycling BCRs, it makes sense to ask the question whether or not these are *additional* benefits (e.g. external benefits not included in individuals' decision-making) or if cyclists already account for improved health in their decision to ride a bicycle (Börjesson and Eliasson 2011).

(Börjesson and Eliasson 2011) note that 4 factors must be considered when deciding whether or not health benefits from cycling should be include in CBAs for pro-cycling policies and infrastructure investment:

- whether or not cyclists derive health benefits from cycling,
- whether or not pro-cycling policies and infrastructure increase levels of cycling, preferably by sedentary people,
- substitution effects between cycling and other forms of physical activity, and
- the extent to which cyclists already account for health benefits from cycling.

This chapter already examines the first two points – individual health benefits are important and pro-cycling policies seem to, at least initially, principally attract non-car users (with geographic disparities). On the latter points, (Börjesson and Eliasson 2011) note that for most of the Stockholm cyclists examined in their study, cycling already represents their primary form of exercise and cite evidence that additional cycling would lead to a drop in other forms of physical activity. This suggests that time constraints may lead new cyclists (coming from other modes) to reduce other forms of exercise thus keeping constant levels physical activity. This would mean that cycling may not necessarily increase levels of physical activity (and thus health benefits) as much as many have assumed as suggested by some research (Yang, et al. 2012). However, it may increase the amount of regular moderate exercise that people get (as opposed to more concentrated but less frequent bouts of exercise) – this would have a health-improving effect (Praznoczy 2012).

Another matter is whether cyclists are aware of, and already account for, the positive health outcomes of cycling. If they do, then including health benefits as *additional* benefits in CBA would constitute double-counting. This has important implications since greatly minimising the health benefits from cycling in CBA, holding all else equal, would greatly reduce positive BCRs for cycling (Börjesson and Eliasson 2011)[13]. It seems unlikely that cyclists are fully aware of the health benefits of cycling and are able to accurately gauge these. However, it seems equally unlikely that cyclists completely disregard improved health as a reason for cycling. This suggests that defining *all* health benefits of cycling as *additional* benefits would seem unjustified. Nonetheless, the current state of knowledge does not allow for an accurate determination of what is and what isn't an additional health benefit from cycling for the purpose of CBA – indicating a need for additional research or, at a minimum, a need to expressly account for this lack of knowledge in CBA.

Another factor to consider is the extent to which health benefits attributed to increased physical activity via cycling remain as high when accounting for non-cycling physical activity. An increase in cycling does not necessarily imply an increase in overall physical activity or vice-versa. The studies cited above typically assume low activity levels for car occupants and health-improving increases in activity linked to cycling. This is a contestable assumption – car users may be physically active in other ways (e.g. sports activities) and pedestrians and public transport users may be nearly as active as cyclists. Car users switching to cycling may increase their activity levels or simply replace sports or other physical activities with cycling (Börjesson and Eliasson 2011) (Yang, et al. 2012). Likewise pedestrians and public transport users may simply replace one form of physical activity (walking) with another (cycling). Another factor to consider is how different countries or cycling populations may or may not be able to substitute cycling for different forms of exercise or vice-versa. It may be that populations whose cycling practice is mainly recreational may be able and willing to substitute cycling for other exercise whereas this may not be the case for populations whose cycling is (or would be) mainly transport-oriented and utilitarian (de Jong 2012). Any change in cycling levels would have a stronger impact on the latter population compared to the former. Overall, however, the fundamental question of how much cycling increases *overall* activity levels is a difficult one that remains largely absent from research.

Summarising the current state of research, we can say that on balance and even accounting for injury risk, cycling seems significantly health-improving when compared to car use by those with low physical activity levels. Policies that successfully lead to a switch towards cycling for this population may increase crash numbers (though not necessarily crash rates) but the adverse effects linked to this increase will likely be more than compensated for by a decrease in mortality and morbidity due to increased physical activity[14]. Increasing crash numbers would be nonetheless a negative policy outcome that must be addressed by specific measures. Conversely, policies that increase cycling but *do not* increase overall physical activity levels bring only risks (Int Panis and de Hartog 2011) though reducing these risks may lead to disproportionate benefits (e.g. by stimulating more cycling).

1.3. “Safety in Numbers”: Do more cyclists improve safety… and if so, how?

Researchers and observers have noted a correlation between an increase in the number of cyclists (or pedestrians) and a relative reduction of the incidence rate of severe/fatal crashes involving cyclists (or pedestrians). This “safety in numbers” effect (Jacobsen 2003) has been cited widely and would suggest that the relative risk ratios for cycling and other modes of transport illustrated in Table 1 are not fixed but change in relation to the modal composition of overall travel activity. The observed “safety in numbers” effect holds not only for multi-participant crashes but for single-bicycle crashes as well (P. Schepers 2012). At the centre of the phenomenon is the observation of non-linearity of risk: an increase of exposure (numbers, volumes, etc.) results in a less-than-proportional increase of the number of crashes (Elvik, 2009). Alternatively, the fewer cyclists there are in traffic (all else held equal) the greater the risk of crash and injury they face. In its most simplified expression, the observation of “safety in numbers” has led some to suggest that policies that increase the numbers of cyclists *de facto* increase safety since, per unit of exposure, the number of crashes decrease. This interpretation has limited use for policy since an absolute increase in crashes, irrespective of crash rate, is hardly a beneficial policy outcome and because the relationship between numbers of cyclists and crash rates is not necessarily straightforward nor uni-directional.

Care must be taken to not conflate observed *correlation* with *causality* when discussing "safety in numbers" as there are numerous plausible explanations for the observed phenomenon. On this note, there is strikingly little empirical research examining the causal factors that could explain the relationship between increased cyclist and pedestrian numbers and decreased crash rates. Hypotheses have been put forward that focus either on the behaviour of motor vehicle operators or, alternatively, on the behaviour of cyclists themselves.

"Expectancy" is one way of explaining "safety in numbers" from the perspective of car drivers. That is to say: if a road user (e.g. a car driver) expects the presence of another road user, or can predict the behaviour of other road users, one may expect lower risks (Houtenbos 2008);(Räsänen and Summala 1998). In this respect, it may be more exact to re-cast "*safety in numbers*" as "*awareness in numbers*" (F. Wegman in (Mapes 2009)). Another possible explanation is that cyclists are simply more visible to car drivers when they are more numerous (Bhatia and Wier 2012).

Researchers have suggested alternative explanations for the "safety in numbers" phenomenon based on hypothetic "crowd-sourcing" behaviour of cyclists themselves. According to this view, the more cyclists there are, the greater the number of individuals scanning the road environment for potential sources of danger and communicating what they detect to other cyclists either directly (verbally, hand signals) or indirectly (by taking observable avoiding action). Individual cyclists can benefit from the scanning behaviour of other cyclists such that larger groups of cyclists enjoy high levels of collective vigilance. In a similar fashion, cyclists may be collectively selecting routes (and possible riding behaviours) that are safer based on the leadership of more experienced cyclists (Bhatia and Wier 2012).

If "expectancy", "awareness in numbers", or "crowd-sourced" safety are valid explanations for the observed "safety in numbers" effect then one might reasonably assume that simply increasing the number of cyclists may indeed result in lower crash rates. At relatively high levels of cycling, it may even be possible that the absolute number of crashes could decrease as indicated by (Elvik, 2009).

However, the risk of confounding causal factors is great, especially when one considers the largely untested temporal direction of the observed "safety in numbers" effect. The explanation could simply be that cycle-safe traffic systems attract large numbers of cyclists – e.g. more people cycle when it is safe to do so. Large numbers of cyclists in the Netherlands, Denmark and Germany are associated with high densities of safe bicycle facilities which may explain why so many choose to cycle there and also why crash rates are relatively low. Without prospective or longitudinal studies looking at ex-ante and ex-post effects of new infrastructure, it will be difficult to determine if the effect observed is "*safety in numbers*" or "*numbers through safety*" (Bhatia and Wier 2012). If the latter explanation is correct, simply adding more cyclists to an unsafe traffic system may increase both absolute numbers of crashes alongside crash rates – clearly an unwelcome outcome.

From the lack of strong evidence on the behavioural or infrastructure-related determinants of "safety in numbers", it would seem that great care should be taken in using the observed phenomenon as a basis for bicycle safety policy. At a minimum, policies seeking to increase the number of cyclists should be accompanied by robust risk-reducing actions.

1.4. Challenges to assessing cycling safety: Cyclist crash under-reporting and lack of exposure data

In the course of this review of cycling safety, it has become clear that most national authorities and many regional/municipal authorities simply lack an adequate basis on which to assess both cyclists' safety and the impact of "safety-improving" policies. Why is this? At the core of safety assessment is the calculation of crash incidence rates (typically split into fatal crashes and others of varying degrees of severity). Schematically; safety (expressed as the crash incidence rate) is the quotient of the number of crashes divided by a measure of exposure or bicycle usage.

$$\textit{Safety (incidence rate)} = \frac{\textit{Number of crashes, fatalities or injuries)}}{\textit{Measure of exposure (trips, km, hrs)}}$$

Box 1.4 **"Reporting on Serious Road Traffic Casualties" Key Recommendations**

The International Road Traffic and Accident Database (IRTAD) housed by the International Transport Forum at the OECD collects international crash and exposure data on a continuous basis. The International Traffic Safety Data and Analysis Group (known as the IRTAD Group) charged with piloting, expanding and improving IRTAD has underscored the problem of under-reporting on crash injuries and outcomes and in 2011 released the report "Reporting on Serious Road Traffic Casualties: Combining different data sources to improve understanding of non-fatal road traffic crashes" (IRTAD 2012). The report's main conclusions are especially relevant for reporting of cycling crashes given the high incidence of under-reporting of non-fatal injuries for cyclists. Below are those most relevant for improving the reporting of cyclists' injuries:

1. A complete picture of casualty totals (killed and seriously injured) is needed to fully assess the consequences of road crashes and monitor programmes

2. Injury information should complement information on fatal crashes to give a fuller picture of road crashes (especially in light of the high number of less severe injuries experienced by cyclists). Information on injuries should become more important for international comparisons.

3. Police data should remain the main source for road crash statistics. However, because of under-reporting problems and possible bias (for example with different rates of reporting for cyclists as compared to motorists), police data should be complemented by hospital data which are the next most useful source.

4. The data from hospital emergency departments, available in some countries, should be monitored regularly and researched to determine if they might shed more light on road casualties. This is especially important for cyclist traffic injuries since these are rarely linked to crash data.

5. The assessment of the severity of injuries should preferably be done by medical professionals, and not by the police at the scene of the crash.

Source: (IRTAD, 2012)

In many cases both numerator and denominator are inadequately measured or may be missing altogether. In practice, this means that many authorities do not have an accurate grasp of the rates of injury-causing cycling (and pedestrian) crashes. This is especially true for non-fatal crashes. Furthermore, in many cases authorities cannot clearly determine if observed trends in crashes result from a change in the *safety* of cycling or in the *number* of cyclists or the *volume* of bicycle travel. With many authorities seeking to increase rates of cycling and walking, it seems crucial that the factual basis on which policy assessment depends be improved.

Under-reporting of cyclist crashes

Overcoming under-reporting of bicycle crashes is an essential challenge for cyclist safety analysis. The underlying reason for under- reporting is that personal injury accidents are not systematically registered in many jurisdictions. In the context of the present report, it should be kept in mind that most of our analysis is based solely on data of *recorded* bicycle accidents – oftentimes from police records. Under-reporting is not limited to bicycle accidents or certain countries and, in a certain way, is inevitable and concerns all types of vehicles and all countries (IRTAD 2012). There is evidence, though, that among all road crash participants, cyclists are the least recorded (Broughton, et al. 2008), (De Mol and Lammar 2006).

Under-reporting is less prevalent when considering *fatal* crashes involving cyclists though there are discrepancies in criteria for attributing post-crash deaths to specific traffic incidents. Lack of coordination between police and hospital record-keeping also contribute to inexact crash-related fatality data. Under-reporting of *non-fatal* cycle crash related injuries is much more prevalent and further hampers road safety assessments (IRTAD 2012).

In principle, the police should always be informed of traffic-related personal injury accidents. However, in practice, not all road users conform to that obligation. There are numerous reasons for this. When there are no seriously injured persons or immediate physical complications (whiplash injury, light concussion, etc.), parties involved generally do not inform the police or, when informed, the police does not always go on the spot. The less serious the accident, the more probable the police does not intervene. When only vulnerable road users such as cyclists are involved, it is less probable that the police intervene than when cars are involved (Elvik and Vaa, 2004), (Vadenbulcke *et al*, 2009). Another reason for under-recording is the number of persons involved in bicycle accidents: the fewer people involved, the smaller the chance of official recording (Elvik and Vaa, 2004), (Vadenbulcke *et al*, 2009).

How severe is under-reporting of cycling crashes? Quite severe – a conservative assessment for Europe finds that police records only capture 50% of hospital admissions for traffic-related cycling injuries (De Mol and Lammar 2006). Another assessment for the United States finds this figure to be only 10%. (Pucher and Dijkstra, 2000). (Langley, et al. 2003) find that only 22% of cyclists seriously injured in a crash were recorded in official crash statistics in New Zealand. In Münster, (Juhra, et al. 2011) report that police records existed for only 34% of all cyclist injuries for a one-year study in 2009. An in-depth prospective cohort-based study for Belgium confirms strong underreporting of non-fatal crash-related injuries finding that only 7% of non-severe bicycle crashes were recorded in police statistics (B. de Geus, et al. 2012), (Vandenbulcke et al, 2009) – a low figure confirmed in other studies (Van Hout, 2007), (Elvik and Mysen, 1999).

Under-reporting complicates the analysis of long-term trends and hides the true picture of cycle safety. In particular, under-reporting impacts the assessment of:

- Evolution of cyclist safety: it is not known if and how under-recording has evolved over the years. In order to be able to reliably compare road safety factors over several years, the extent of under-recording should remain stable. In any case, each change in the number of crashes recorded, even annually, has an influence on crash statistics. This runs the risk that an increase or a decrease in statistics on bicycle crashes is strictly interpreted as such and not necessarily as a consequence of a change in the number of crashes recorded.

- Accident severity: crashes involving slightly injured persons are less well recorded than those involving seriously injured. The latter are less well recorded than those involving fatalities (i.e. death occurs within thirty days after the crash). This implies that amongst all road crash victims, the slightly injured are proportionally the most under-recorded and hence average bicycle crash severity is over-rated.

- Specific bicycle accident characteristics: as already mentioned, crash recording currently differs according to the types of crash opponents involved. At present, certain bicycle crash characteristics are proportionally less well documented than others. In particular, single-bike, bike-on-bike and bicycle-pedestrian crashes are likely strongly under-estimated, partly because of the reduced severity of crash outcomes.

- Overall vision on bicycle accidents: As the proportion of bicycle crashes in the overall number of road crashes is largely under-estimated, policy-makers face difficulty in correctly estimating the social implications of bicycle crashes (both in quantity and quality). This, in turn, hinders their ability to take appropriate measures. In the absence of an objective point of reference and comparison, it is also difficult to set quantified goals for reducing the number of cycling road accident victims.

Lack of bicycle usage and exposure data

Most countries and/or cities are ill-equipped to assess cycling safety because of a lack of accurate and detailed information on actual bicycle usage. The lack of exposure data is a real hindrance to understanding the current status of cycling safety and complicates the assessment of cycling policies. Crucially, exposure-based injury rates would allow authorities to understand if policies improve safety by *reducing exposure* (e.g. by decreasing bicycle use) which, given the benefits of cycling would be a bad thing or if they increase safety by decreasing crash-related injuries for a same level of usage.

Information about *how many* cycle crashes occur *is* useful for problem identification and allocation of resources. If substantial numbers of cyclists are injured, then there is a problem worthy of investigation and intervention. If many injuries occur in a particular situation then it is worth allocating resources to rectify the situation.

In contrast, *understanding* patterns of crashes and injuries requires that cycling exposure be considered. There are numerous possible exposure indicators including both direct and indirect or proxy measures (Wundersitz and Hutchinson 2008):

Travel surveys:

- Distance travelled
- Number of trips
- Time spent travelling

Traffic monitoring:

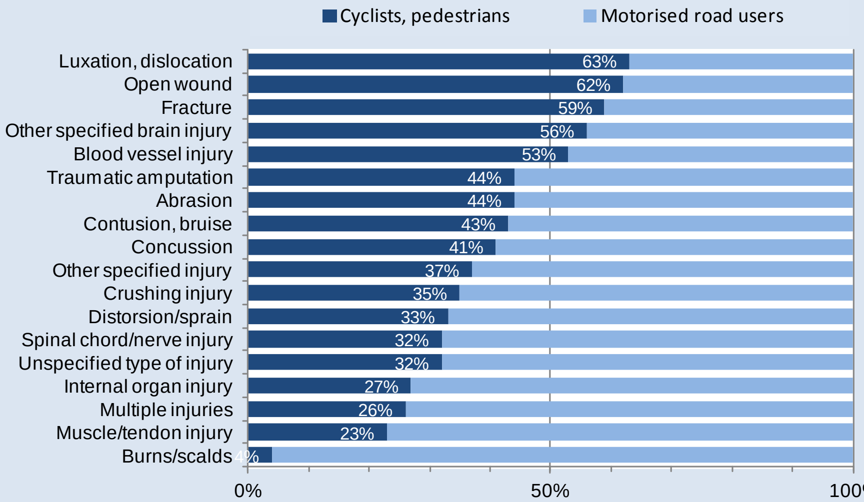
- Traffic volumes
- Traffic conflicts

Box 1.5 **Bicycle injury characteristics and reporting rates from the EU Injury Database (IDB)**

In Europe, police-reported crash data is centralised in the CARE database (see Chapter 4) which tracks several data points related to the crash participants, context, conditions, location and outcomes. In addition, the EU Injury database (IDB) collects standardised data on injury treatment from hospitals in the following countries: Austria, Denmark, France, Germany, Ireland, Italy, Latvia, Malta, The Netherlands, Portugal, Sweden and the United Kingdom. Traffic crash data in IDB supplements CARE police-reported statistics with more detailed hospital information on injury severity and treatment when linked via a common identifier number. However, most IDB bicycle crash data concerns crashes that are not reported to police -- or if they are, where no link has been made. IDB data can thus can serve as a good basis for understanding the scale and scope of injuries from bicycle crashes as well as to assess the extent of bicycle crash under-reporting in official statistics.

According to IDB injury statistics, cyclists represent 41% of all hospital-treated traffic injury patients in reporting countries and 30% of hospitalised traffic injury patients. Hospital length of stay for cyclists is about 7days – longer than the average length of stay for car occupants but shorter than the average stay for pedestrians and motorized two-wheelers. Upper body (37%), head injuries (26%) and lower extremity injuries (26%) dominate cyclist crash-related injuries. Head injuries for cyclists represent slightly more than the average for all injured traffic participants (24%). Cyclists have a slightly higher share of head injuries than car occupants (24%), a much higher share of head injuries than motorised two wheelers (16%) and a much lower share than pedestrians (30%). Cyclists have the highest share of upper body injuries of all road users reported in IDB. In terms of injury types, Cyclist and pedestrian injuries In terms of injury types, vulnerable road users dominate in 5 of 18 IDB-catalogued injuries – mainly traumatic force injuries (dislocations, open wounds and fractures) -- and a account for slightly higher share of overall non-concussion brain injuries.

IDB data on injury type for vulnerable road users versus motorized road users



Comparing IDB data with national police-reported crash statistics underscores the significance of bicycle crash under-reporting. In Austria, for example, official police-reported statistics report 5495 bicycle injury crashes in 2009. In contrast, IDB hospital statistics report 28 200 bicycle crash victim treated in hospitals which when accounting for travel survey data on private-practitioner bicycle crash consultations should be adjusted upwards to approximately 37 000 bicycle injury crashes. Police statistics only account for 15% of the total number of bicycle injury crashes in Austria in 2009 – a number consistent with other reported data on under-reporting of bicycle crashes.

Source: (Brandstaetter and Bauer 2012)

Arguably, the best measures of cycling exposure are distance, or time, cycled. In the absence of this information, proxy exposure measures can be used, but these are far less accurate. For example, length of cycling infrastructure in a particular country might give an indication of how much cycling occurs in that country. It is of course possible that a country has a great deal of cycling infrastructure that does not see much use. Other proxy measures include number of bicycles owned (some of which go unused, many of which may be used exclusively for recreation) and population (many of whom don't cycle). Rates calculated using less accurate indicators of exposure should be treated with caution.

This report has confirmed that most countries do not collect reliable information about distances cycled (i.e. cycling exposure) with which to calculate crash or injury rates (per kilometre travelled). This makes it difficult to answer questions such as how safe is cycling, and how does cycling compare to other modes of travel? Without information about distances cycled in different countries it is difficult to compare the safety of the cycling systems in those countries. Furthermore, without information about distances cycled under different circumstances it is difficult to answer questions such as how safe is cycling-specific infrastructure compared to cycling on roads without facilities for cyclists, and how safe is cycling during the day compared to cycling at night, and so forth? Without information about how much cycling is being done, statements about *how many* cycle crashes occur are of limited use.

Countries that do collect information about the volume of bicycle travel typically do so via relatively expensive national travel or mobility surveys based on interviews or panel travel diaries. Depending on the survey design, some surveys may under-report the level of cycling if respondents are asked to give only the main mode of transport used for a trip (for example, combined bicycle-public transport trips may be counted as public transport trips only if the latter segment dominates the former). The periodicity of travel surveys is not uniform across countries as well. Some countries, such as Denmark, the Netherlands and the United Kingdom, undertake yearly surveys, others undertake travel surveys much less often.

In the absence of distance, duration or trip-based indicators, proxy exposure measures can be used, but these are far less accurate. For example, length of cycling infrastructure in a particular country might give an indication of how much cycling occurs in that country. It is of course possible that a country has a great deal of unused cycling infrastructure, however. Other proxy measures include number of bicycles owned (some of which go unused or are used exclusively for recreational cycling) and population (many of whom don't cycle). Rates calculated using the less accurate indicators of exposure should be treated with caution.

Traffic surveys and traffic monitoring can also give a sense of the level of bicycle use – especially at the local or regional level or at the scale of a single facility. They also allow for more precise *ex-ante* and *ex-post* assessment of specific cycling safety measures. Additional reporting may also be helpful. For instance, the City of Copenhagen produces a biennial Bicycle Account that monitors the implementation of the city's cycling policies and highlights opportunities for further progress. Comparative cycling statistics can help compare performance among urban areas -- in the United States, the not-for-profit Alliance for Biking and Walking benchmarks the cycling and walking performance among 50 States and the 51 largest cities on the basis of comparable data sources.

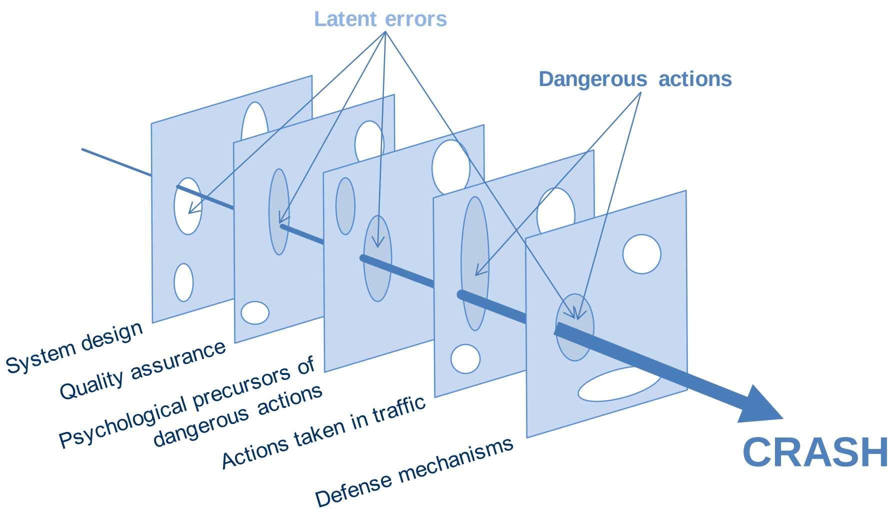
Various methods have been used in this report in analyses of crash patterns to accommodate lack of exposure information, and conclusions should be interpreted in the context of the shortcomings of these methods. More fundamentally, however, countries should begin to collect better exposure information if they do not already do so in order to guide future policies and assess their effectiveness.

1.5. How to deliver sustainable safety? The safe system approach

Based on the previous review of evidence, it would seem that on balance, more bicycle use will be beneficial for the health of individual cyclists and, given high rates of uptake, for the urban environment. Given what we know about the vulnerability of cyclists in traffic, how then should authorities design safety strategies encompassing all road users?

Authorities have often approached cycling safety (or all traffic safety) in a piecemeal and reactive approach – focusing alternatively on cyclists, pedestrians or other traffic participants and, rarely, on the entire traffic system. Reaching high levels of safety for cyclists (and other traffic participants as well) requires a more proactive approach that seeks to design (or re-design) the system to accommodate all road users and to account for their characteristics. This is especially true where policy would seek to preserve or increase cyclists' numbers. If the system is unsafe for cyclists, policy should focus on making the *system* safe, not just focusing on incremental improvements to cyclists' safety in an inherently *unsafe* system. The "Safe System" approach extends beyond cyclists only and has been recommended as a general safety planning approach for all traffic classes. Safe road systems incorporate strategies for better managing crash forces among disparate road users and should accommodate human error (OECD, 2008). The "Safe System" approach aims to reduce or eliminate crash risk by avoiding latent errors and dangerous actions in all phases of the traffic transport system (Figure 1.8).

Figure 1.8 **Schematic representation of the development of a crash**



Source: A. Djikstra, SWOV

One of the first iterations of the safe system approach was the "sustainably safe traffic" framework developed in the Netherlands starting in 1992 (Koornstra et al., 1992; Wegman & Aarts, 2006). At the heart of this approach is the notion that each category of road user knows what behaviour is required of them and what they may expect from other road users. This implies that the all aspects of the road environment should be made explicitly *recognisable* by each category of road user.

For infrastructure, the concept of "*recognisability"* in a sustainably safe traffic system rests on five crucial principles:

- Functionality
- Homogeneity

- Predictability
- Forgiveness
- State Awareness

We address each of these in turn below.

Functionality

Sustainable Safety's "functionality" requirements are intended to intrinsically guide individual road users to choose a safe route, for themselves and also for others. The functionality principle of the traffic system is important to ensure that the actual use of the roads conforms to the intended use. Road systems should be separated into different functional groups (e.g. through roads, distributor roads, residential access roads and urban mixed residential/commercial streets). Each road or street should have one principal function; for example, a distributor road should not have any direct dwelling access so that users understand clearly what they can expect in that environment (e.g. mixed traffic, pedestrians and cyclists, spontaneous road crossing behaviour, etc. on mixed residential/commercial urban streets). According to the functionality principle, through-trips should not cross residential areas. Nor is it desirable to for cyclists to ride along an unsafe road too long. A large residential area is safe for internal motorised traffic as well as for cyclists and pedestrians. Too many junctions with the surrounding through roads should be avoided. There is a balance though -- an area that is too large leads to much internal traffic; one that is too small leads to many junctions with surrounding through roads.

For cyclists, the benefit of this principle is that motorised traffic will be concentrated on a limited number of main roads. Consequently, facilities for separating cyclists from motorised traffic can be concentrated on these roads.

Homogeneity

Road crash injuries stem from differences in speed and mass amongst crash opponents. The notion of homogeneity in road design is intended to avoid large differences in speed, direction, and mass by lowering traffic speeds to levels that are safe for all participants or, if this is not possible or desirable, by separating different traffic users based on their characteristics, mass and relative speeds. Based on this principle, traffic speeds where cyclists are present or are to be encouraged should be lowered to a safe (for cyclists and pedestrians) level, otherwise separate bicycle and motor vehicle facilities should be made available.

Table 1.6 **Safe speeds for different road types**

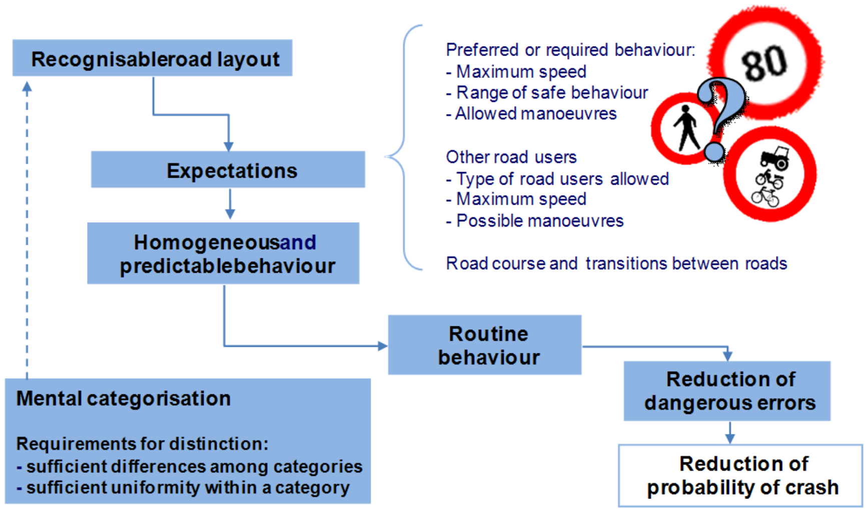
Road types	Safe speed (km/hr)
Roads with possible conflicts between cars and unprotected users (e.g. cyclists)	≤ 30
Junctions with possible lateral conflicts between motorised users	50
Roads with possible frontal conflicts between motorised users	70
Roads with no possible frontal or lateral conflicts among motorised users	≥ 100

Source: A. Djikstra, SWOV

Predictability

The design of the traffic environment (including the road and its surroundings) should increase the recognisability, and therefore the predictability, of traffic situations that may occur (Figure 1.9). Undesirable traffic situations can thus be acknowledged and avoided in time. In particular, a predictable road environment reduces distracting searching behaviour on the part of road users, and maximises the use of uniform and recognisable design treatments so that users intuitively know what to expect and what is expected of them. This is particularly important for cycling infrastructure design and treatments as these are less harmonised internationally than for motorised traffic. Limitation of the number of road categories makes the largest contribution to predictability. Furthermore, the differences between road categories should be large, while the differences within a road category should be small. In a predictable road environment, road users can concentrate on their main driving/riding task and conflict can be detected at an early stage.

Figure 1.9 **How "predictability" works to reduce crash risk**

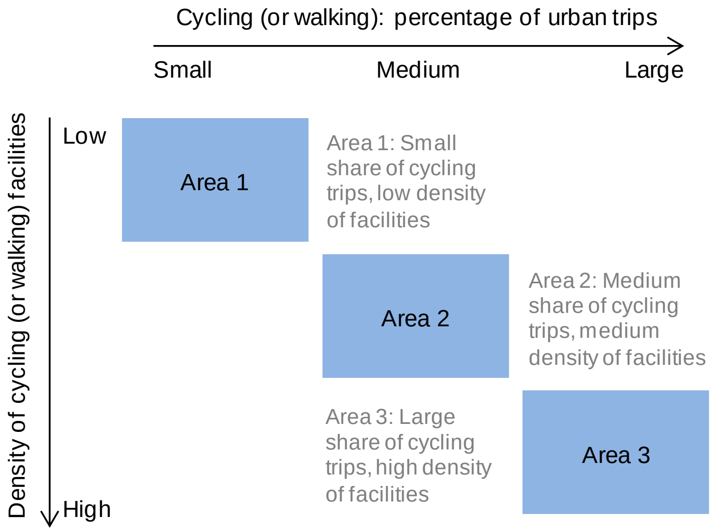


Source: A. Djikstra, SWOV

Forgivingness

If a crash cannot be avoided, the fourth principle, forgivingness, is meant to prevent a serious outcome of the crash. For cyclists, this means removing possible obstacles in the cycling environment as well as ensuring that cycling and road infrastructure design takes into account motorist behaviour (vis-à-vis cyclists) and the likely behaviour of cyclists themselves (e.g. reluctance to stop and lose momentum).

Figure 1.10 **Bicycle facilities and bicycle share**



Source: (Danish Road Directorate, 1998)

State awareness' of the road user.

Finally, a Safe System approach should include a component linked to the road users' ability to assess their capacity to handle the driving or riding task. This means that cyclists should be trained to handle a bicycle, but as well to use a bicycle in a mixed traffic environment. This may take place at an early age (safety in cycling classes) but should not be neglected for new adult cyclists or those not having any prior experience cycling in a traffic environment. This principle inherently recognises that there is no single type of cyclist - there are old and very young cyclists, experienced and inexperienced cyclists, commuting and recreational cyclists, etc. High impact safety policies should account for this heterogeneity.

Safe Systems in line with local conditions

Municipalities, regions and countries display different levels of bicycle use. They also differ in the degree to which they provide facilities for cyclists. The type of cycle facilities offered should depend on the share of cycling -- the more cycling, the more bicycle facilities (Danish Road Directorate, 1998). Facilities typical for a high share of cycling do not fit in a traffic environment with a low share, while facilities belonging to a low share are not compatible with a high bicycle share (Figure 1.10). Setting facilities within their context can help avoid "over" or "under" investing in safety.

Key Messages

- Many jurisdictions have or are putting in place pro-cycling policies and yet evidence points to the vulnerability of cyclists in road traffic. Do policies that increase the number of cyclists contribute to less safety and more crashes?
- The short answer to this question is that when the number of cyclists increase, the number of crashes, both fatal and non-fatal, may increase as well – but not necessarily so if attention is paid to good policy design.
- Furthermore, the rate of cycling crashes may decrease, especially if accompanying safety-improving policies are implemented.
- Many authorities are poorly equipped to assess the impact of pro-cycling and cycling safety policies as data on bicycle crashes is biased by under-recording and few authorities, especially at the national level, collect adequate exposure data necessary to understand crash rates in relation to bicycle usage.
- There is an observed safety-improving effect correlated with large numbers of cyclists however this "safety in numbers" or more precisely "awareness in numbers" effect cannot be shown to be causal – pro-cycling policies should seek to increase safety and not just the number of cyclists.
- Cycling safety should not be disassociated from the overall health impacts of cycling. Pursuing increased safety for cycling makes sense since these policies expressly reduce the negative outcomes linked to crashes for those *already* cycling. Understanding the balance of positive/negative health outcomes from cycling, however, is essential in helping frame efforts to *increase* cycling.
- Robust and consistent evidence indicates that the health benefits derived primarily from physical exercise due to cycling outstrips by several orders of magnitude the negative health outcomes for cyclists linked to crashes and exposure to air pollution. Pro-cycling policies have a largely beneficial impact on society despite higher crash rates than cars or public transportation.
- As far as crash outcomes are concerned, two, not incompatible approaches, present themselves.
    - The first is to attenuate the severity of crash outcomes in an otherwise dangerous system by, for instance, focusing on protective equipment for cyclists and vehicles, and
    - The second is to make the road environment itself safer via a "Safe System" approach that focuses on speed management and reducing the possibility for unequal (in mass, speed and behaviour) crash opponents from coming into contact with one another in the first place.

Notes

1. Absent other accompanying policies, it is not at all clear that pro-cycling policies *alone* can reduce congestion and pollution since newly released roadway capacity may be taken up by automobile traffic.
2. The 2004 report "National Policies to Improve Cycling" (ECMT, 2004) highlights the motivations behind national efforts to increase cycling.
3. Cycling was found to be 2.5 times more deadly per billion kilometres of travel including motorway travel by cars and 2 times more deadly per billion kilometres of travel when excluding motorway travel by cars.
4. 10% if including taxis.
5. Pro-cycling policies are also credited with congestion reduction benefits. For the same reasons outlined above, these may be (greatly) overestimated; at least insofar as road congestion is concerned. Nonetheless, there may very well be a not-inconsequential public transport congestion reduction benefit linked to pro-cycling policies that successfully attract new riders.
6. Evidence indicates that fine particulate matter emitted by internal combustion engines is more toxic than background levels of fine particulate matter (Laden, et al. 2000) – this suggests that a reduction in ambient levels of particulate matter emitted by motor vehicles would have a disproportionate and beneficial health impact.
7. This suggests that the installing bicycle facilities that severely reduce or eliminate polluting vehicles from such streets would reduce pollutant exposure, at least locally.
8. Consistent with the time-lagged nature of the formation of ozone. By the time primary pollutants are transformed into ozone, the pollutant plume will have moved downwind away from emission sources.
9. http://www.dft.gov.uk/statistics/releases/reported-road-casualties-gb-main-results-2010, accessed 10 September 2012.
10. Disability-Adjusted Life Years (DALYs) are defined by the World Health Organization as the sum of life years lost (YLL) and years of poor health (YLD) linked to health burden. One DALY can be interpreted as "one lost year of healthy life".
11. and one third of *overall* crash victims.
12. Lower bound of car-to-bicycle mode shift and lower bound of air pollution-related deaths.
13. (Börjesson and Eliasson 2011) note that while the case for full inclusion of health benefits as *additional* benefits in CBA may be overstated, they find that cyclists' high values of time in their study and the low relative cost of cycling infrastructure still imply positive BCRs for cycling infrastructure investments.
14. This finding, however, should not be seen as a way of minimising the importance of reducing crash rates

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2. Policy measures and administrative framework for bicycle safety

This Chapter looks at how countries and regional/local authorities are developing, facilitating or guiding cycling policy. Based on a questionnaire of International Transport Forum members, this chapter inventories national cycle plans and discusses their key features. It also reviews the different legal frameworks and rules surrounding bicycles and cycling across countries and presents some findings relating to the funding of bicycle infrastructure and programmes.

2.1 Introduction and Methodology

There are a number of countries, regions and municipalities which are seeking to develop, or in some cases, retain, cycling as an important element of everyday mobility. In order to achieve this aim, many have developed explicit pro-cycling policies. While most pro-cycling efforts are anchored at the local or regional level, having a supportive framework at the national level can serve as a catalyst and can ensure widespread implementation. In this section, we focus mainly on these national-level policies, building on a previous survey undertaken in 2004 (ECMT 2004). In particular, this chapter reviews the role of safety in cycling related policy.

We define cycling policy here as the different instruments devoted to bicycle mobility including:

- Planning instruments: particularly those related to mobility[1] or safety thematic
- Legislation
- Budget
- Other measures

Planning and legislative instruments have been reviewed from the perspective of their actual content as well from the perspective of the administrative framework in which they are embedded. In addition, we describe (where available) the budgetary treatment of cycling policies and other related measures.

The information presented in this survey was obtained via a common questionnaire circulated to International Transport Forum members in 2010. The questionnaire comprised one part focusing on policy and asked the following:

- What is the main focus in current cycling or transport policy regarding cycling safety?
- What is the administrative structure regarding bicycle use?
- What is the role of cycling in urban planning?
- Is there a national cycling safety plan?
- What is the budget allocated to the promotion and improvement of cycling safety?

A related set of questions regarding legislation was also sent:

- Which laws regulate road safety aspects related to cycling and what level of authority is responsible for implementing these regulations?
- Are bicycles treated explicitly in road safety legislation?
- Do sub-national authorities have jurisdiction for cycling safety policy? Which aspects are covered by these authorities?
- What are some Please, name some of the specific aspects related to the use of bicycle contained in your country's regulations established by national/federal authorities

2.2 Cycling and Safety Planning

Countries vary in their approach to cycling policy and to safety policy for cycling. There are two principal manners in which cycling safety planning has been approached; plans focusing on improving road safety specifically or plans addressing transport, spatial, environmental and health planning more generally. Even though the second approach does not target safety specifically, its outcomes inevitably have an impact on cycling and thus can have an impact on cycling safety. This chapter focuses on the first approach – plans focussing expressly on improving road safety. Nevertheless approaches belonging to the second category are important to account for, especially when there is no specific policy regarding cycling safety.

Institutional Framework

Policies at the national level generally seek to promote improved safety for cycling through measures which create a friendlier environment for cyclists; planning instruments, legislation, enforcement, guidelines, awareness campaigns, training initiatives, promotion of best practices and research.

Regional authorities are typically in charge of elaborating on the general framework established by national government in relation to legislation and political guidelines. They are also typically responsible for developing a transport network which enhances intermodal links, enforcing legislation and financing programmes and infrastructure.

Local authorities are typically responsible for building and maintaining cycling infrastructure. Like regional authorities, they too may be responsible for the enforcement of legislation and funding programmes and infrastructure.

Planning and Strategy

Given that cycling is primarily a means of local, short-distance transport, many local authorities play a strong role in deploying supportive policies that, in some cases, build on higher level plans. In some countries these policies may only focus on education whereas in others, there is a strong focus on planning, building and improving cycling infrastructure. However, in many cases the existence of a national-level cycling policy framework serves to inspire, support and helps coordinate efforts among different institutional levels[2], particularly at the local level. Indeed, in 2004 the European Conference of Ministers of Transport (ECMT) stressed that "national-level commitment [is] important in setting the right legal, regulatory and financial framework so that successful implementation of cycling strategies can take place" (ECMT 2004). In 2004, 75% of the countries surveyed by ECMT had in place national plans and since then, several more have been announced. These plans help guide local and regional deployment of pro-cycling policies and in many cases, countries have explicit plans relating to cycling safety.

Responsibility for national transport planning is assigned to specific transport departments. In the case of Spain, responsibility is assigned to the "*Dirección General de Tráfico*" (Ministry of Interior) in charge of traffic. This responsibility may be assigned to authorities responsible for transport generally (Austria, Czech Republic or Netherlands), roads (Denmark with the Road Directorate, in the Ministry of Transport and Japan), or other authorities with broader responsibilities relating to mobility (e.g. Ministry of Sustainable Development in France). In Korea bicycle network planning is under the authority of the Ministry of Public Administration and Security (MOPAS) while bicycle *safety* planning is under the responsibility of Ministry of Land, Transport and Maritime Affairs (MLTM).

Some countries have an independent national entity that manages and coordinates implementation of the national bicycle plan or strategy. This is the case of the Australian Bicycle Council (ABC) that manages and coordinates implementation of The Australian National Cycling Strategy 2011 – 2016, produced by the Australian Transport Council[3] (The Australian Transport Council, which also produced the National Road Safety Strategy, was replaced by the Standing Council on Transport and Infrastructure in September 2011). The Australian Bicycle Council[4] is part of Austroads, the association of Australian and New Zealand road transport and traffic authorities. ABC members are government representatives, state and territory road and transport agencies, local government, bicycle industry and cyclist users.

The case of Denmark is illustrative of a broad scale approach extending beyond transport alone. The last national *cycling* plan was issued in the 1990's but since then cycling has been addressed by more holistic plans such as the "Transport and Energy Strategy", "Green Transport Plan" or "Sustainable Mobility" strategy. The latter plan establishes a broad framework for integrating cycling into not just transport planning, but energy and environmental planning as well.

There is also a particular case in France where, from 2006 on, an interministerial coordinator for bicycle policy, "*Monsieur Vélo*[5]" is in charge of implementation of the national bicycle policy. Another similar mechanism is the German Joint Working Group on Cycling (B/L-AK) supervised by the Ministry of Transport Building and Urban Development (BMBVS). Since 1998, this body brings together all levels of administrations, transport operators, cycling, cyclists' associations and other stakeholders. Topics addressed by this Group are: regulatory framework, coordination, funding, tourism and communication.[6].

In some of cases where no national plan exists, regional authorities fill this gap as in the case of Belgium.

Road safety

Road safety regulations and planning typically occurs at the national level in almost all cases. France is one exception which does not have a National Safety Plan, and where road safety policy is derived from Ministers' councils and regulations. In federal governments, regions and states can adopt different approaches to cycling safety as in the mandatory use of helmets, for example, as in the United States and Canada (and as it used to be the case in Australia).

Governmental bodies in charge of road safety can be part of the Ministries of Interior, with a behavioural, sanctioning and control approach towards safety (for example, Spain and France) or ministries in charge of transport and infrastructures (for example, Denmark, Poland and Japan).

At a local level, road safety regulations are often embedded either in traffic by-laws or cycling plans, linked to national plans and policies (if they exist).

Measures and key priorities

The principal objectives of cycling-related plans of countries surveyed for this report are:

- To increase the number of people cycling
- To improve safety and security awareness when cycling
- To balance cycling speed and comfort

One of the principal motivators for promoting bicycle use is the benefits that cycling brings to both society and people[7]. Cycling is often portrayed as an enjoyable activity that promotes healthy (and health-improving) exercise and contributes to reducing the environmental impacts related to transport. Other purported benefits include the reduction of congestion and improvement of quality of life. On the other hand, many plans note that cyclists are vulnerable road users[8], and so most of strategies include specific measures to make cycling safer.

The following typology of measures is included in mobility or safety planning instruments with the specific objective to increase safety

Infrastructure

Most measures relating to cycling infrastructure identified in this scan tend to be non-compulsory guidelines. These include Denmark's "Collection of cycling concepts" (2012), or France's "Fiches Vélo" fact sheets edited by the Centre for studies on networks, transport, town planning and public building (CERTU). In the Netherlands, the public-private non-profit National Information and Technology Centre for Transport and Infrastructure (CROW) issues cycling guidelines[9]. In the United States, two national-level guidelines for bicycle infrastructure design exist, the American Association of State Highway and Transportation Official's (AASHTO) Guide for the Development of Bicycle Facilities (4th Edition and the National Association of City Transportation Officials (NACTO) Urban Bikeway Design Guide`. Neither is compulsory but the former has historically served as a reference to ensure that local bicycle infrastructure meets a recognised standard. Some countries have issued regulations about technical guidelines, making them compulsory, like Italy[10] and Korea where the Ministry for Land, Transport and Maritime affairs has recently amended technical guidelines for building bicycle roads (July 2010).

Regional and local authorities are typically in charge of constructing bicycle infrastructure with the following measures appearing prominently the local and regional plans reviewed:

- Developing consistent bicycle networks with adapted infrastructure solutions
- Ensuring safe crossing conditions
- Maintaining cycle paths clean and in good condition

The design and implementation of national level cycling networks (These networks are principally devoted to tourism and leisure) have traditionally been piloted by cycling non-profit organizations, as in the case of the UK (National Cycle Network, promoted by Sustrans with funding from the National Lottery) or Italy (*Rete ciclabile nazionale*, promoted by the national bicycle promotion organisation - *Federazione Italiana Amici della Bicicletta* - FIAB). In contrast, France's "*Mission National des Veloroutes*" has the support of the Ministry of Sustainable Development[11]. The network Eurovelo (an initiative by the European Cyclists' Federation) gathers and connects national level networks forming a European cycling network. In Spain, the Spanish Railways Foundation[12] (FFE), currently a foundation of the state sector and managed by different public enterprises related to Spanish railways has developed the project, *Vías Verdes* (Green Ways) that consist of recovering and reconditioning old disused railway lines to be used by walkers and cyclists. Similarly, the Rails-to-Trails Conservancy in the United States helps authorities and citizen's organisations create linear parks for cyclists and pedestrians from abandoned railroad corridors.

Signalisation

Road traffic signals aim to warn drivers of cyclist's presence. Signalisation contributes to cycling *conspicuity*, a key aspect for safety.

Traffic calming

Traffic calming is refers to efforts to reduce motorised vehicle speeds in residential and urban core zones so as to facilitate sharing roadspace with cyclists and pedestrians. Some national safety plans, like the Czech Republic, focus on the intelligent coexistence of cyclists in urban traffic flow. Other countries formalise the definition of traffic-calmed zones (30km zones, complete streets, etc.) Concrete measures found in these plans include:

- Road safety-oriented categorisation of road users and uses.
- Improvement of those roads and streets shared by pedestrians, cyclists and vehicles through physical and regulatory traffic calming measures.

Training, campaigns and information

Most national safety plans include awareness campaigns on the following topics:

- Road safety education for cyclists (for children, adults or the elderly): For example, the Netherlands has a longstanding (since 1932) tradition of bicycle training for children that culminates with a written and on-road practical traffic exam ("*Verkeersexamen*"[13], Figure 2.1). This ensures that road users (both cyclists and drivers of motor vehicles) understand safety rules and practices necessary to ride in traffic and on different types of bicycle facilities. Other examples include the "*Brevet du cycliste*"[14] campaign in the Wallonie region of Belgium that provides cycling safety training for children of school age. Another example is the "Bikeability"[15] cycle safety education project of the UK Department for Transport.
- Campaigns to promote the use of bicycles (and walking) to access schools. One example is the US "Safe Routes to School Program".
- Cycle awareness campaigns for motor vehicle users: These seek to integrate cycling issues and awareness of cyclists' behaviour into car driving courses and driver license education.
- Making cycling attractive: to promote cycling as a popular means of transport and as an enjoyable recreational activity (e.g. the Federal Ministry for the Environment (Germany) "*Radlust*"[16] (the joy of cycling) campaign.
- Awareness-raising regarding drivers' blind spots: In this regard, the Dutch Ministry of Transport launched the campaign "*Alle regels rondom spiegels*" in 2007 to inform lorry drivers of the perils of blind spots[17]. Between 2004 and 2007, fatalities among cyclists due

to crashes involving lorries averaged 34 per year. In addition, there is an average number of 71 casualties each year.[18]

Figure 2.1 **Extract from the Dutch Verkeersexamen child traffic safety exam**

Source: Veiligverkeer NL., http://www.veiligverkeernederland.nl/kids/node/27535/quiz/start, accessed 24 September 2013 (Translated by Google translate)

Ensuring vehicle and operator safety

Most countries have in place rules relating to the safety of motor vehicles and some of these rules relate specifically to safety in regards to pedestrian and cyclist crashes. These rules may cover vehicle design standards, safety equipment for cyclists and traffic rules relating to cycling.

Enforcement and legislation

In some cases, national plans also contain measures regarding legislation and enforcement. In particular, these measures relate to:

- Enforcement of speed limits, especially in urban areas.
- Promotion of measures to sanction dangerous or illegal behaviour on the part of some cyclists (especially behaviour which can result in injuries pedestrians or other cyclists).

Research and knowledge sharing

Some national plans call for efforts to improve accident-related analysis and research, on monitoring and evaluating cycling programs. Some plans also call for work on developing a national decision-making process in support of investment for cycling.

In many instances, there are national-level cycling promotion agencies and institutions in charge of facilitating the development of pro-cycling policies:

- In **Germany**, the Bicycle Academy is one of the 4 pillars of the national bicycle policy (together with the national working group, an internet portal and a federal aid program). The academy is funded by the Federal Ministry of Transportation, Building and Urban Development (BMVBS) and provides training for the municipal administration.[19]

- In **Australia**, the Australian Bicycle Council houses the Cycling Resources Centre[20], which provides information related to cycling: planning, education, promotion, road safety, recreation, funding sources and research.

- The Cycling Embassy of **Denmark**[21] is a comprehensive network of private companies, local authorities and non-governmental organizations working together to promote cycling and communicate cycling solutions and know-how around the world.

- In the **Netherlands**, Fietsberaad[22] is an expertise centre for cycling policy financed by the Ministry of Transport, Public Works and Water Management. The objective of this centre is the development, dissemination and exchange of practical knowledge and experience for cycling policy and it aims to be the portal for cycling knowledge worldwide, in order to promote cycling as an everyday means of transport. Fietsberaad supports the Cycling Embassy of the Netherlands which helps to disseminate Dutch cycling knowledge internationally. In addition, the Dutch national road safety research institute, SWOV, issues fact sheets about cycling safety and carries out research in this field.[23].

- In the **Czech Republic**, the Transport Research Centre[24] has a Bicycle Coordinator who is in charge of the cycling policy issues. The centre houses a website devoted to the cycling strategy[25]. This Centre is under the responsibility of the Ministry of Transport.

Best practices and networks

In some countries, best practice networks have developed to further the uptake of cycling, especially at the local level. Such networks of "cycling cities" or "offices of the bicycle" serve as clearinghouses for information requests by local and regional administrations. These agencies are usually managed by nonprofit organizations. Examples include the "*Red de ciudades por la bicicleta*" (Spain) and the "*Club de Villes Cyclables*" (France).

Other measures for increasing the use of the bicycle

These are measures not devoted specifically to cycling safety, but may help generate an indirect effect on road safety via the greater bicycle use. Ultimately, whether or not increased cycling leads to improved safety is conditioned on the effect of accompanying policies but these types of policies are often part of an overall approach to addressing cycling and its safety.

- *Integration with public transport:* When combined with public transport, cycling can serve as an essential range extender for travellers. Integration can be achieved through good connectivity of public transport facilities with cycling facilities and bicycle services as well as allowing, where possible, for bicycles to be transported on public transport networks. Bicycle-public transport integration features essentially at the local and regional level though national authorities may encourage this practice as well.

- *Parking facilities:* Ensuring adequate on-street, workplace and commercial bicycle parking can help in the uptake of cycling. Local authorities and transport operators often play a role here though the generalised framework for the taxation of workplace provided parking may also come into play here as well.

- *Cycle hire schemes*: Bicycle sharing schemes have developed rapidly in recent years throughout the world (see Figure 1.1). They facilitate the use of bicycles by those who do not, or cannot (because of home parking space or storage space constraints), own them. They also serve as a catalyst for cycling since they raise the visibility and attractiveness of cycling by inhabitants in cities where they have been deployed.

- *Security:* Fear of theft is an important deterrent to cycling and policies that reduce the threat of theft can serve to increase cycling. Addressing bicycle theft requires a broad approach implicating key stakeholders and including some or all of the following components: Bicycle registers, dissuasive public (shared) bike deposits, parking design and location, guarded bicycle parking and bicycle theft insurance are some of the aspects at stake about cycling security.

- *Urban planning*: Land use planning that results in short trips and ensures high quality access in dense urban neighbourhoods facilitates the uptake of cycling. Along with the functional categorisation of neighbourhoods and streets, bicycle and cycling friendly land use planning can also contribute to reduced crash risk and lessened severity of crash outcomes via slower traffic speeds and reducing the number of motor vehicle-bicycle conflicts.

- *Monitoring policy implementation:* Not all jurisdictions having a bicycle plan consistently monitor its implementation or its effects but many do. Some countries regularly monitor cycling activity as part of ongoing travel surveys (e.g. Denmark, Netherlands and United Kingdom). At the local level, some jurisdictions publish detailed reporting of progress on multiple policy objectives. A good example of this approach is the biennial Copenhagen Bicycle Account.

Description of selected national plans and polices

Australia	
Cycling Strategy and planning policy	*Road safety policy*
Australian National Cycling Strategy 2011-2016[26]..	National Road Safety Strategy 2011-2020[27]
Main focus of cycling safety policy	
Promotion of cycling as a safe and enjoyable activity and mode of transport, create a comprehensive and continuous cycling network and end-of-trip facilities, improving monitoring and evaluation programs support the development of national guidance for stakeholder and share best practices	
Cycling and/or safety goals	
To double the number of people cycling in Australia by 2016	

Austria

Cycling Strategy and planning policy	*Road safety policy*
Masterplan Radfahren 2007-2012	Road Safety program 2011-2020

Main focus of cycling safety policy

Safety road categorization, "shared space", training courses on safety and behaviour, road campaigns, speed limits regulation, mandatory helmet for children.

Cycling and/or safety goals

An increase of the National cycling modal shift from 5% to 10% in 10 years (2017). Prevent 900 child head injuries

Belgium

Cycling Strategy and planning policy	*Road safety policy*
No national cycling plan. Regional cycling strategies (one per region): • Plan Vélo 2010-2015 of the Brussels Capital-Region • Mobiliteitsplan Vlaanderen 2012-2020 of the Flemish Region • Plan Wallonie cyclable 2010-2020 of the Walloon Region	No national safety plan. Safety plans are developed at regional & local levels (one per region) : • Plan de securité routière 2010-2020 of the Brussels Capital-Region • Verkeersveiligheidsplan Vlaanderen of the Flemish Region • Etats généraux de la sécurité routière of the Walloon Region

Main focus of cycling safety policy

- Development of high quality cycling infrastructure.
- Publication of best practice guidelines.
- Cycling promotion campaigns.
- Implementation of new traffic regulations (the so-called street code or code de la rue/straatcode) in view of better protecting the most vulnerable road users.

Cycling and/or safety goals

No national goals.

Regional goals :

- The Brussels Capital-Region aims at a 20 % cycling share in trips by 2018 and at reducing the number of accidents by 50 % by 2015.
- The Flemish Region has set as an overall goal (so not just for cyclists) a maximum of 250 fatalities and 2 000 seriously injured by 2015.
- To date, the Walloon Region has not yet determined specific figures. However, it has expressed the will to significantly increase bicycle use and cycling facilities quality by 2020.

Czech Republic	
Cycling Strategy and planning policy	*Road safety policy*
National cycling development strategy, 2005.	Considered main topic in National Safety Strategy Plan 2011-2020
Main focus of cycling safety policy	
Promotion of shared space, safety campaigns for cyclists, enforcement & cooperation with municipalities and other stakeholders to develop cycling infrastructures and traffic calming measures.	
Cycling and/or safety goals	
50 percent growth by 2010 and 100 percent growth compared with 2005 by 2013 in terms of the length of bicycle routes, separated from motor transport[28]	

Denmark/Copenhagen	
Cycling Strategy and planning policy	*Road safety policy*
National Transport Strategy, 2009. City of Copenhagen has its own Cycle Policy 2002-2012.	"Every accident is one too many" 2001-2012[29] , Copenhagen Eco-Metropolis 2015 contains cycling safety goals.
Main focus of cycling safety policy	
Denmark: Cycling is a key area of the Danish road safety strategy together with speeding, alcohol and junction treatment. 85% of accidents involve these factors. To make cycling safer, the plan focuses on campaigns and training and targets specific measures tested in cycling cities such as Odense. It also mentions cycle-path networks and maintenance, traffic segregation, redesigning road junctions and safety equipment. **Copenhagen:** Safer, continuous and green cycling network, parking facilities, better conditions in city, combining cycling and public transport, improved signal junctions, better maintenance of cycling paths, campaigns and information, use of helmets.	
Cycling and/or safety goals	
Denmark: No specific targets/goals for the national plan. **Copenhagen:** From 2002 to 2012: Increase speed of 5 km cycle trips by 10%, increase cycling comfort: no more than 5% of unsatisfactory opinion, increase work commute cycling up to 40% in 2012 and up to 50% in 2015, reduce the risk of being injured or killed by 50% in 2015, increase the perception of safety from 57 to 80% in 2015.	

France

Cycling Strategy and planning policy	*Road safety policy*
National Bicycle Plan (January, 2012) along with an interministerial coordinator for cycling policy; "Mr. Vélo"	No national safety plan. Safety policy is defined by the *Comité Interministériel de la Sécurité Routière* (C.I.S.R.)[30] and integrated in the "Code de la Rue"

Main focus of cycling safety policy

Integration of cycling in all aspects of road planning, facilitation of deployment of "complete" streets, 30km zones (and extension of these) – contra-flow cycling to be allowed in these zones. Nearside (right) turn on red to be allowed upon local initiative. Inclusion of active travel in National Health policies. Allowing cars to pass cyclists under certain conditions in no passing zones, releasing the constraint that cyclists travel as far to the nearside as possible on certain shared streets. Including cycling in drivers licence education and increasing cycling training for all (adults and children). Inventory of cycling infrastructure needs on National roads,

Cycling and/or safety goals

10% increase in cycling by 2020 (1% per year)

Germany

Cycling Strategy and planning policy	*Road safety policy*
German National Cycling Plan 2002-2012. New plan announced for 2013-2020 (Nationaler Radverkehrsplan 2020[31]	"2011 Road Safety Programme (Verkehrssicherheitsprogramm)[32]

Main focus of cycling safety policy

Enhance safer behaviour by and towards cyclists, safe cycling education for children, high visibility clothing for cyclists as addition to safety devices for bicycles (e.g. reflectors), campaign for the use of helmets ("*Ich trag Helm*"), research on the safety of pedelecs and extension of the cycle network. Promoting actions to avoid dangerous situations via safe road design: avoiding conflicts in road design, arranging good visibility between cyclists, pedestrians and motorised traffic.

Cycling and/or safety goals

The main goal is the promotion of cycling. Cycling is treated as a system (see National Cycling Plan). Increase of cycling safety must be achieved while increasing cycling's share of all traffic. Specific target is to double cycling mode share to 15% of trips by 2020 (16% in urban areas and 13% elsewhere).Suggested spending on bicycle infrastructure and programmes - €8-€19 per inhabitant.

Italy

Cycling Strategy and planning policy	*Road safety policy*
No national cycling plan. Cycling plans are being developed at regional, provincial and local level. There is a proposal, by FIAB (cyclists' NGO of Italy), of a national cycling network (*Rete ciclabile nazionale*) called Bicitalia.[33]	The national plan for road safety (*Piano Nazionale della Sicurezza Stradale*), 2002, is in its 3rd national action plan (*Programma nazionale di attuazione*) 2008-2013.

Main focus of cycling safety policy

Design protected locations for pedestrians and cyclists in urban areas with heavy traffic, awareness and information campaigns to encourage safer traffic behaviour with particular reference to motor vehicles, promote helmet use and devices to increase the visibility of cyclists, promotion of voluntary agreements with manufacturers for the definition of minimum standards of quality and safety of the bicycles[34]

Cycling and/or safety goals

No national goals or targets

Japan

Cycling Strategy and planning policy	*Road safety policy*
No national cycling plan. Guidance issued by the Ministry of Land, Infrastructure, Transport and Tourism and National Police Authority for the development of cycling infrastructure ("Guidelines for creating a safe and comfortable environment for cyclists", November 2012) -	Cycling included in the 9th Traffic Safety Program for 2011-2015.

Main focus of cycling safety policy

Improve the road traffic environment, implement safety awareness, ensure vehicle safety and enforcement, cycle safety education campaigns.

Cycling and/or safety goals

General goal: achieving the world's safest road traffic by lowering the number of 24-hour fatalities to 3000 or less by 2015 and to lower the number of casualties to 700.000 or less by 2015.

Korea

Cycling Strategy and planning policy	*Road safety policy*
Cycling Promotion Plan along with Bicycle Network Plan have been conducted by the Ministry of Public Administration and Security (MOPAS)	National Bicycle Safety Plan issued by Ministry of Land, Transport and Maritime Afairs (MLTM) is reflected in 7th National Transport Safety Plan for 2012-2016.

Main focus of cycling safety policy

Traffic accident investigation and management of crash hotspots involving cyclists, revision of guidelines for road safety audits reflecting bicycle safety checks, bicycle policy audits, design of cycle tracks and lanes, introduction of bike boxes along and dedicated cyclist traffic signalisation, developing legal framework for ensuring right-of-way of cyclists in residential streets, downsizing speed-limit in built-ups to 50km/h, extension of 30km-zones

Cycling and/or safety goals

General goal: 5% cycling mode share in 2013 (up from 1.2% in 2009), 20% mode share in 2020.

Reducing the severity of accidents involving cyclist and preventing probable accidents on National Bicycle Network in the coming years.

Specific goal: cutting death toll of 333 cyclists (2010) down to 150 by 2016.

Netherlands

Cycling Strategy and planning policy	*Road safety policy*
No national cycling plan[35]. Cycling policy is decentralized with support from the National government.[36]	Cycling is a specific area of emphasis in the Road Safety Strategic Plan 2008-2020.

Main focus of cycling safety policy

Promotion of friendlier passenger cars for cyclist, ensuring safe crossing situations, required helmet for children, national cycle teacher training school, information drivers' blind spots and use lamps and reflectors.

Cycling and/or safety goals

General goal: reduce of 25% the number of road casualties.

Norway

Cycling Strategy and planning policy	*Road safety policy*
National Cycling Strategy as a component of the National Transport Plan 2010-2019.	National Plan of Action for Road Safety: 2010-2013 (conforming to the "Vision-Zero" strategy; a goal of eliminating all traffic fatalities and severe injuries).

Main focus of cycling safety policy

Construction of new infrastructure (1.3 billion Kroner 2010-2013), quality inspections of existing infrastructure, speed control, land-use rules – ensure cycling is addressed in urban planning via implementation of National Planning and Building Act (2009), creation of working group to suggest policies to reduce cycling crashes, cycling accidents, cyclist training (Children and adults), bicycle awareness included in motor vehicle licence training, Helmet awareness campaigns for adults (especially students), Road-sharing awareness-raising campaigns,

Cycling and/or safety goals

Increase the share of bicycling in the transport system from 4–5 per cent in 2010 to 8 per cent by 2019.Public Roads Administration target that 50 per cent of all towns with more than 5,000 inhabitants have a plan for an interconnected network of bicycle paths by 2010. 80 % of children aged 6-15 walking or cycling to school by 2019.

Poland

Cycling Strategy and planning policy	*Road safety policy*
National authorities are preparing a national cycling plan.	Integrated Road Safety Programme (GAMBIT) 2005 adopted as the 2005-2007-2013 National Road Safety Programme.

Main focus of cycling safety policy

Development of cycling infrastructure network, campaigns to promote cycling as a popular and safe means of transport, improving infrastructure legislation.

Protecting pedestrians and cyclists is one of the main targets of GAMBIT 2005.

Cycling and/or safety goals

General goal: to reduce deaths to 2,800 by 2013 (50% related to 2005) and 1,500 by 2020.

Spain	
Cycling Strategy and planning policy	*Road safety policy*
No national cycling plan.	Cyclist considered as specific area of emphasis in Road Safety Strategy 2011-2020.
Main focus of cycling safety policy	
Cycling-related road safety education for children, promoting helmet, lamps and reflector use, improving traffic signalisation for cyclists, maintenance of road hard shoulders, promoting cycle-friendly car driving, enhancing the bicycle as a sustainable and efficient mode of transport.	
Cycling and/or safety goals	
Specific goal: Increasing the number of cyclist in one million in 2020 with no increase of cyclist fatalities rate.	

United Kingdom	
Cycling Strategy and planning policy	*Road safety policy*
Part of Local Transport strategy (e.g. Creating Growth Cutting Carbon“ White paper 2011.	Strategic Framework for Road Safety, 2011.
Main focus of cycling safety policy	
Improvement of infrastructure (including junctions), cycle training for children, promoting helmet use, improving lorry vision, Cycling Stakeholder Forum, 20mph zones and limits, road safety campaigns.	
Cycling and/or safety goals	
No national targets	

2.3 Laws and Regulations relating to Bicycle Safety

Rules and regulations governing the bicycles and their use are much less harmonised internationally (and in some cases, even within countries with separate regional transport jurisdictions) than motorised vehicles. One possible explanation for this that most bicycle travel is local, or at least does not cross international boundaries contributing to less perceived need for a common and consistent legal framework governing bicycle use. Of course, the same could be said for most car traffic (which is largely composed of local/regional trips) giving some impetus to the notion that greater consistency in the legal treatment of bicycles would be desirable. Despite the uneven regulatory landscape for cycling, a common “core” of rules does seem to emerge in many (but not all countries).

Road safety laws and regulations by national and regional authorities

Few countries have a standalone body of rules and regulations relating specifically to cycling safety, unlike the bicycle-specific planning regimes mentioned in the previous section. Bicycle safety rules and regulations tend to be nested inside road safety strategies or may be linked to broader transport and mobility strategies.

Some countries with a federal structure or other form of devolved governance have very basic regulations at national level with more detailed regulations at the state or regional level. For example, under Australia's federal system of government, individual states and territories are primarily responsible for policy, regulatory and administrative arrangements related to cycling. Road traffic regulations are established at a state and territory level but most are based on nationally agreed 'model' regulations known as the Australian Road Rules (ARR). These contain numerous specific rules related to bicyclists, including a requirement for all cyclists on public roads to wear an approved bicycle helmet. [37]. The United States is similar in that is does not have a national traffic code. Instead, the Uniform Vehicle Code (UVC) established by the National Committee on Uniform Traffic Laws and Ordinances (NCUTLO) is adopted by most States as the basis for their traffic laws. The Federal Highway Administration also suggests approaches and develops voluntary guidelines for States to adopt vis-à-vis cycling.

In some countries, cycling regulations are centralised at the national level, although regional and local levels also may have developed additional rules and regulations. This is the case of Austria, Denmark, Poland and France.

In countries like Spain, road *safety* regulations are established at the national level although rules related to the *use of infrastructure* are differentiated by territorial level of government. Rules relating to the *use* of the road network by bicycles outside urban areas are set by the national government whereas local authorities establish rules governing bicycle use inside urban areas.

Generally, laws relating to cycling and cycling safety fall in one of the following categories:

1. Vehicle design standards (for motor vehicles and bicycles)
2. Safety equipment (for motor vehicles and cyclists)
3. Traffic rules
4. Liability and Responsibility rules

Vehicle design standards (for motor vehicles and bicycles)

Many countries have developed or adopted rules relating to the safety of vehicles operating on public roadways. Some countries have mandated specific safety design standards that seek to reduce the severity of motor-vehicle – bicycle/pedestrian crashes. For example, both Europe and the United States have or are developing stricter design standards for light-duty vehicle pedestrian/cyclist crash contact points (hood/bonnet and bumper)[38]. In addition, EU Directive 2000/40/EC mandates front, rear and side underrun protection for large trucks in order to avoid under-run incidents that are especially harmful for cyclists. Japan, the Russian Federation and Ukraine all apply UNECE rule ECE-R93 which has similar provisions. Other rules mandate the fitting (or retro-fitting) on trucks of blind spot mirrors or cameras to (EU Directive 2003/97/EC and EU Directive 2007/38). New pedestrian and cyclist detection technologies are also under study and may complement existing approaches to cyclist fatalities due to nearside-turning trucks

Safety equipment (for motor vehicles and cyclists)

Countries surveyed typically have rules relating to mandatory safety equipment on bicycles. Foremost among these are rules in many jurisdictions calling for two operating brakes[39] Other typical rules relate to the presence of forward, rear and pedal reflectors or lights and warning devices such as bells (Netherlands). Countries surveyed typically have rules relating to the carriage of additional passengers on bicycles designed for one person (usually limited to children under a certain age or weight) and in some cases may limit the use of bicycle trailers.

As for cyclists, countries have issued rules relating to the use of reflective clothing and helmets. In order to increase the conspicuity of cyclists riding at night, a number of jurisdictions mandate the use of reflective clothing. These rules sometimes apply selectively to extra-urban areas alone or extend to riding in tunnels or other low-visibility situations. Jurisdictions with rules on reflective clothing at night include France (extra-urban), Hungary (extra-urban), Italy (extra-urban), Lithuania, Malta, Slovenia and the State of New Hampshire (US). Some local jurisdictions may also impose rules relating to the use of reflective clothing by cyclists.

Most rules mandating the use of safety equipment for cyclists address the use of helmets. This is an area fraught with controversy in a number of jurisdictions as the overall health impact of such rules are unclear. Mandatory helmet rules will, when followed, reduce the rate of cyclist head injuries in crashes but may contribute to a significant erosion of overall health should they inhibit cycling and thus reduce the benefits derived from physical activity. We discuss these issues further in Chapter 5. Rules relating to helmet use may apply only to certain age categories or to all riders. It is not clear that all helmet rules are equally enforced. As with rules for reflective clothing, many local jurisdictions may impose rules relating to helmet use. National or regional-level jurisdictions with helmet use mandates include the following:

Jurisdictions mandating helmet use by all cyclists:

- Australia
- Canada (4 Provinces)
- Dubai, United Arab Emirates
- Finland (little enforcement)
- Israel (compulsory on interurban roads)
- New Zealand
- Spain (all extra-urban cyclists except when very hot or on long climbs. Proposal to make mandatory for urban cyclists)
- Slovenia
- South Africa (little enforcement)

Jurisdictions mandating helmet use by classes of cyclists (essentially children):

- Austria (<12 y. old)
- Canada (2 Provinces, <18 y. old)
- Croatia (<16 y. old)
- Czech Republic (<18 y. old)
- Estonia (<16 y. old)
- Iceland (<15 y. old)
- Israel (<18 y. old)
- Japan (<13 y. old)
- Republic of Korea (<13 y. old)
- Slovak Republic (<15 y. old)

- Sweden (<15 y. old)
- United States (22 States have mandatory rules for children and youths of varying ages)

Some jurisdictions have or are in the process of reviewing rules on helmet use (e.g. Spain) and some jurisdictions have had rules mandating helmet use repealed (e.g. Mexico City, Israel). On balance, however, most jurisdictions have seemed to be reluctant to mandate helmet use for adults. Many jurisdictions, including those that do not have helmet use mandates, have undertaken helmet awareness campaigns and some officially recommend helmet use by all cyclists.

Traffic rules[40]

Most countries surveyed for this report view the bicycle as a road vehicle for the purposes of national traffic laws. Some countries have special provisions within their traffic codes relating to bicycles and their operation in the road environment. In some instances, special rules may apply to the use of bicycles on cycle-specific infrastructure.

Generally, bicycles are to circulate on the roadway though many countries impose limits on more than one cyclist riding abreast. Because of concerns regarding bicycle-pedestrian crashes, many jurisdictions do not allow bicycles to ride on sidewalks/pavements. In some cases, as in Japan, sidewalk/pavement riding is unofficially tolerated in light of local practice. In a few instances, authorities may have no explicit rules banning bicycles from sidewalks or pavements. Rules governing offside turns typically stipulate that bicycles proceed as motor vehicles. One notable exception is Denmark where cyclists are required to make a two-point manoeuvre by first riding through the junction to the far right-hand side and then proceeding left when safe to do so (or under a green signal).

Rules relating to the mandatory use of bicycle facilities, especially when they run parallel to roads, also differ. In some jurisdictions cyclists must use parallel cycle tracks if these meet agreed standards and are marked as compulsory (e.g. Australia, France, Germany, Korea, Netherlands, United States (Federally-managed roads with 30 mph or more speed limit, 7 States and many local ordinances, e.g. New York City). In other cases, there is no obligation to use bicycle facilities when they are provided (though their use may be recommended).

Rules relating to right-of-way differ from country to country. In Europe, bicycles and pedestrians have right of way over road traffic crossing pavement/sidewalks or cycle tracks with the exception of France and Finland (in some cases). In all European countries save Portugal[41], cyclists and pedestrians engaged in crossing at signalised junctions have unconditional right of way over offside- or nearside-turning vehicles during the crossing cycle. In Austria, Germany, Denmark, France, Finland, Ireland, Sweden and the United Kingdom, road users entering roundabouts must give way to cyclists engaged on the roadway, cycle track or withdrawn cycle track[42]. The opposite is true in Belgium and Greece. In Italy cyclist priority at roundabouts is indicated when applicable and in Portugal, cyclists never have priority in roundabouts. Contra-flow cycling, when indicated, is allowed in Austria, Australia (local jurisdictions), Belgium, France, Germany, Denmark, the United States (local jurisdictions) and Italy. In some cases, as in Belgium and in France, contraflow cycling is allowed by default in traffic calmed zones unless otherwise indicated. Many countries define rules relating to the shared use of reserved bus lanes – Austria, Denmark, Finland, France, Germany, Ireland, Sweden and the UK allow bicycles to use bus lanes except otherwise indicated.

Some countries such as Belgium and France have recently modified their traffic codes to better take into account cyclists and pedestrians. In the latter country, national authorities have established a new body of traffic rules and regulations pertaining to the shared use of street space – the "*Code de la Rue*".

This code stipulates two new rules relating to cycling in France: first, the definition of "*zones de rencontre*" or shared motorised-non-motorised roadspace with a maximum allowable speed of 20 km/hr (Figure 2.2), and second, the legalisation of contra-flow cycling in "*zones de rencontre*" and in traffic-calmed 30 km/hr zones. The introduction of these regulations in the "*Code de la Rue*" follows on decisions of the Interministerial committee for road safety (*Comité interministériel de la Sécurité Routière* - CISR) of February 2008 which came into force in July 2010. Other regulations addressing cycling in the Code include, for example, bicycle traffic signalisation[43].

Figure 2.2 **Shared roadspace "*Zone de rencontre*" in France (St. Germain-en-Laye)**

Photo credit: Authors

Some countries and jurisdictions that already ban cell phone use while driving extend this ban to cyclists given that the latter are held to respect the same rules as operators of motor vehicles (e.g. in France, Germany). Some local jurisdictions have enacted similar bans (e.g. Chicago, California). In some instances, cellphone use while cycling is allowed, or at least tolerated (e.g. The Netherlands). Even where tolerated, cell phone use may contravene rules prohibiting hazardous road user behaviour at the discretion of traffic authorities.

Some countries have put in place rules relating to the mandatory provision of infrastructure or cycling policies – this is the case in France that has mandates to provide cycling infrastructure in urban areas (1996 "LAURE" law on air quality and energy efficiency), cycling parking in car parks (2010 Urban Planning Law) and to develop the legislative framework for public bicycle schemes (Grenelle 2).

Many countries surveyed treat cycling while impaired the same as for motor vehicles. One exception is Germany which has different blood alcohol limits for cyclists (0.16%) than for car drivers (0.05%). Jurisdictions that do not specify specific rules relating to cycling while impaired may have rules stipulating that bicycles should not be operated in a hazardous manner which might encompass impaired operation.

Finally, while not strictly a traffic rule, countries have different approaches to apportioning civil liability for bicycle-motor vehicle crashes. In some instances, cyclist must prove they were not at fault in a crash whereas in other cases, a strict liability regime automatically assigns liability to the least vulnerable crash participant (the cyclist) in all cases, or in cases where the vulnerable road user was not in contravention of the law. Most EU countries (e.g. like the Netherlands) have in place some form of strict liability. Strict liability is not a crash prevention measure *per se* (since in most cases civil liability is handled directly among insurers and drivers may not be aware of the existence or provisions of strict liability regimes) but can be part of a pro-cycling regulatory framework.

Supra-national regulations

From the previous section, it is clear to see that the body of rules governing the use of bicycles and their safety are relatively diverse. In some instances, efforts have been made to develop general rules relating to the technical homologation of bicycle design standards. This is the case of the bicycle safety standards produced by the European Committee for Standardization (CEN)[44].

For other aspects such as vehicle regulation and traffic rules, the Vienna Convention (1968)[45], now supplemented with the consolidated resolutions on road traffic[46] and road signs and signals[47] (2010), offers a very basic framework, aimed at facilitating the "conditions for the admission of cycles to international traffic" but countries must complete it and may stipulate exceptions. For example, the transport of passengers on bicycles is prohibited by the convention but country parties may authorise exceptions as many do for the carriage of children. Nonetheless, many large countries are not signatories of the Vienna Convention and have developed a regulatory framework for bicycles that may be quite different in some important aspects. Non-signatory nations include Australia, Canada, Japan and the United States. At least on a continental scale, efforts to better align rules governing cycling could benefit safety in that a common, recognisable framework is established (e.g. the “recognisability” principle of Sustainable Safety”.

2.4 National spending on cycling

Government spending on cycling may take place at different levels (national, regional, local) and may encompass many expenditure categories (new infrastructure, maintenance and operation of existing facilities, cycling education, cycling and safety awareness campaigns, etc.). There are also different revenue sources for cycling and co-financing may extend to multiple partners.

Given the complexity of funding and expenditure streams, few countries have a clear view of total government expenditure on cycling. One exemption is the Netherlands where total spending on cycling (all levels of government) reached €487 million in 2010, or about €30 per capita[48].

At the national level, the German Federal Budget earmarked €100 million for the construction and maintenance of cycle ways along federal roads and waterways in 2002 and similar amounts were earmarked during the following years. In 2010, €110 million have been employed for this purpose and also for projects to improve the integration with public transport and public bikes[49]. Promotion is also addressed by the federal government with a fund of €3 Million for visible measures and campaigns, research initiatives, informational measures, advanced and further training programmes, transport safety improvement measures, general promotion of dialogue and dissemination of information on positive impacts of cycling.[50]

Several other countries have announced national cycling budgets. These include Austria (approximately €100 million per year spent on infrastructure, promotion and safety), Australia (€60 million on infrastructure during 2009), Denmark (€140 Million to support cycling initiatives), the Czech Republic (€30 million spent on cycling infrastructure between 2001-2010 and the United States ($1 and

$0.7 billion respectively in 2010 and 2011 on both bicycle and pedestrian projects, Federal spending often matched at the State/local level).

In some cases, rules on financing bicycle infrastructure accompany national financing mechanisms. This is the case in Italy with the national rules for financing cycling mobility (*Norme per il finanziamento della mobilita' ciclistica*, law 19th October 1998, no 366, G.U. n. 248 23 October 1998). This law gives guidance instructions for cycling investments including provisions stating that abandoned railways and river banks must be used for cycling paths, and that new local and distributor roads in urban environments must be accompanied with a parallel cycle infrastructure.

In light of recent economic downturns, some countries like Australia and Spain have included cycling in stimulus packages or jobs strategy funding. In Australia the Federal government has set aside €30 million in 2010 for the construction of bike paths under the National Bike Path Projects component of National Jobs Fund local jobs initiative[51]. As for Spain, the National Fund for Local Investment, aiming to improve urban areas, dedicated €380 Million from the total €8 Billion (8.000 Million) to sustainable mobility, including cycling facilities[52].

Regional and local budgets

In countries where policies are decentralised, funds for cycling are allocated at the regional level, as is the case in Belgium. In the Brussels-capital region there is a budget of €11 million per year to be spent in infrastructure from 2011 on, up from €4.5 million per year on average from 2005-2009. In addition, the region also spends €500000 annually on bicycle promotion and education. The other two Belgian regions spend strongly divergent amounts on cycling: the Walloon region spends €10 million annually in infrastructure (exclusive of subsidies for communal projects) whereas the Flemish region spends €60 million annually since 2006.

The bulk of funds spent on cycle infrastructure is programmed and spent at the local level. The most recent National Bicycle Strategy for Germany (*Nationaler Radverkehrsplan 2012*) suggests that per-capita spending on cycling at the local and regional level should be in the range of €8 to €19 per capita (€6 to €15 on investment, maintenance and operations, €1 to €2.5 on parking and €0.5 to €2 on communications and promotion). The spread in spending estimates accounts for different starting points.

Germany presents a case of derived budget where cycling could be included. Within the framework of the Local Authority Transport Infrastructure Financing Act, the Federal Government uses about €1.7 billion per year from the mineral oil tax revenue to promote investment in the improvement of transport infrastructure in municipalities. Although cycle tracks are not explicitly referred to in the Act as being eligible for funding, the construction or maintenance of cycle infrastructure is nevertheless permissible. Besides this, the fact that the Federal Budget has earmarked significant funds at the national level for construction and maintenance of cycle ways since serves to generate spending on cycling at other levels of government.

At the city level, some leading cities dedicate an important budget to cycling: Copenhagen invests about €30 million annually on cycling infrastructures. Other cities invest much less; Warsaw (1.716.855 inhabitants) invested €1.7 million in cycling infrastructures during 2010, and there is an estimated budget of €4 million on building the city-bike programme around the city. In Spain, the city of Zaragoza (675.121 inhabitants) invested €3,2 million in 2010. Main items included are: cycle paths, on-street parking, communication campaigns, information and services centre and a survey.

Cycling's proportion of overall transport budgets is still very small: for example, it is less than 1% of the UK national transport budget, whilst in the City of London (7,825.200 inhabitants), cycling accounts for only 0.45 per cent of the €155 million transport budget, amounting to around €700.000[53].

Key messages

- National-level commitment, or at a minimum, regional-level commitment, is important in setting the right legal, regulatory and financial framework so that successful implementation of cycling strategies can take place.
- Not all countries address cycling safety at the national level but those that do either establish plans focusing on improving bicycle (or road) safety specifically or plans addressing transport, spatial, environmental and health planning more generally. The first approach is more direct though the second approach may impact the cycling environment and thus indirectly impact safety.
- The principal objectives of cycling-related plans of countries surveyed for this report are:
  - to increase the number of people cycling
  - to improve safety and security awareness when cycling
  - to balance cycling speed and comfort
- Cycling is impacted by and in turn impacts a number of other government policies e.g. health and land-use alongside transport. In addition to developing national plans, some administrations assign a person or institution responsibility for coordinating cycling policy across all of government. This practice has the benefit of ensuring consistent policy action in favour of cycling.
- One key area for national policy is to set up the regulatory framework surrounding traffic rules for motorists, cyclists and for urban space. This allows for consistent treatment of cyclists in the traffic environment.
- Authorities in many high-cycling countries/regions ensure that all citizens (not just cyclists) receive adequate training regarding cycling skills and, crucially, rules relating to the use of cycling infrastructure and governing the interaction between cyclists and motorised traffic at junctions and other points of conflict.
- Most countries surveyed for this report view the bicycle as a road vehicle for the purposes of national traffic laws. Some countries have special provisions within their traffic codes relating to bicycles and their operation in the road environment or, in some instances, statutorily define specific traffic environments that favour the use of bicycles and walking.
- While the overall share of national and regional budgets is relatively small, high-cycling jurisdictions spend more per capita on infrastructure and operations.

Notes

1. Mobility here refers widely to the different categories found in the references: transport, traffic, alternative modes.
2. ECMT (2004)
3. http://www.atcouncil.gov.au/, accessed July 18,. 2012
4. http://www.austroads.com.au/abc/, accessed September 23, 2013
5. http://www.developpement-durable.gouv.fr/-Monsieur-Velo-et-ses-partenaires-.html, accessed September 23, 2013
6. http://www.nationaler-radverkehrsplan.de/en/transferstelle/downloads/cye_o-01_national-cycling-plan.pdf, accessed July 18,. 2012
7. See recent UK study, as an example of the economic revenues that cycling can have at national level: http://corporate.sky.com/documents/pdf/press_releases/2011/the_british_cycling_economy, accessed September 23, 2013
8. For a complete definition see OCDE (1998), pp. 9 and 10.
9. http://www.crow.nl/nl/Publicaties/publicatiedetail?code=REC25, accessed July 18, 2012
10. DECRETO MINISTERIALE 30 novembre 1999, n. 557. Regolamento recante norme per la definizione delle caratteristiche tecniche delle piste ciclabili (G.U. n. 225, 26 settembre 2000, Serie Generale)
11. http://www.developpement-durable.gouv.fr/-Mission-nationale-des-veloroutes-.html, accessed July 18, 2013
12. http://www.ffe.es/principal.asp, accessed July 18, 2012
13. http://www.veiligverkeernederland.nl/verkeersexamen, accessed July 18, 2013
14. http://www.brevetducycliste.be/, accessed September 23, 2013
15. http://www.dft.gov.uk/bikeability/, accessed September 23, 2013
16. http://radlust.info/en/index.html, accessed September 23, 2013
17. http://www.signaal.org/files/1%20Folder%20Alle%20regels%20rondom%20spiegels.pdf, accessed September 23, 2013

18. http://www.swov.nl/rapport/Factsheets/UK/FS_Blind_spot_crashes.pdf, accessed September 23, 2013

19. http://www.fahrradakademie.de/konzept/index.phtml, accessed September 23, 2013

20. http://www.cyclingresourcecentre.org.au/, accessed September 23, 2013

21. http://www.cycling-embassy.dk/, accessed September 23, 2013

22. http://www.fietsberaad.nl/, accessed September 23, 2013

23. http://www.swov.nl/, accessed September 23, 2013

24. http://www.cdv.cz/en/, accessed 23 September, 2013

25. http://ww.cyklostrategie.cz/, accessed 23 September 23, 2013

26. http://www.austroads.com.au/documents/AP-C85-10.pdf, accessed July 18, 2012

27. http://www.atcouncil.gov.au/documents/files/NRSS_2011_2020_20May11.pdf, accessed July 18, 2013

28. http://scp.eionet.europa.eu/facts/factsheets_waste/fs_scp/pdf/showcase_czech, accessed 23 September 23, 2013

29. http://www.trm.dk/graphics/synkron-library/trafikministeriet/publikationer/pdf_uk/003.pdf, accessed 23 September 2013

30 http://www.securite-routiere.gouv.fr/article.php3?id_article=3525, accessed 18 July, 2012

31. http://www.bmvbs.de/SharedDocs/DE/Artikel/UI/fahrradverkehr-nationaler-radverkehrsplan.html, accessed September 23, 2013.

32. http://www.verkehrssicherheitsprogramme.de/, accessed September 23, 2013

33. http://www.bicitalia.org/cakebi/, accessed September 23, 2013

34. http://www.arcss.it/progetti/piano_nazionale.pdf, accessed July 18, 2013

35. Last planning document dates from 1999 “The Dutch Bicycle Masterplan” accessible at: http://www.fietsberaad.nl/library/repository/bestanden/The%20Dutch%20Bicycle%20Master%20Plan%201999.pdf, accessed July 18, 2012

36. For more information, see “Cycling in the Netherlands”, 2009, accessible at: http://www.fietsberaad.nl/library/repository/bestanden/CyclingintheNetherlands2009.pdf, accessed September 23, 2013

37. From the policy questionnaire

38. Regulation (EC) No 78/2009 and Commission Regulation (EC) No 631/2009 on the type-approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users and the US NHTSA-proposed amendments to the Global Technical Regulations affecting the hood and bumper areas of light vehicles to reduce injuries and fatalities to struck pedestrians.

39 Fixed gear bicycles, now gaining popularity in many areas, may not conform to these laws if they do not have at least one brake (the fixed gear serving as the second brake).

40 Traffic rules relating to cyclists in Europe are drawn from (TiS.PT 2004).

41 In Portugal, cyclists and pedestrians never have priority unless otherwise indicated.

42 And in Germany, Denmark, Finland, Ireland, the Netherlands, Sweden and the UK, road users exiting a roundabout must give way to cyclists whereas in Belgium, Spain, Greece and France, the opposite is true.

43 L'Instruction Interministérielle sur la Signalisation Routière (ISSR), 2009.

44 http://www.cen.eu, accessed September 23, 2013

45 http://live.unece.org/trans/conventn/legalinst.html, accessed September 23, 2013

46. http://live.unece.org/fileadmin/DAM/trans/roadsafe/publications/docs/Consolidated_Resolution_on%20Road_Traffic_RE1_e.pdf, accessed September 233, 2013

47. http://live.unece.org/fileadmin/DAM/trans/roadsafe/publications/docs/Consolidated_Resolution_on%20Road_Traffic_RE2_e.pdf, accessed 23 September, 2013

48. Official response by Minister Eurlings (Letter VenW/ DGMo-2010/2849): http://www.fietsberaad.nl/library/repository/bestanden/reactie_atsma2.pdf, accessed September 23, 2013

49. http://www.bmvbs.de/SharedDocs/DE/Pressemitteilungen/2010/246-bomba-eurobike.html, accessed September 23, 2013

50. http://www.nationaler-radverkehrsplan.de/en/transferstelle/downloads/cye_o-01_national-cycling-plan.ppt, accessed September 23, 2013

51. http://www.regional.gov.au/regional/national_bike_path.aspx, accessed September 23, 2013

52. http://www.mpt.gob.es/prensa/Documentos/Libro-FEIL/document_es/documento.pdf, accessed July 18, 2012

53. http://corporate.sky.com/documents/pdf/press_releases/2011/the_british_cycling_economy, accessed September 23, 2013

3. Analysis of international trends in bicycle use and cyclist safety

This Chapter reviews trends relating to cycling safety as reported and vetted by ITF members via a questionnaire. This information is complemented by different national and regional sources of information. Trends relating to fatalities, injuries and crash rates are presented alongside international data on levels of cycling. Where possible, exposure-adjusted safety figures are given and some of the underlying factors contributing to observed trends are discussed.

3.1 Introduction and methodology

This chapter is intended to highlight international trends in bicycle use and cyclist safety. To that end, members of the International Transport Forum/OECD Joint Transport Research Centre and other selected countries were asked to fill out a questionnaire in September 2010 relating to three overall themes:

- Road accidents involving cyclists
- Bicycle use
- Existing cycling infrastructure

The collected data provided WG members with up-to-date and validated information from responding countries. The aim of this chapter being to analyse international trends, the collected data concern aggregate national level data and do not consider sometimes significant local differences (urban vs. rural). In some instances, questionnaire data has been complemented by other sources as noted in the text.

Countries participating in the Working Group on Cycling Safety and/or the International Traffic Safety Data and Analysis Group (IRTAD) were specially targeted because of the known quality and common methodological practices in relation to the collection of road safety data (Table 3.1.).

Table 3.1. **Selected Countries for Review (shaded = no response)**

Australia	Denmark	Hungary	Italy	New Zealand	Spain
Austria	Finland	Iceland	Japan	Norway	Sweden
Belgium	France	India	Korea	Poland	Switzerland
Canada	Germany	Ireland	Malaysia	Portugal	United Kingdom
Czech Republic	Greece	Israel	Netherlands	Slovenia	United States

Twenty-three out of the thirty countries filled in available data and returned the questionnaire, i.e. a response rate of 77 %. The responding countries were Australia, Austria, Belgium, Canada, Czech Republic, Denmark, France, Germany, Greece, Hungary, Israel, Italy, Japan, Korea, Netherlands, New Zealand, Poland, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States.

One thing that stood out from all responses was the lack of data on bicycle use. As noted earlier, this compromises any assessment of cycling safety. The data on road accidents involving cyclists and existing cycling infrastructure were fairly complete and could be used for a more detailed analysis.

3.2 Terms and definitions

For a correct understanding and interpretation of this analysis of international trends in bicycle use and cyclist safety, readers need some essential information on the data collected and dealt with in the context of the present report.

Safety variables and their definition may differ from one country to another. For some terms an internationally agreed definition exists, for others not. For instance, a *road fatality* is internationally defined as a person who died in a traffic crash, within 30 days of the crash, whereas *seriously injured* may be defined quite differently in various countries. In France, a person is considered *seriously injured* when hospitalized for more than 24 h[1]. In Hungary, the term is referred to as bone fracture, dislocation of a joint, injury of a cavity of the body (skull, chest, abdomen) or injury of vessels, tendon or nerves, which take longer than 8 days to heal. In Austria, the difference is even greater since they define a *seriously injured* person as a person suffering an injury which entails an inability to work or personal difficulty for more than 24 days. Table 3.2 presents an overview of the definitions of *injured person* in IRTAD countries.

In view of obtaining comparable data, terms and definitions were specified in the survey questionnaire. However, it would seem that many countries most likely transmitted data based on their national definitions nonetheless. Therefore, this chapter mostly describes and compares trends, rather than presenting absolute figures.

3.3 Road crashes involving cyclists

The relatively high response rate (78 %)[2] on questions with regard to road accidents involving cyclists allows us to discern certain trends and make comparisons between different countries in terms of the evolution of the absolute number of recorded injury-causing road crashes involving cyclists (Figure 3.1). In addition to questionnaire responses, IRTAD[3] data for 1970-2008 from the respondent countries (except Australia) was used in order to refine those trends as was data from the CARE[4] database for countries in Europe and from the Fatal Accident Reporting System (FARS) database for the USA.

For all countries represented in Figure 3.1, the overall evolution (black line) of recorded injury crashes involving cyclists is relatively constant since 2000, with a slightly downward trend since 2005. However, this trend is quite different from one country to another. There is a near-constant decrease in the Netherlands, Poland and Denmark since 2000 (approximately 50 % less), whereas the number of recorded injury bicycle crashes has increased significantly in Spain and New Zealand, though the most recent figures for New Zealand show a break in the trend. Two thirds of the countries report a lower or equal number of recorded injury bicycle crashes in 2009 compared to 2000[5]. What this figure does not reveal is whether the trends displayed are linked to changes in the safety of cycling or a changes in the number of cyclists travelling or volume of bicycle travel. Since Figure 3.1 shows the evolution of *all* recorded bicycle injuries, it says little about the impact of under-reporting of non-fatal crashes in the observed trend.

Table 3.2 **Road injuries – ITF-EUROSTAT-UNECE definition and application in IRTAD countries**

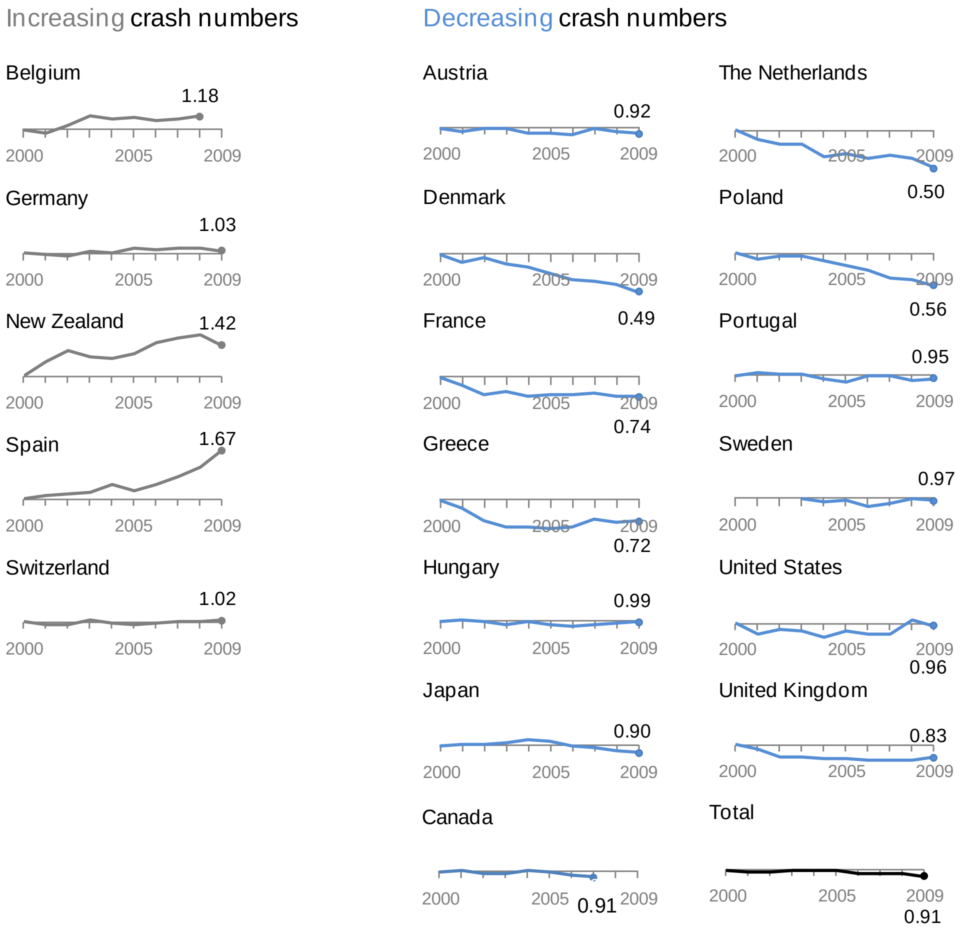
	Injured					**Seriously Injured**			**Slightly Injured**
	All injured road users including death >30 days	Requires medical treatment	Lesser wound (minor cuts and bruises)	Attempted suicides	Inability to work	Hospitalisation	Hospitalisation or serious injuries	Inability to work	Other than seriously Injured
ITF-Eurostat-UNECE classification	Yes	Yes	No	No	..	>24 hrs	..	..	Yes
Australia	..	..	..	..	..	Admitted	..	..	..
Austria	Yes	Yes	No	No	..	..	..	[a]	..
Belgium	Yes	Yes	No	Yes	..	>24 hrs	..	..	Yes
Canada	Yes	Yes	No	No	..	>24 hrs	..	..	Yes
Czech Republic	Yes	Yes	Yes	Yes	..	..	Yes	..	Yes
Denmark	Yes	Yes	No	No	..	..	Yes	..	Yes
Finland	Yes	..	No	Yes	..	> 1 day	..	..	..
France	Yes	..	..	..	..	> 24 hrs	..	..	Yes
Germany	Yes	Yes	Yes	No	..	> 24 hrs	..	..	Yes
Great Britain	Yes	Yes	Yes	Yes	..	..	Yes	..	Yes
Greece	Yes	..	Yes	No	..	> 24 hrs	..	..	..
Hungary	Yes	Yes	No	No	..	..	Yes	..	Yes
Iceland	Yes	..	..	..	..	..	..	..	..
Ireland	Yes	Yes	No	No	..	..	Yes	..	Yes
Israel	Yes	Yes	Yes	..	..	> 24 hrs	..	..	..
Italy	Yes	..	..	..	..	..	..	..	..
Japan	Yes	Yes	No	No	..	..	..	..	Yes
Netherlands	Yes	Yes	No	..	..	> 1 night	..	..	Yes
New Zealand	Yes	..	Yes	Yes	..	..	Yes	..	Yes
Poland	Yes	Yes	Yes	No	Yes	> 7 days	..	..	..
Slovenia	Yes	Yes	Yes	..	..	> 24 hrs	..	..	Yes
Spain	Yes	Yes	Yes	Yes	..	> 24 hrs	..	..	Yes
Sweden	Yes	Yes	No	No	..	..	..	..	Yes
Switzerland	Yes	Yes	..	..	..	..	..	> 24 hrs	Yes
United States[b]	Yes	..	..	..	..	..	..	..	..

[a] Inability to work or health problem > 24 days

[b] The United States employs the KABCO scale (K=Killed, A= Incapacitating injury, B= Non-incapacitating injury, C= Possible injury, O= no injury and U=Injured, severity unknown)

Source: (IRTAD 2012).

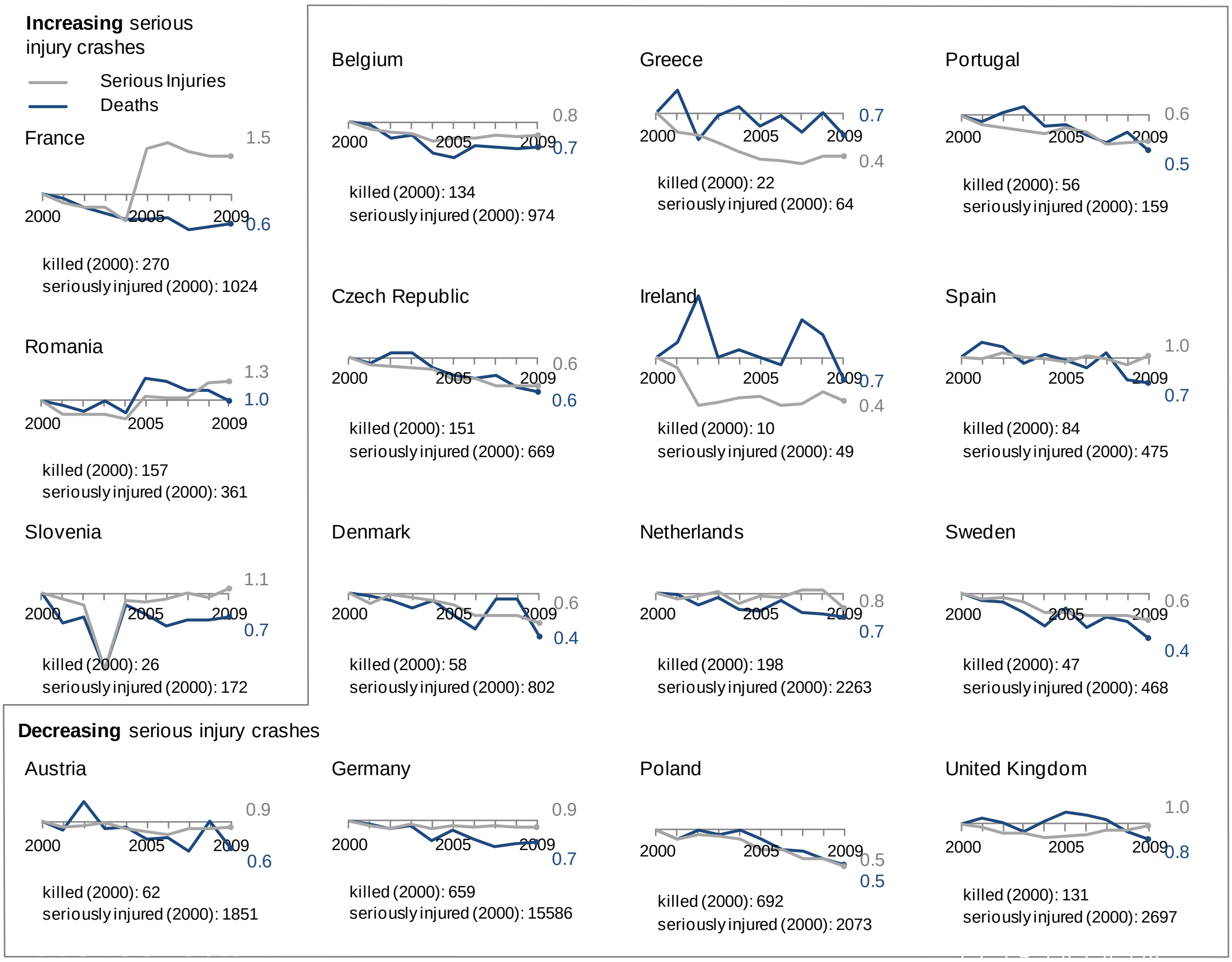
Figure 3.1 **Evolution of *all* recorded injury bicycle crashes 2000-2009, selected countries, 2000=1**



Source: Questionnaire responses

Figure 3.2 displays the evolution of serious and fatal bicycle crashes for a subset of European countries reporting 2000 to 2009 bicycle crash statistics to the CARE road safety database[6]. All countries reporting data on bicycle fatalities from 2000-2009 have either stabilised or decreased their number. Some countries, however, report an increase in the number of serious injury bicycle crashes[7]. Romania and Slovenia). Twelve of the sixteen countries in Figure 3.2 have reduced cyclist fatalities at a greater rate than seriously injured cyclists from 2000 to 2009, highlighting that the reducing the latter remains a serious and persistent road safety challenge. This is especially the case as serious injury bicycle crashes are not adequately captured by police reporting mechanisms and are therefore under-reported.

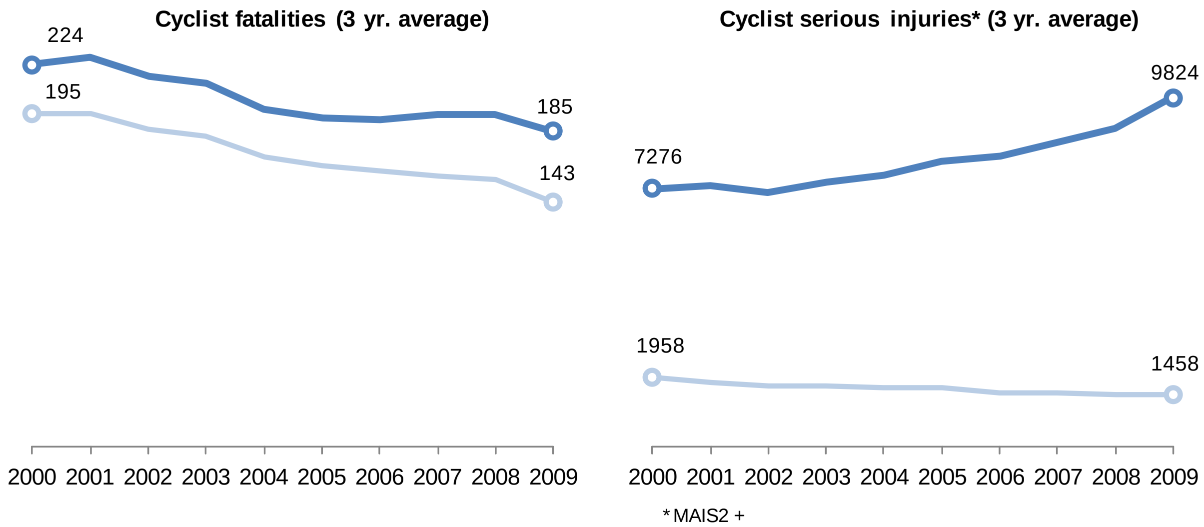
Figure 3.2 **Evolution of recorded serious injury and fatal bicycle crashes 2000-2009, selected countries reporting to CARE database, 2000=1**



Source: Questionnaire responses

The Netherlands provides an interesting example of the evolution of fatal and serious injury crashes, not least of which because they collect and report data aggregated from police *and* hospital records giving a more precise view of the evolution of injury and fatal bicycle crashes – and of the scale of under-reporting in the case of serious injuries (Figure 3.3). For the period 2000-2009, police-recorded crash data shows a decrease of approximately 27% in fatal bicycle crashes and a 26% drop in serious injury crashes. In contrast, estimates of actual (police and hospital recorded) deaths show a lower decrease in deaths (17%) and, crucially, a significant increase in serious injuries (+35%) over the same period. Dutch data shows that the 60-69 year old age category has had the strongest rise in actual deaths and serious injuries over this period. Most other age categories have seen a decrease in actual deaths whereas all age categories have seen an increase in actual serious injuries.

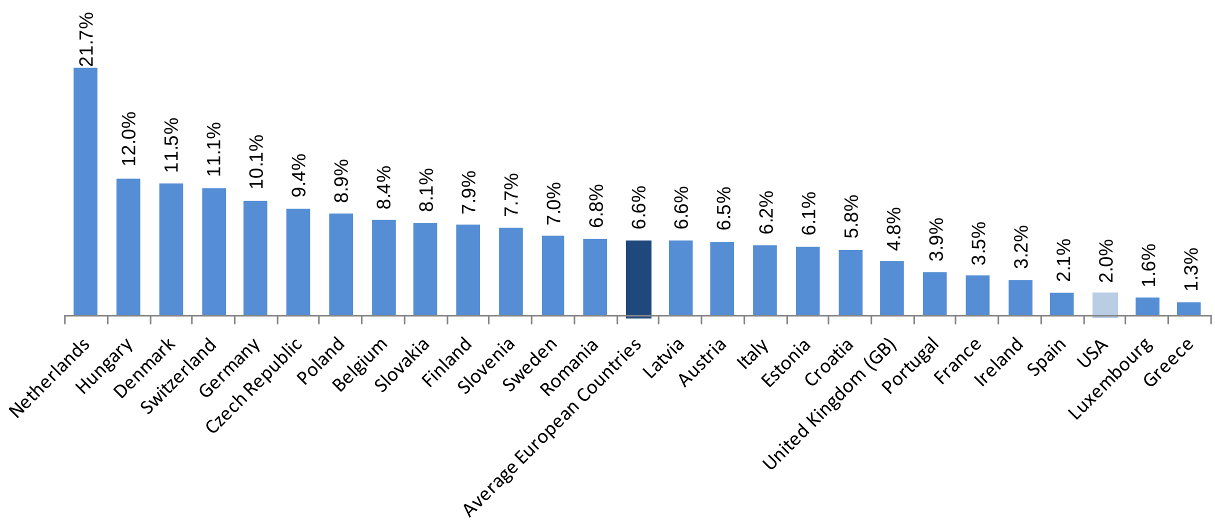
Figure 3.3 **Actual vs. Registered number of fatalities (30 days) and serious injuries (MAIS 2+) in the Netherlands 2000-2009 (3 year rolling average)**



Source: Netherlands Road Safety database, SWOV

Figure 3.4 displays the percentage of fatal bicycle crashes compared to overall traffic deaths for a range of countries based on CARE and FARS data. These percentages are likely linked to cycling participation (e.g. high participation in the Netherlands leads to a high share of cyclist fatalities in overall traffic deaths, low participation in Greece leads to the opposite) and it is difficult to say conclusively whether cycling is actually safer in some countries than in others based on this data. In some cases, a low percentage may indicate that cycling is, or is perceived to be, less safe than other modes thus reducing participation and resulting in a smaller share of overall fatalities. What is perhaps more revealing is that the share of cycling fatalities gravitates around 5-8% in a number of (European) countries.

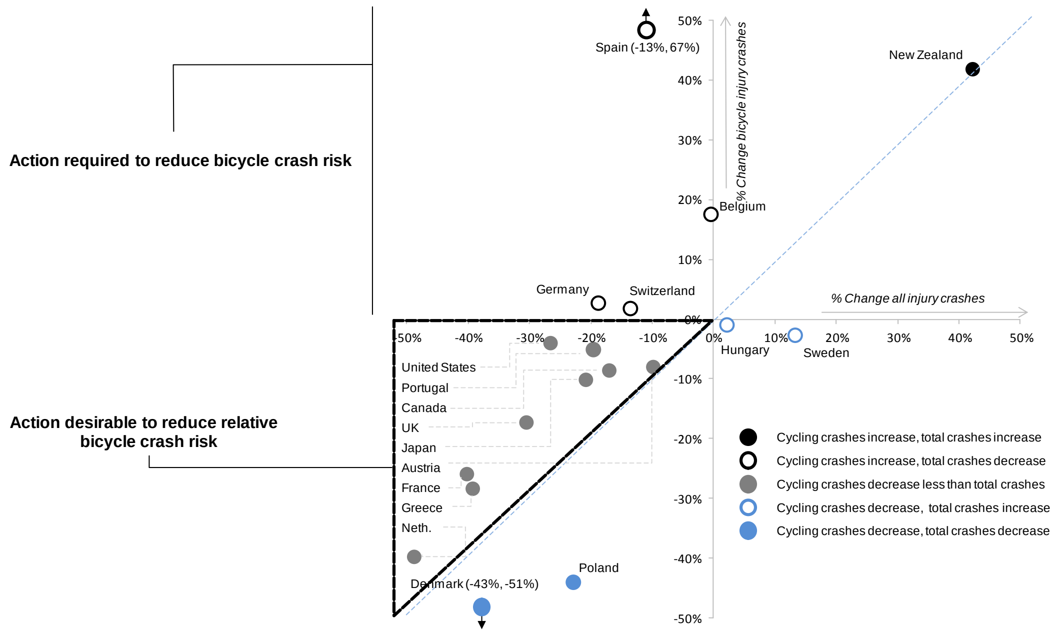
Figure 3.4 **Share of bicycle crash fatalities in overall traffic crash fatalities for selected European countries**



* 2005-2010, except for Croatia2007-2010, Estonia 2005-2009, Netherlands 2005-2009, Sweden 2005-2009 and Switzerland 2008-2010
** 2005-2011

Source: EU* CARE database and USA** FARS database

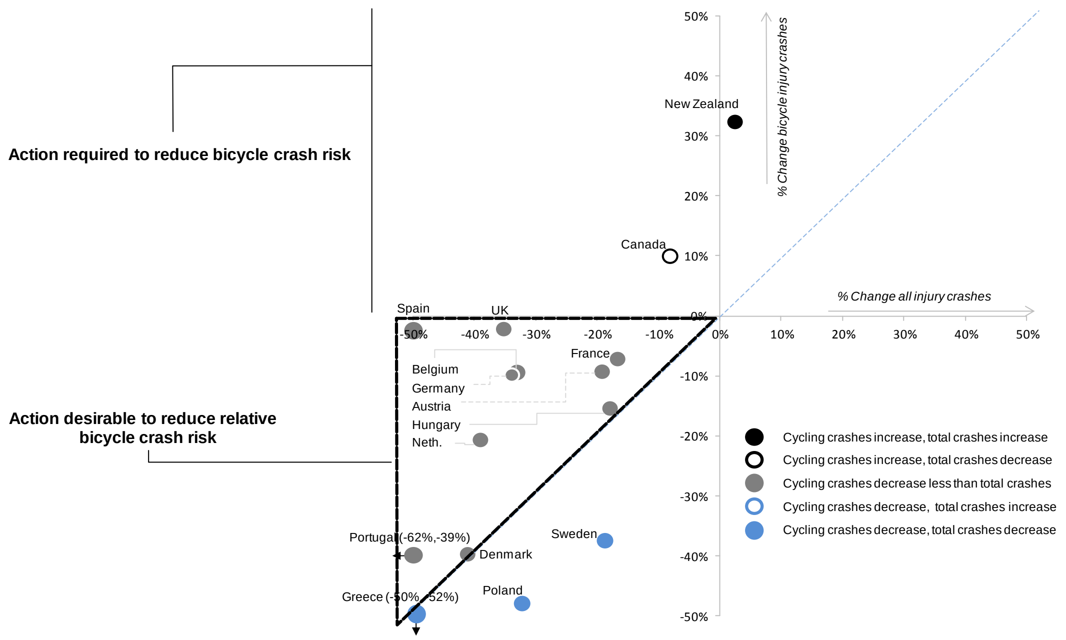
Figure 3.5 **Percent change in all recorded injury crashes compared to % change in recorded bicycle injury crashes, 2000-2009*, selected countries**



* Except for Sweden (between 2003 and 2009) and 2000 and 2007

Source: Questionnaire responses

Figure 3.6 **Percent change in all recorded serious and fatal injury crashes compared to % change in recorded serious and fatal bicycle injury crashes, 2000-2009*, selected countries**



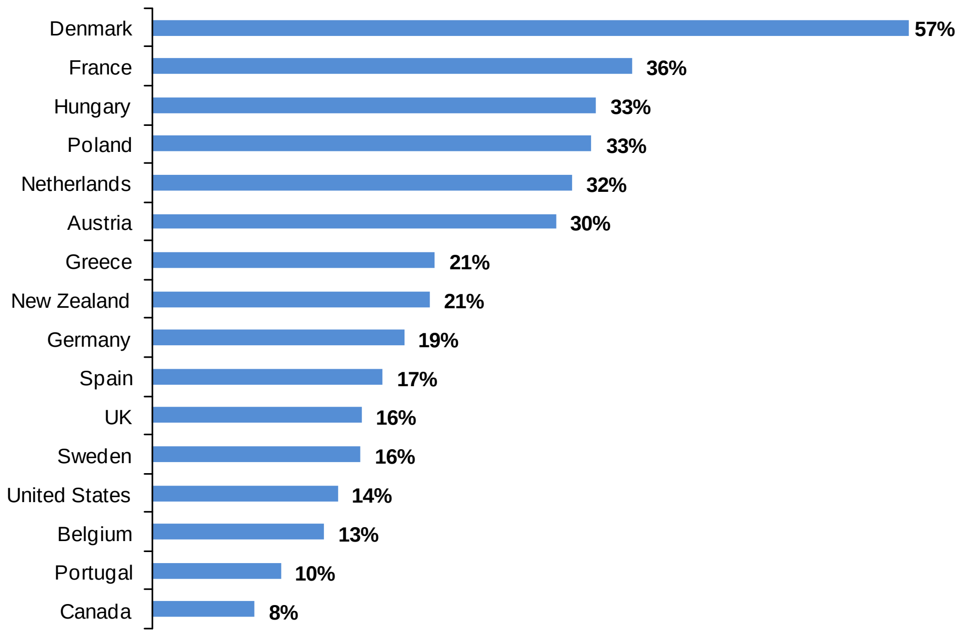
* Except for Sweden (between 2003 and 2009) and 2000 and 2007

Source: Questionnaire responses

It may be useful to compare national *trends* in bicycle crash numbers with *trends* in overall road traffic crash numbers to detect possible divergences and, hence, the need to adapt road safety policy. Figure 3.5 compares the evolution of all overall personal injury road crashes and that of personal injury bicycle crashes. In a general way, and with the exception of Sweden, Poland, Denmark and, to a lesser extent, also Hungary, the evolution of overall personal road accidents shows a more positive trend than for personal injury bicycle accidents.

A relatively large group of countries have seen the number of all road crashes decrease at a greater rate than bicycle injury road crashes and a few (Germany, Switzerland, Belgium and Spain) have seen the number of all injury crashes decrease while bicycle injury crashes have increased. This is also the case of Korea (not shown on the graph) where all traffic fatal fatalities have decreased by 3.4% per year on average from 2003 to 2009, while bicycle fatalities have increased by 4.8% per year over the same period. These findings suggest that most countries should intensify efforts to reduce the number of bicycle crashes and improve cyclist safety. The greater the divergence between all injury crash trends and bicycle injury crash trends signals a need for special targeting of safety policy (e.g. Spain, Belgium). This is true even in cases where both trends show a reduction in absolute number of crashes since it signals that cyclists are benefitting less from overall safety improvements that are reducing overall crash rates.

Figure 3.7 **Cycle crash severity: Ratio of recorded serious injury and fatal bicycle crashes to all recorded bicycle crashes (3 year average)**



Source: Questionnaire responses

These results may be biased when accounting for underlying changes in exposure and when under-recording of bicycle crashes is not stable and varies annually. Without information on these variables, we cannot be certain if Figure 3.5 provides an accurate representation of trends. One way to reduce possible bias is to constrain the analysis to only serious and fatal injury classes as these have lower documented under-recording rates as described in Chapter 1. Figure 3.6 only takes into account accidents involving fatalities and seriously injured cyclists and shows some differences to the trends represented in Figure 3.5, notably with only two countries showing a rise in recorded serious or fatal bicycle injury numbers from 2000 to 2009 (Canada and New Zealand). Overall, with the exception of some countries, trends are quite similar with those shown in Figure 3.5, e.g. they are more positive for overall road crashes than for bicycle crashes. This confirms that in many countries, efforts to reduce all road crashes are outstripping efforts to reduce bicycle crashes and that there is a need to intensify efforts to reduce the number of fatalities and seriously injured in bicycle crashes. Again, stronger efforts seem justified where discrepancies in observed trends are largest -- e.g. Spain (27 %), New Zealand (30 %) and the United Kingdom (22 %). Results may still be biased, however, when data provided was based on differing definitions of “serious” injuries.

Crash severity is another important indicator of cyclist safety. Crash severity is defined as the ratio of the number of recorded fatalities and seriously injured in bicycle crashes to the total number of recorded bicycle crashes. The severity of bicycle crashes (Figure 3.7) varies strongly from one country to another. In Canada, the crash severity ratio is rather low (8 %), while it is very high in Denmark (57 %). In the latter more than half of recorded cyclist crashes result in seriously injured persons or fatalities. A major reason for that high figure as compared with other countries is that a lot of injury crashes with only slight injuries are not recorded in Denmark, either because they are not registered by the police at all or because they are not categorized as injury crashes. The average crash severity ratio for all 16 respondent countries is 23.5 % or nearly one out of four recorded crashes. That high figure may in part be explained by the vulnerability of cyclists. In a car crash, the vehicle partly absorbs the crash impact, whereas a cyclist’s body absorbs almost all of the kinetic crash forces.

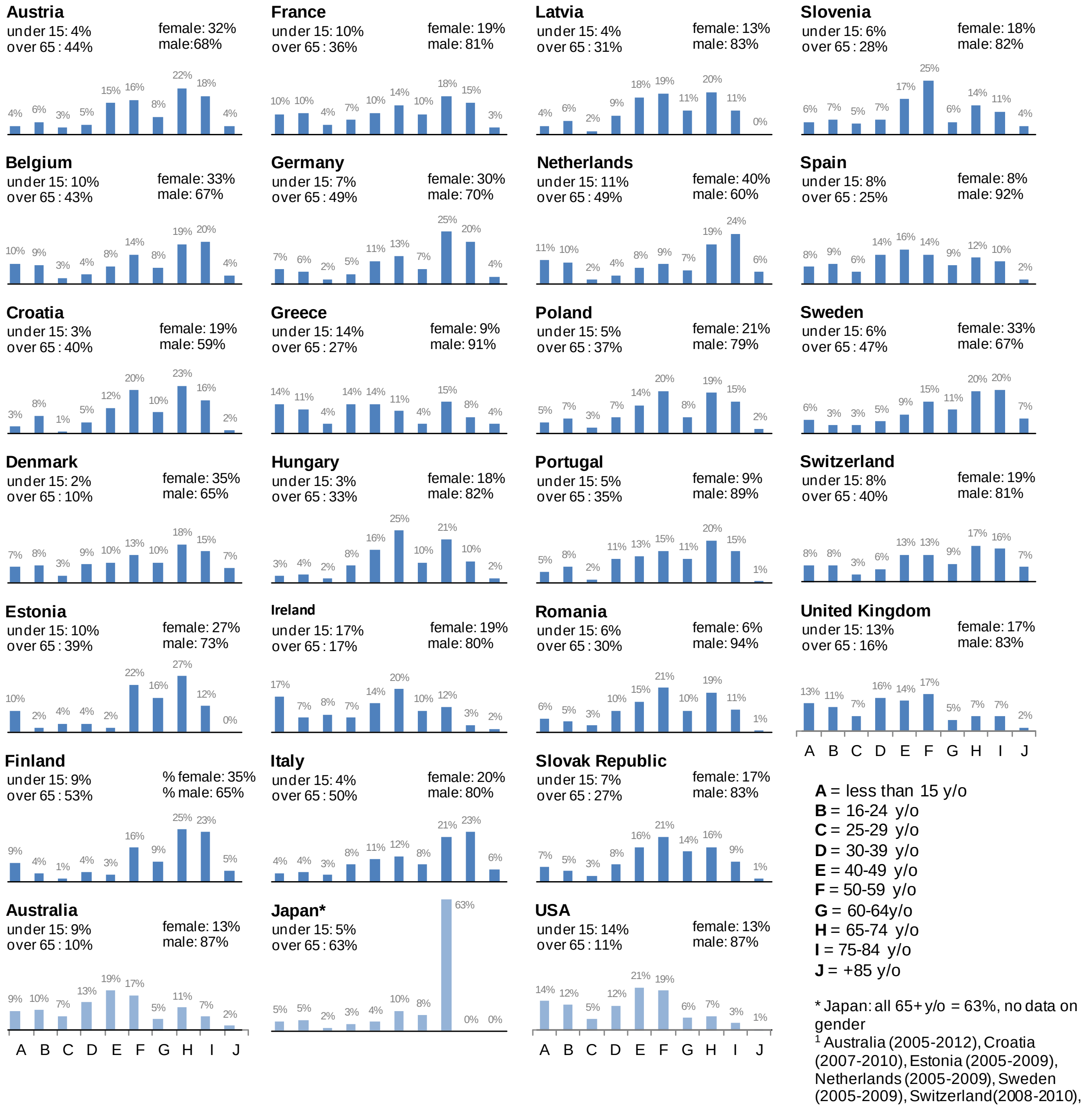
Distribution of cyclist fatalities by age group is another way to interpret cycle crash statistics. In general, as seen in Figure 3.8, the distribution of cyclist traffic fatalities by age group is quite similar for most countries. It follows a u-shaped curve with a local maximum in victims below 15 years old (especially, 10-15 years old when many youths are venturing autonomously into road environments) and an even greater spike in fatalities among those 65 years and older. In many countries, fatalities increase with age starting in the mid-20s.

Some countries display a flatter distribution than others – this is the case for Australia (and New Zealand, not shown here), Greece, the United Kingdom and USA. Generally those over 65 years old represent a significantly large proportion of cyclist fatalities. A clear over-representation of those over 65 years old is apparent in Japan whereas in Italy, the age groups over 25 years old are proportionally more important than in most other countries. One explanation for the over-representation of the elderly in fatal cycle crashes is the more severe consequences of crashes due to the sometimes lessoned physical condition of many older people. In particular the combination of more brittle bones, less elastic soft tissue weakened locomotive functions including reaction times results in more crashes for this population group and more severe crash outcomes (Wegman and Aarts 2006). For children, a combination of factors may be at play: a greater propensity to expose themselves to crash risk and the location of crash contact points between motor vehicles and their bodies (head and upper body).

In most countries, fatal bicycle crashes largely concern male cyclists (Figure 3.8). In countries where utilitarian cycling is widespread (e.g. Denmark, Belgium, Finland, Germany), a more balanced distribution of fatal crashes among genders can be observed – most likely reflecting greater female cycling rates.

It is difficult to reach conclusive findings on the relationship between age (or gender) and fatal bicycle crashes without robust data on bicycling participation rates among different demographic segments and, as noted throughout this report, this data is often lacking thus complicating the task of bicycle safety analysis.

Figure 3.8 **Distribution of recorded cyclist fatalities by age group (2000-2010), selected countries**[1]



Source: Questionnaire responses

3.4 Exposure data: Bicycle use

Only eight out of the twenty-three respondent countries could provide some data on the level of bicycle use or travel. We have, where possible, complemented this information with official statistics on bicycle usage (or other sources) where available. Nonetheless, this is a small sample and thus does not represent a firm basis for a broad scale interpretation of international trends.

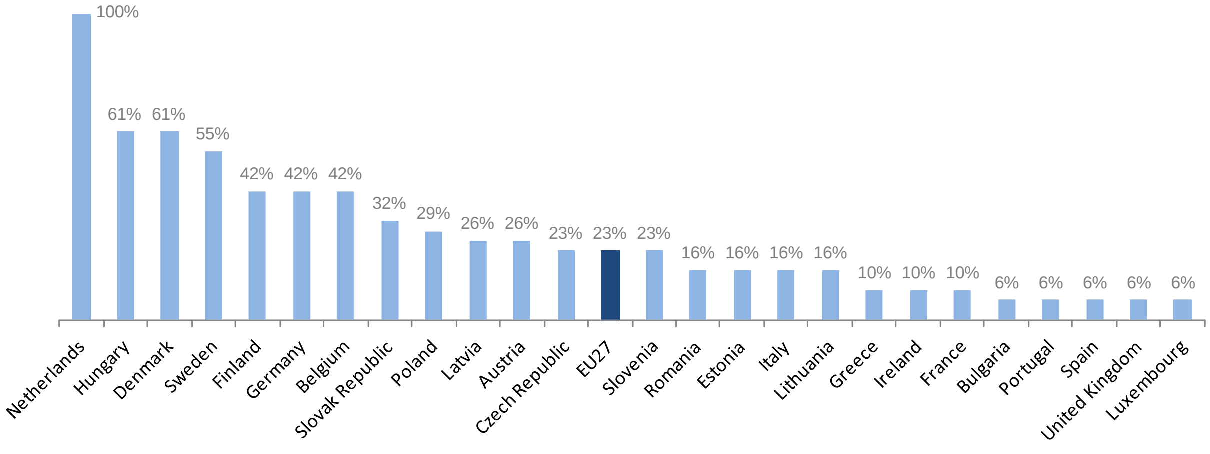
Note: As noted in Chapter 1, relatively few countries collect and report exposure data at the national level. For instance, for this report only 9 countries were found with national data on distance travelled by bicycle or number of trips taken by bicycle. National statistics on shared bicycle schemes is lacking as well and few countries are able to produce statistics on bicycle ownership per capita or mode shares. Those that do collect distance- or trip-based bicycle data typically do so via (relatively expensive) national mobility or travel surveys. Data on exposure may be more available (and relatively less expensive to collect) at the local level – though aggregating this data in a useful way could benefit from a common reporting framework.

The evolution of the cycling modal share in passenger transport seems *relatively constant over a ten-year period* in countries where cycling is well-developed – perhaps indicating a relative saturation level for this mode. The Netherlands and Denmark report a stabilisation of bicycle mode share for passenger kilometres travelled at around 8% for the former (and 25% of all trips) and 4% for the latter. Some countries such as the United States and the United Kingdom report an increase in mode share in the past 5 years, though from a low starting point (1% and 2%, respectively).

The comparability of aggregate modes shares derived from travel surveys should be approached with caution as many countries or surveys employ different methodologies for defining a "trip" (e.g. does it include only the dominant leg of a multi-modal trip? Does trip refer to one leg or a return segment as well?). National-level mode shares also hide great local variability – e.g. while the reported bicycle mode share for all of Denmark was 3.6% in 2009, cycling mode share in Copenhagen was several orders of magnitude greater.

In 2010, The European Commission conducted a survey among a representative sample of EU citizens that included the question "What main mode of transport do you use on a daily basis?"(Gallup 2011) Figure 3.9 shows self-reported levels of cycling as compared to the Netherlands (which reported the highest level of cycling in the survey). According to survey responses, a number of countries display relatively high levels of daily cycling on the order of 40-50% of the levels achieved in the Netherlands. Many, but not all, "high cycling" countries have deployed extensive networks of bicycle facilities.

Figure 3.9 **Daily cycling mode shares in Europe 2010, compared to the Netherlands (Netherlands=100%)**

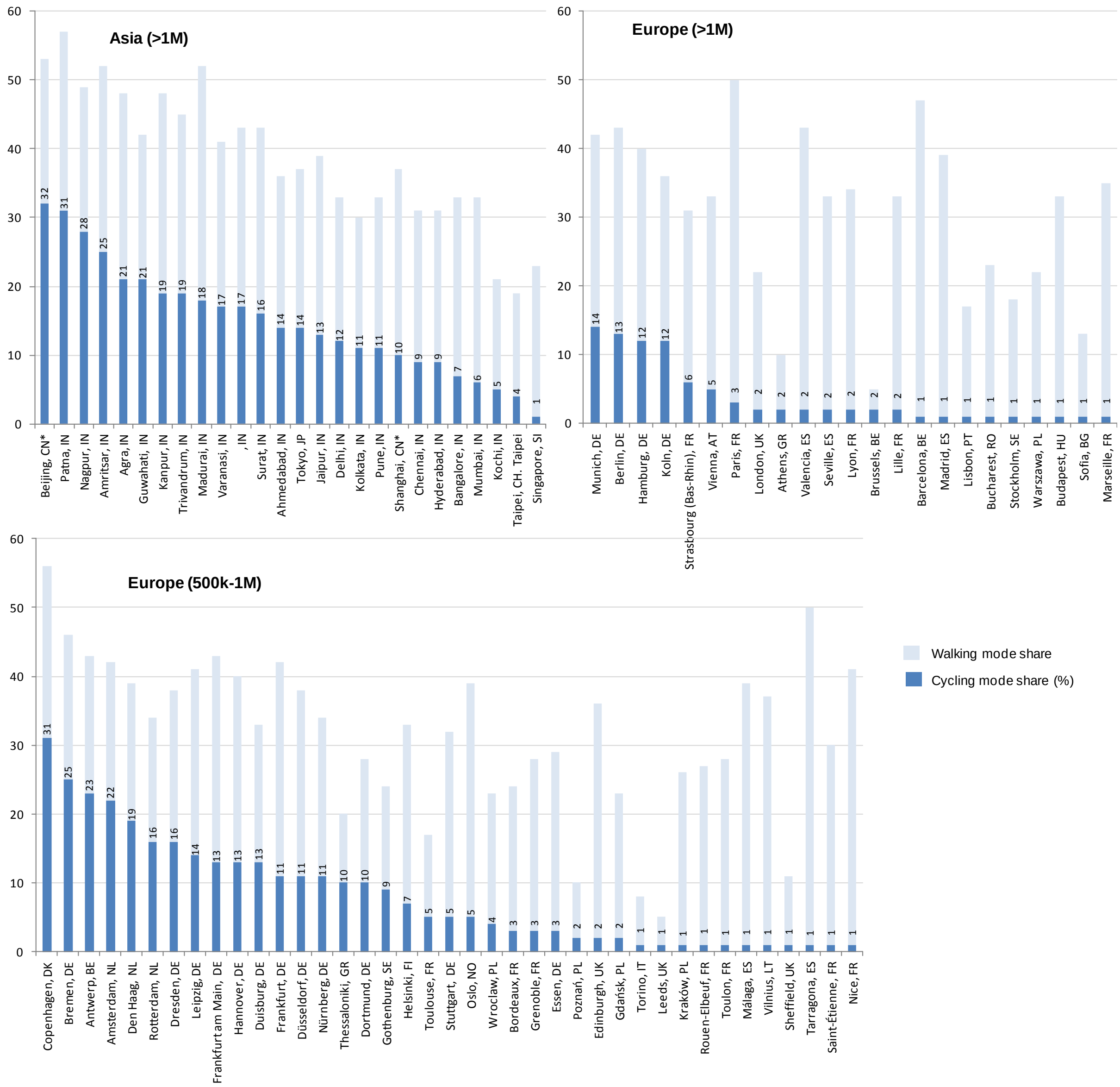


Source: (Gallup 2011)

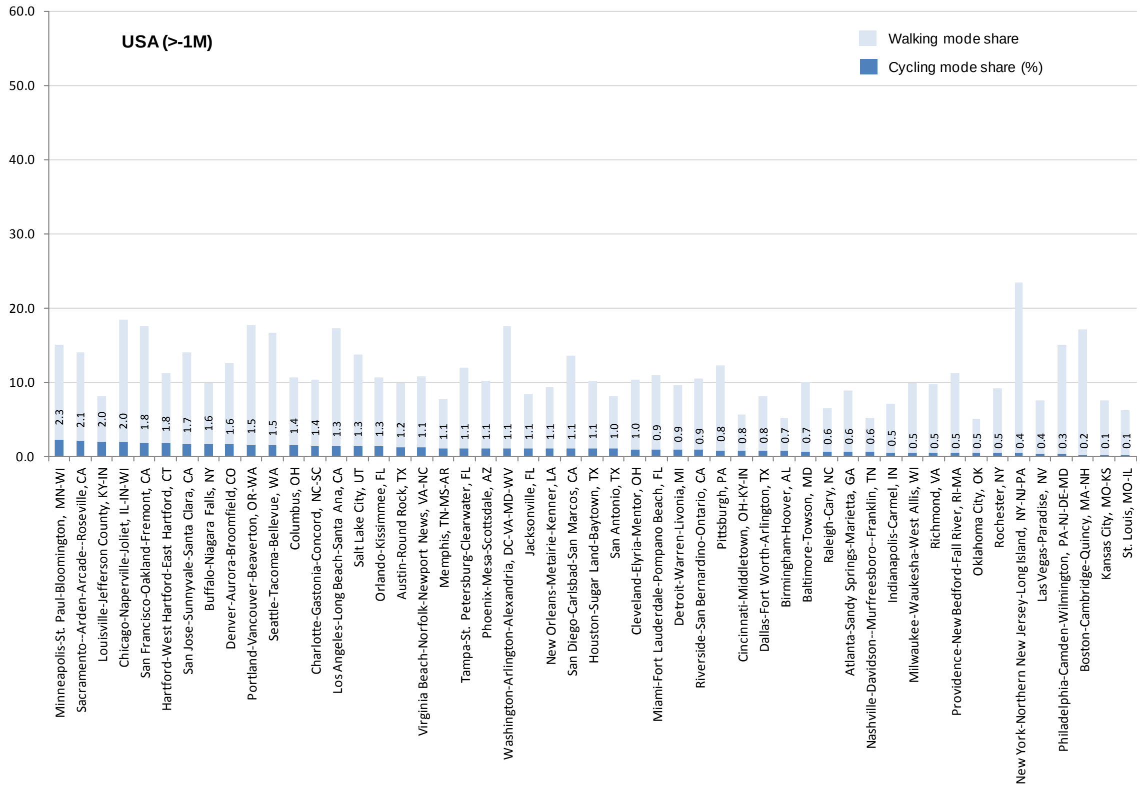
Urban bicycle share

Figure 3.10 displays travel-survey derived mode shares for major urban agglomerations on three continents. Despite the caveat that these travel surveys also have various methodological differences that render precise comparison challenging, the figure underscores the fact that not all cities are equally bicycle friendly or have comparable rates of cycling. There are many reasons for this. On the one hand, large Asian cities (e.g. in India and China) display elevated cycling and walking mode shares largely because these modes remain the most affordable (and sometimes practical) transport option for many inhabitants. Most cyclists in these cities ride not out of choice but out of necessity (see Annex 2). With increased incomes, these shares will likely decrease as cyclists turn to public transport or private motor vehicles. China, unlike India, has historically developed and retained significant bicycle infrastructure that is still used today (though this infrastructure is now shared with electric bicycles).

Figure 3.10 **Cycling mode share (% of all trips) in selected major cities from travel surveys**



(Figure 3.10 cont.)



* Beijing includes electric bicycle and pedelecs in its mode share calculation, Shanghai does not (and estimates that electric bicycle/pedelec mode share is 10%, for a combine bicycle and electric bicycle/pedelec mode share of 20%)

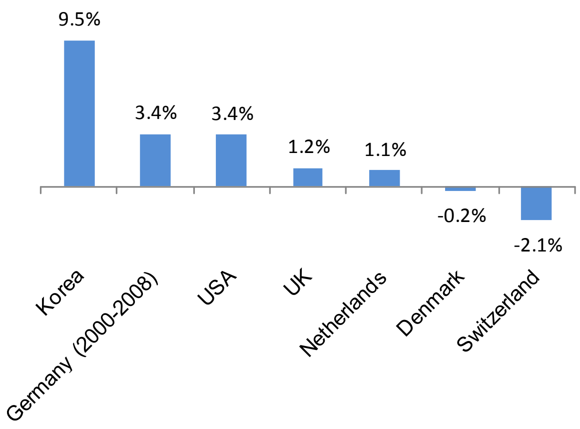
Sources: Beijing (Beijing Transport Yearbook, 2005), Shanghai (Shanghai Construction and Transport Commission, 2009), Singapore (Travel Survey 2011, Land Transport Authority), Taipei ("Analysis of Taiwan Transport Modes", MOTC, 2009), Indian Cities (Study on Traffic and Transportation Policies and Strategies in Urban Areas in India, Ministry of Urban Development, 2008), Europe (Various travel surveys as inventoried by EPOMM TEMs tool: http://www.epomm.eu/tems, accessed December 15, 2012), USA (CBSA Extract from the 2009 National Household Travel Survey)

Many "high-cycling" European cities have deployed a wide range of pro-cycling measures that have allowed them to retain and even expand the use of the bicycle in recent years – this is the case of Copenhagen, Amsterdam and several other Dutch and German cities. Other cities have sought to increase cycling, albeit from low numbers (such as London and Paris). The United States displays significantly lower cycling shares though the urban agglomerations selected here (Core Based Statistical Areas – CBSAs – from the 2009 National Household Travel Survey) may hide city-level cycling activity. For example, the Portland-Vancouver-Beaverton CBSA has a 1.5% bicycle mode share (all trips) whereas the City of Portland reports 5.8% bicycle use for work trips.

Trend in bicycle travel

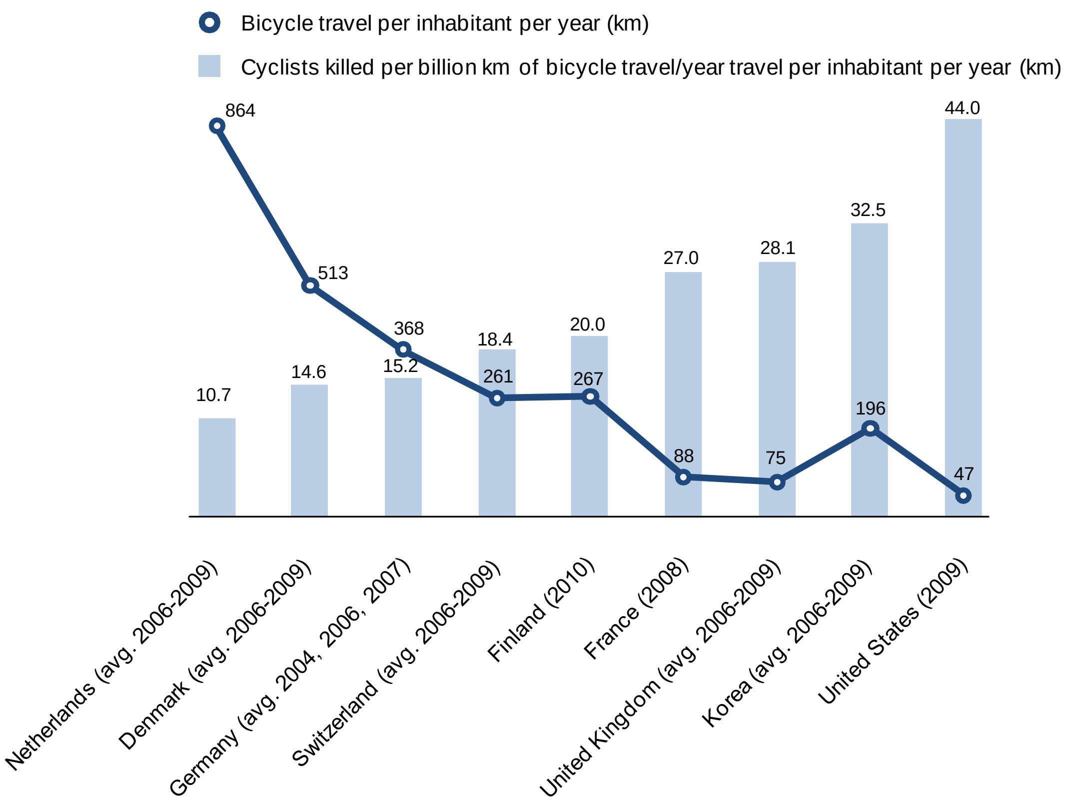
Data collected for this report indicate a slight but constant increase the number of kilometres travelled by inhabitant in many countries with the exception of Korea which reports stronger than average growth (Figure 3.11). The United States shares the same rate of growth as Germany despite much lower absolute distances travelled per inhabitant (368 km/inh./yr for Germany in 2008 and 47 km/inh./yr. in the USA). In countries displaying high volumes of bicycle travel (Netherlands and Denmark) there is a trend towards stabilisation while Switzerland reports a decline.

Figure 3.11 **Kilometres travelled by bicycle per capita: Average yearly rate of change 2000-2009**



Source: Questionnaire responses

Figure 3.12 **Bicycle travel per inhabitant per year (km) and number of cyclists killed per billion kilometres of bicycle travel (averages 2006-2009 or indicated years)**

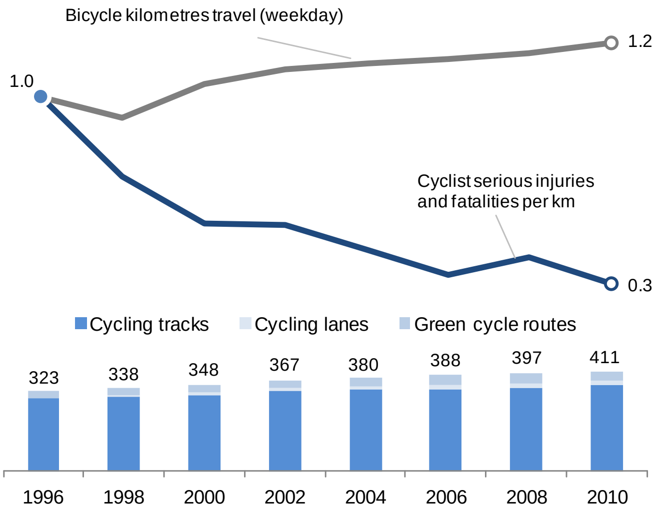


Source: Questionnaire responses

Figure 3.12 compares bicycle travel per inhabitant per year to the number of cyclist fatalities per billion kilometres of (bicycle) travel. It suggests that countries with relatively high levels of cycling per inhabitant register relatively lower fatal crash rates – an illustration of the "safety in numbers" phenomenon discussed in Section 1.2 though this figure does not resolve the uncertainty regarding either causality or directionality of the effect. Korea seems to not fit the pattern with a higher number of fatal cycling crashes than the amount of daily travel by bicycle would suggest. One possible explanation could be the rapid increase in cyclists numbers illustrated in Figure 3.11 – neither cyclists nor other transport participants have had time to assimilate each other's' presence in the traffic environment.

The evolution of fatal or severe injury crash risk *per kilometre of travel* can also be tracked in countries reporting bicycle travel volumes. In Denmark, the risk of death or serious injury to cyclists per kilometre of travel has dropped by about 40% over 10 years[8] (Figure 3.14). Bicycle travel has remained essentially stable over the same period. In the city of Copenhagen, bicycle travel has increased by 20% from 1996 to 2010 while at the same time police-reported fatalities and serious injuries have dropped by 70% (Figure 3.13). These findings are significant and, in the context of the expansion of well-designed bicycle facilities over the same period, indicate that targeted policies can simultaneously increase cycling and safety.

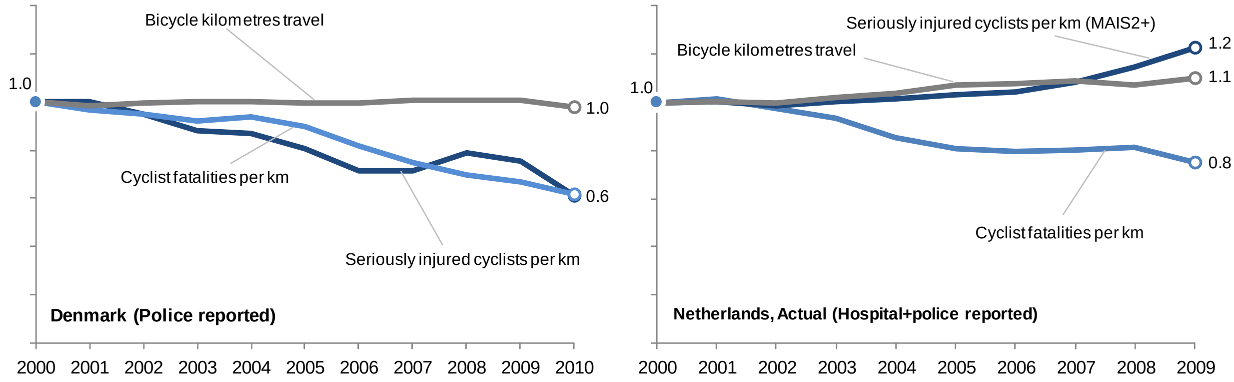
Figure 3.13 **Index of bicycle travel and per-kilometre cyclist casualties for Copenhagen (Police-reported, 1996-2010) and kilometres of cycling infrastructure.**



Source: City of Copenhagen

Nonetheless, such findings, especially for severe and slight injuries, may be somewhat tempered by crash under-reporting. In the Netherlands both the risk of death or serious injury per kilometre of bicycle travel has decreased by about 30% from 2000 to 2009 when looking at official police-reported statistics. However, combined *police and hospital* records paint a different picture with risk of death per kilometre of bicycle travel decreasing less (-20%) and, critically, risk of serious injury per kilometre of bicycle travel increasing by 20% from 2000 to 2009 (Figure 3.14).

Figure 3.14 **Index of bicycle travel, and per kilometre cyclist casualties (3-year rolling average) for Denmark (Police-reported, 2000-2010) and the Netherlands (Police and hospital reported2000-2009)**



Source: City of Copenhagen, SWOV Road Safety database

Bicycle ownership

Most countries report less than 1 bicycle per inhabitant, even those with high cycling use such as the Netherlands. This means that not all inhabitants have a bicycle (it should also be taken into account that some may have more than one bicycle). On average, the number of bicycles per inhabitant is higher in Germany than in the Netherlands, while in the latter country bicycle use is higher. This may indicate a high level of sports bicycle usage (less daily use) in the former and more utilitarian bicycle use in the latter.

3.5 Cycling infrastructure

This report adopts the following functional categorisation of cycling infrastructure (See Glossary at front of report for a break-down of these into sub-categories):

- Separate Linear Infrastructure;
- Mixed Linear Infrastructure;
- Point Infrastructure.

Countries were asked to indicate the presence of each of these types of cycling infrastructure on their territory and to indicate since when as a way of gauging the maturity of bicycle infrastructure networks. Nineteen respondents could indicate the presence of various bicycle facility types but only thirteen could give an estimate of their first implementation. Four countries (Australia, Japan, New Zealand and Portugal) did not provide information on either point. A related question asked for the length of the bicycle network by type of facility but too few countries provided data to allow for an adequate analysis of that aspect.

Respondents were asked to validate the analysis based on this input in order to avoid errors in recording and interpreting data.

Separate Linear Infrastructure in OECD/ITF member states

Table 3.3 gives an overview of the types of separate linear infrastructure implemented in eighteen respondent countries, as well as of the date of appearance (when available).

Table 3.3 **Presence of separate linear bicycle infrastructure (date implementation if known)**

	Cycle Track	Greenway	Cycle Lane	Combined cycle-pedestrian track
Austria	Yes (<1970)	Yes (<1970)	Yes (1990)	Yes (<1970)
Belgium	Yes (<1970)	Yes (2000)	Yes (<1970)	Yes (2004)
Canada	Yes	Yes	Yes	Yes
Czech Republic	Yes (1980)	Yes (2000)	Yes (2005)	Yes (1980)
Denmark	Yes (<1970)	Yes (<1970)	Yes (1980)	Yes (<1970)
France	Yes (<1970)	Yes (2004)	Yes (<1970)	**
Germany	Yes (<1970)	Yes (<1970)	Yes (1990)	Yes* (<1970)
Greece	Yes	Yes	Yes	Yes
Hungary	Yes (1975)	Yes (1990)	Yes (1997)	Yes (1984)
Israel	Yes	Yes	Yes	Yes
Italy	Yes (1970)	Yes (1990)	Yes (1990)	Yes (1990)
Korea	Yes (1990)	Yes (2000)	Yes (2000)	Yes (1990)
Netherlands	Yes (<1970)	Yes (<1970)	Yes (<1970)	No
Poland	Yes	Yes	Yes	Yes
Spain	Yes (2008)	Yes (1990)	Yes (2000)	Yes (2004)
Sweden	Yes (<1970)	Yes (<1970)	Yes (<1970)	Yes (<1970)
Switzerland	Yes	Yes	Yes	Yes
UK	Yes (<1970)	Yes (<1970)	Yes (<1970)	Yes (<1970)
United States	Yes	Yes	Yes	Yes

* Only for mixed cycle-pedestrian track

** Only for separated cycle-pedestrian track.

With the exception of combined cycle-pedestrian track in France (where it is a mixed cycle-pedestrian track) and the Netherlands, the four types of separate linear infrastructure are applied in all of the countries responding to the survey. The major reason for France not having any combined cycle-pedestrian tracks are the potential risks for incidents between cyclists and pedestrians, especially when they are partially sighted. Combined cycle-pedestrian tracks have never been seriously considered in the Netherlands, mostly because the high numbers of cyclists do not allow for such a combined use.

As for the date of first implementation, countries such as the Netherlands, Germany, Sweden, Austria, the United Kingdom, Denmark and Italy started constructing specific cycling infrastructure in the 1970s and before, as opposed to Spain and to a lesser extent also Korea[9].

When comparing the date of appearance of specific cycling infrastructure with the number of injury accidents involving at least one cyclist, we note a similar trend. Indeed, in the Netherlands, Sweden, Austria, United Kingdom and Denmark the number of such accidents is lower than average, whereas it significantly exceeds the average (and continues to grow) in Spain. We observe that the more separate linear cycling infrastructure that exists in a given country, the fewer recorded injury accidents involving at least one cyclist. The date of appearance of separate linear cycling infrastructure (and of course also its quality) seems therefore to be correlated to bicycle safety. There is some research evidence that, at least at the micro-level, road users (motorists and cyclists) adapt their behaviour over time in the presence of new cycling infrastructure leading to a clear and sustained reduction in conflict events and an increase in yielding events on the part of motorists (Phillips, et al. 2011). Whether or not this phenomena still holds at the level of regional or national cycle infrastructure networks is unclear and worth further exploring.

Mixed Linear Infrastructure OECD/ITF member states

Table 3.4 gives an overview of the types of mixed linear infrastructure applied in the eighteen respondent countries, as well as of the date of appearance (when available).

The situation is quite different among the responding countries with countries such as Belgium, the Netherlands, Germany, Canada and France implementing mixed cycling-car infrastructure, whereas this infrastructure does not appear in Greece, Israel, and Korea.

Table 3.4 **Presence of mixed linear bicycle infrastructure (date implementation if known)**

Country	Suggested cycle lane	Central traffic lane	Cycle street	Combined bus-cycle lane	Contra-flow cycling
Austria	No	Yes	No	Yes (<1970)	Yes (1990)
Belgium	Yes (2000)	Being tested	Yes (2012)	Yes (2006)	Yes (1991)
Canada	Yes	-	Yes	Yes	Yes
Czech Republic	No	-	No	Yes (2009)	Yes (2005)
Denmark	No		No	Yes (1980)	Yes (1980)
France	Yes (2000)	Being tested	Yes (2008)	Yes (2005)	Yes (1983)
Germany	Yes (2000)	Yes	Yes (2000)	Yes (1990)	Yes (2000)
Greece	No	-	No	No	No
Hungary	Yes (2010)	-	No	Yes (2001)	Yes (2001)
Israel	No	-	No	No	No
Italy	No	-	No	Yes (2000)	No
Korea	No	-	No	No	No
Netherlands	Yes (<1970)	Yes	Yes (2000)	No	Yes (<1970)
Poland	No	-	No	Yes	No
Spain	Yes (2000)	-*	No	Yes (2008)	Yes (2008)
Sweden	Yes (<1970)	-	No	Yes (<1970)	No
Switzerland	Yes	Yes	No	Yes	Yes
UK	Yes (<1970)	Yes	No	Yes (<1970)	Yes (1990)
United States	Yes	-	Yes	Yes	Yes

* No data collected on this type of infrastructure for all countries

Point infrastructure in OECD/ITF member states

Table 3.5 gives an overview of the types of point infrastructure that are applied in the eighteen respondent countries, as well as the date of their appearance (when available). With the exception of Austria, Greece, Israel and Korea, most of the respondent countries implement some or all types of point infrastructure. However, there does not seem to be one predominant type.

Generally speaking, point infrastructure has appeared more recently than linear infrastructure in all countries, except for Sweden, Denmark, the Netherlands and the United Kingdom. As for cyclist safety, there is no marked correlation between having point infrastructure or not and aggregate national-level accident data.

Table 3.5 **Presence of point bicycle infrastructure (date of first implementation if known)**

Country	Cyclist signals	Cycle box or advanced stop line
Austria	No	No
Belgium	Yes (<1970)	Yes (2000)
Canada	Yes	No
Czech Republic	Yes (1990)	Yes (2007)
Denmark	Yes (1980)	Yes (2007)
France	Yes (<1970)	Yes (1998)
Germany	Yes (1990)	Yes (1980)
Greece	No	No
Hungary	Yes (1975)	Yes (2001)
Israel	No	No
Italy	Yes (1980)	No
Korea	No	No
Netherlands	Yes (<1970)	Yes (1990)
Poland	Yes	No
Spain	Yes (2000)	Yes (2008)
Sweden	Yes (<1970)	Yes (<1970)
Switzerland	Yes	Yes
UK	Yes (1980)	Yes (1980)
United States	Yes	Yes

Two-way cycle tracks

In section 3.4, cycling infrastructure that may cause incidents between cyclists and pedestrians was examined. In addition, possible bi-directional cycling infrastructure that may cause incidents between cyclists had to be addressed. Although very few countries could provide data on that matter, a list of such types of cycling infrastructure could be drawn up.

Cycle Track or Separated Cycle Lane

In order to avoid incidents between cyclists and motorised vehicles at crossroads, this type of cycling infrastructure along roads is preferably one-way. By way of exception, they may be conceived as two-way tracks on no built-up roads in Belgium, Denmark, Canada, Japan, Italy, the Czech Republic, etc., principally to avoid too many detours and to make the bicycle network more direct and attractive. In some cases, road marking (broken line, directional arrow + bike logo, etc.) is used as a means of separation.

Greenway

Since this type of cycle track follows its own path, away from road networks, most countries (Belgium, Greece, Hungary, Germany, etc.) allow two-way cycle traffic. This is often indicated by means of road marking at the beginning and the end of a greenway section.

Combined cycle-pedestrian track

Some countries (Belgium, Hungary, Germany, etc.) allow two-way cycling traffic on the cycling part of combined cycle-pedestrian tracks. In that case, the cycling part must be clearly separated from the pedestrian part by means of special road marking (e.g. white line), different surfacing material or a physical separation.

Two-way cycling traffic is also possible on a cycle street or in case of contra-flow cycling. However, the separation is then provided by the vehicle lanes.

Key Messages

- While there is convergence in many countries towards common terminology and definitions for injury severity, important differences remain that may cloud cross-country analysis of trends – greater convergence along the lines of terminology defined by IRTAD would simplify safety analysis.

- Two thirds of the countries responding to our survey report fewer bicycle injury crashes in 2009 than in 2000 though relatively few countries show a deep and constant improvement. What is not clear is the extent to which these trends are linked to changes in the safety of cycling or changes in the volume of travel by bicycle. The role of under-reporting may also bias findings based on non-fatal crashes.

- Non-fatal crash under-reporting may hide the true scale of traffic injuries for cyclists and in some cases may even mislead authorities on the direction of traffic safety improvements for cyclists. Combining police-recorded and hospital data can better inform progress on bicycle safety.

- While most countries report a decrease in both injury and fatal bicycle crashes, in most countries the decrease of bicycle injury and fatal crashes is lower than the decrease in overall injury and fatal crashes. The safety performance of cycling continues to lag behind overall transport safety performance.

- On average, one out of 4 recorded bicycle injury crashes in responding categories was categorised as severe or fatal. This number is indicative of risk but is also fraught with uncertainty given data limitations and wide-spread and inconsistent under-recording of all bicycle crashes.

- The distribution of cyclist traffic fatalities by age group is quite similar for most countries and follows a u-shaped curve age with spike in victims under 15 years old and an even greater spike in fatalities among those 65 years and older. The latter represent a significant number of overall casualties warranting special attention in many countries.

- Countries and (even more so) cities display widely different cycling mode shares across the world. Cycling mode shares in many large Asian and medium-sized North European cities are above 10% of all trips whereas in many large European and North American cities, cycling mode shares are much lower. This is linked to income (in Asia) and to pro-active policies in northern Europe.

- Data collected for this report indicate a slight but constant increase the number of kilometres travelled by inhabitant in many countries with the exception of Korea which reports stronger than average growth. In high-cycling countries, the mode share for bicycles may be reaching a plateau.

- For countries reporting both bicycle travel per inhabitant and bicycle crash data, a clear relationship can be observed between higher levels of cycling and lower recorded fatal crash rates – “safety in numbers” is *observable* but no *causal* relationship can be ascertained from the data.

- Most countries have adopted and implemented most of the forms of linear bicycle facilities outlined in this report. Implementation of mixed bicycle/pedestrian infrastructure is less common as is implementation of various forms of point bicycle infrastructure which, in addition, has been implemented more recently in most countries. Data on density and network length for bicycle infrastructure was not ascertained.

Notes

1. ITF – Reporting on Serious Road Traffic Casualties – IRTAD – December 2011
2. No questionnaire data available for Australia, Czech Republic, Israel, Italy and Korea.
3. International Traffic Safety Data & Analysis Group (IRTAD), Road Safety 2009, Annual Report,pp237
4. EU Community Road Accident Database (CARE), covering EU member countries and associate states.
5. From 2003 onwards for Sweden
6. EU Community Road Accident Database (CARE), covering EU member countries and associate states, provides detailed incident-level crash information for 15 211 cyclist deaths (registered up to 30 days after the crash) and169 283 seriously injured cyclists (recorded up to 30 days after the crash)).
7. The noticeable jump in serious injuries reported by France is due to a change in reporting methodology. Up to 2004, crash victims hospitalised more than six days were considered seriously injured. In 2005, this threshold has shortened to 24 hours or more.
8. The risk of slight injury has fallen by about 60% over the same period.
9. Korea's expansion of bicycle infrastructure has been especially rapid. The country's bicycle infrastructure has grown from 120 kms in 1995 to 189 km of on road bicycle lanes, 1427 km of separated bicycle paths and 9770 km of mixed bicycle/pedestrian paths. (Wee, et al. 2012), (Shin 2011).

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4. Overview of bicycle crash characteristics in selected countries

This chapter presents detailed analysis of bicycle crash characteristics across a range of countries based on a detailed questionnaire and other sources of national information. It provides an up-to-date comparison of factors relating to bicycle crashes among responding countries and discusses the policy implications that emerge.

4.1 Introduction and methodology

The present chapter aims to present the characteristics of crashes involving bicycles in selected countries. An understanding of crash characteristics can assist with the design and targeting of policies and interventions to conditions in particular countries.

This chapter is based on several sources of information. The first is a detailed questionnaire sent to all Working Group members (See Annex A). Most questionnaire data was reported at the national level though some exceptions concerning Australia, France and Poland are noted in Annex A. We received more complete questionnaire data for the year range (2005-2009) than for the most recent year (2010). More complete data were available for fatal crashes than for injury crashes.

In addition to questionnaire responses, bicycle crash data from both the EU Community Road Accident Database (CARE) for EU member countries and associate states and from the US National Highway Traffic Safety Administration Fatality Analysis Reporting System (FARS) were used. Together, CARE and FARS provide detailed incident-level crash information for 20 888 cyclist traffic deaths[1] (15 211 in CARE and 5 677 in FARS) occurring in the years 2005-2010 in Europe and 2005-2011 in the USA.

US FARS data concerns only fatal crashes involving a motor vehicle travelling on a publicly open roadway and resulting in the death of a person (vehicle occupant or non-motorist). As such, FARS data does not report fatal bicycle crashes that do not involve a motor vehicle (bicycle-bicycle, bicycle-pedestrian or single bicycle crashes or falls) and therefore under-reports all bicycle crash deaths by an unknown, but likely small, margin.

CARE also provides incident-level details for 169 283 cyclists seriously injured (e.g. where victims were injured and hospitalised at least 24 hours) as a result of a road traffic crash. CARE data on seriously injured cyclists is not as reliable as data on cyclists' traffic deaths as there may be discrepancies among countries in recording "serious injuries" despite a harmonised definition within the CARE database. As such, data on seriously injured cyclists is not consistent and comparisons of one country's safety performance with another's' should be interpreted with caution.

Additional data sources included the United Kingdom's Road Accident and Safety database for incident-level details for fatal bicycle crashes in the UK as well as data from Australia's Bureau of Infrastructure, Transport and Regional Economics and from the Australian Transport Safety Bureau. We also received input from the Korean Transportation Safety Authority – this data is included in the discussion of the questionnaire results where appropriate. Detailed findings from crash microanalysis in Korea are presented in Box 4.2.

Our analysis is based on crash and victim numbers, because most countries do not have reliable exposure information with which to calculate rates. Population-based rates are not very useful, given the vastly different cycling participation levels and patterns in different countries, as discussed in Chapters 1 and 3. Because our main concern is to consider crash patterns, and to compare these across countries, in almost all cases we present our data in terms of the percentage of all cycle crashes or cycle crash victims represented by each level of each characteristic. In some cases we present bicycle crash data as a percentage of cycle crash victims to total traffic crash victims in order to highlight the relative share of cycle crashes for selected characteristic. This accounts to some extent for cycling exposure *per se.* It does not account for exposure to different levels of each characteristic, so that, for example, the greatest proportion of bicycle crashes occur during the day simply because more cycling occurs during the day. Nonetheless, for the purposes of designing and targeting policy and interventions, arguably what is important is that greatest proportion of bicycle crashes occur during a day (even if this is due to exposure).

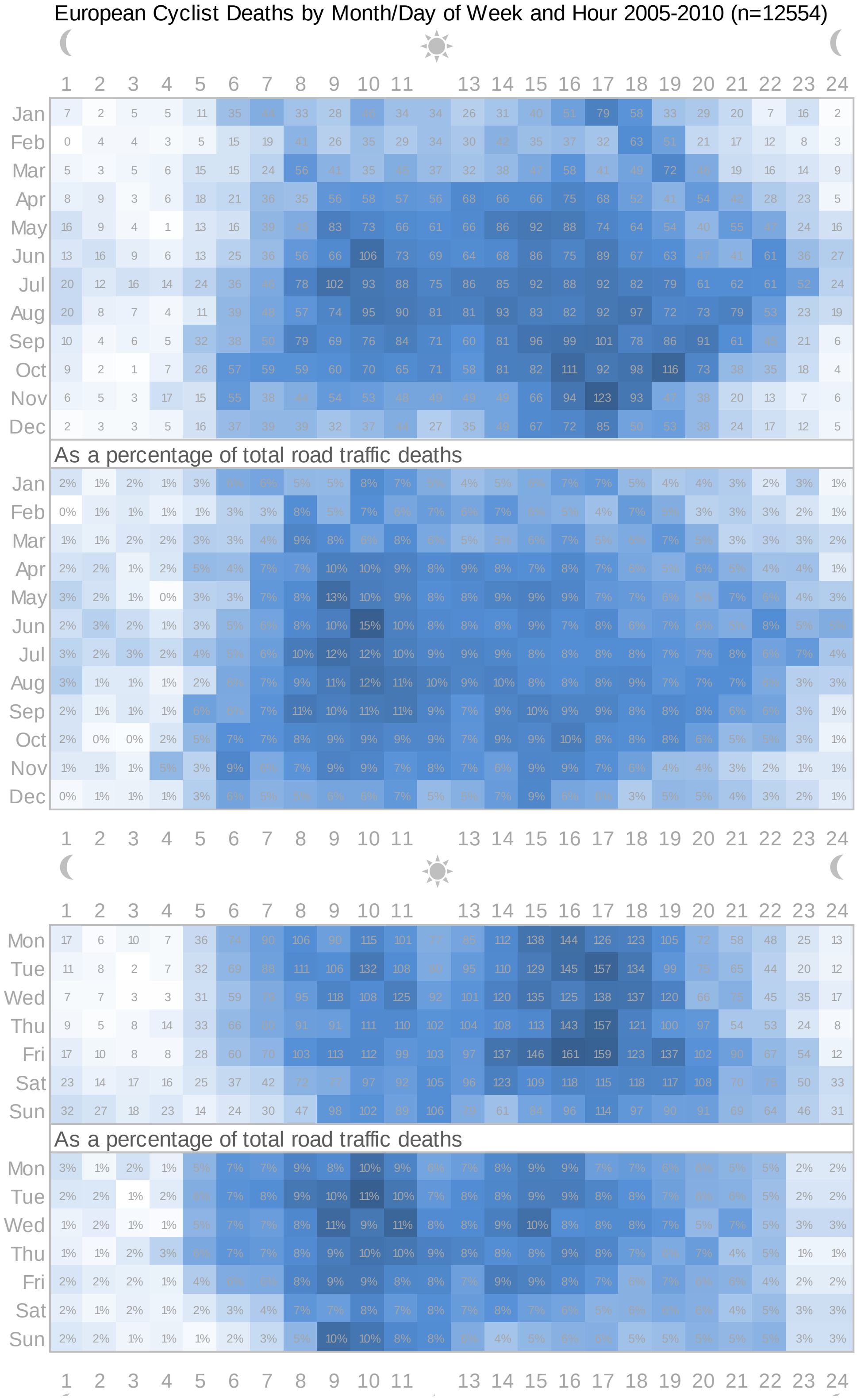
Crashes were police-reported for all respondent countries as well as for CARE and FARS data. As noted in Chapter 1, bicycle crash and injury under-reporting is the norm in many countries. Further, many crashes are not recorded either in police-reported or hospitalisation data. The likelihood of inclusion in official records increases with injury severity, and so the data can be considered to be most accurate for fatal crashes. For this reason, we treat fatal and serious injury crashes separately in sections 4.2 and 4.3.

4.2 Fatal crashes

When do fatal bicycle crashes occur?

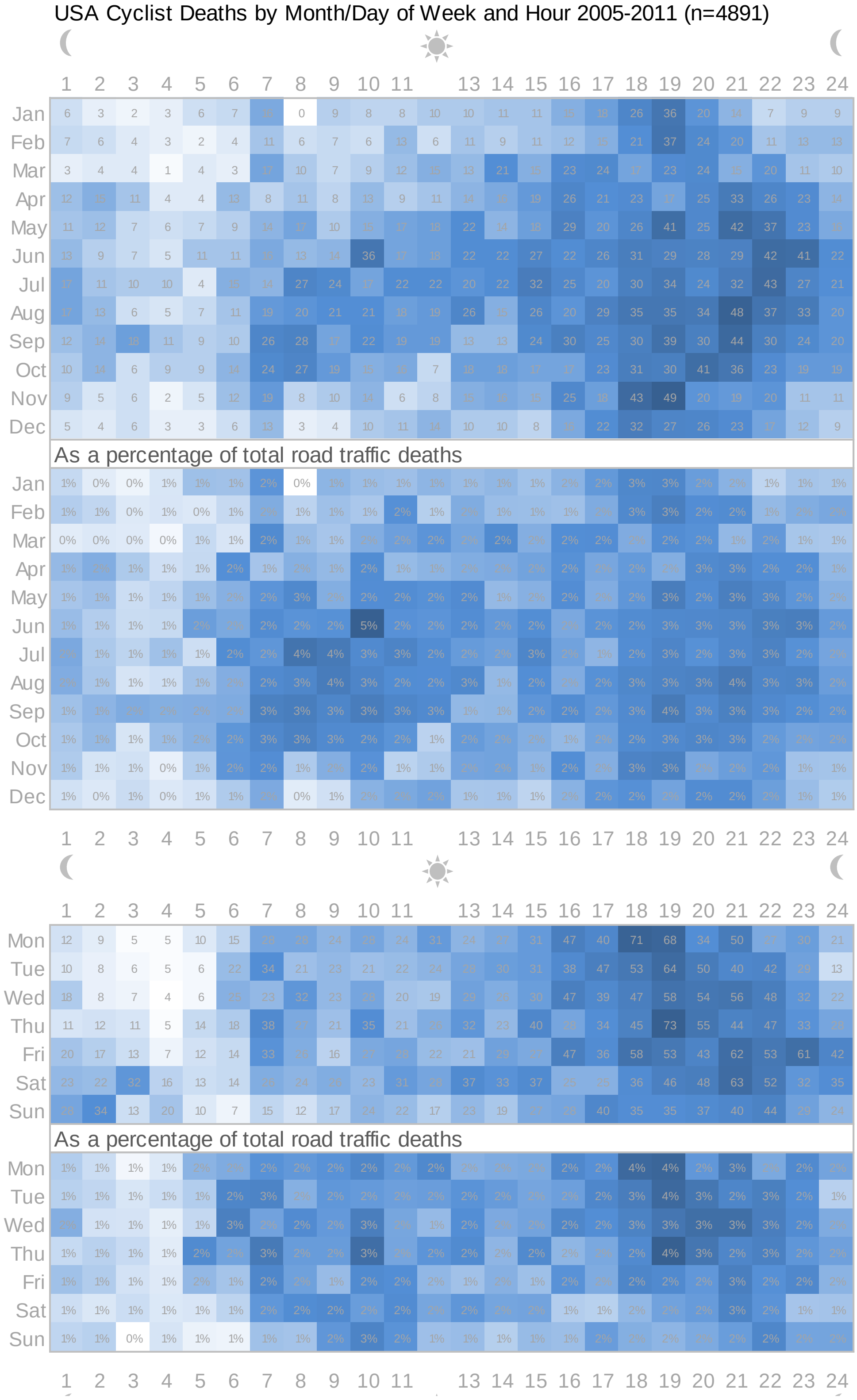
Figures 4.1 and 4.2 display a heatmap of monthly and weekly patterns of fatal bicycle crashes (in terms of actual number of fatal bicycle crashes) in Europe and the United States over the most recent five to six years. Several things stand out from the figures and the underlying data.

Figure 4.1 **Cyclist traffic fatalities by month or day of week and by time of day, EU, 2005-2010**



Source: available reports in EU CARE database for EU27 countries, Norway and Switzerland

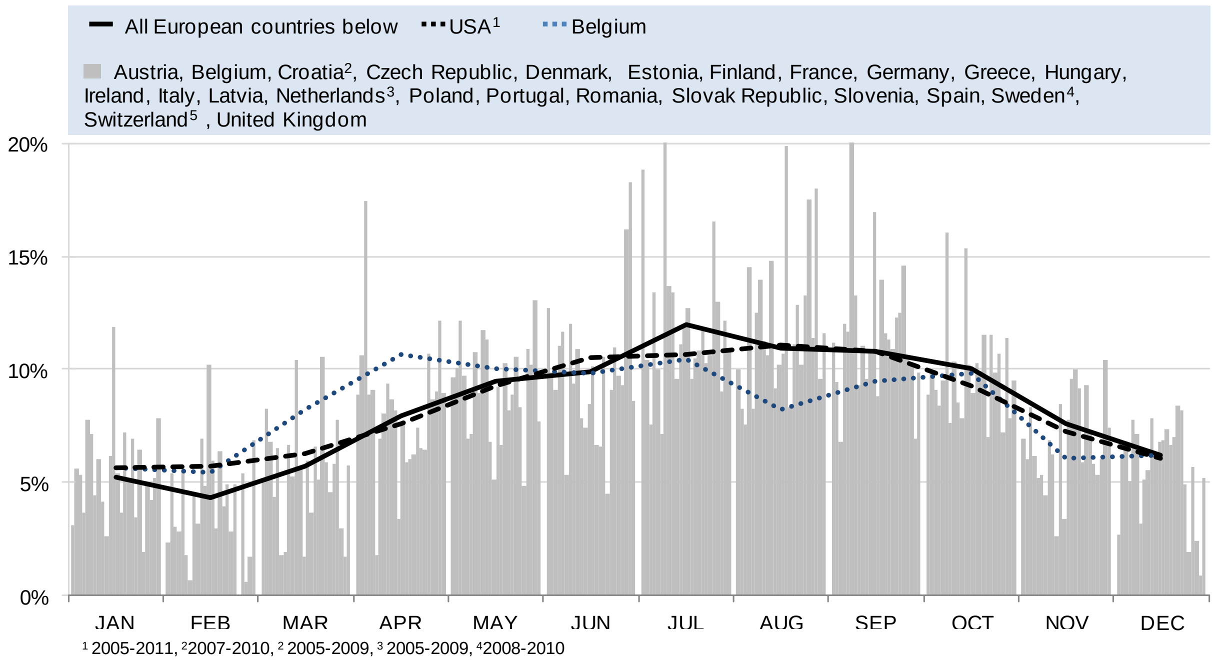
Figure 4.2 **Cyclist traffic fatalities by month or day of week and by time of day, USA, 2005-2011**



Source: FARS database

The first is that fatal bicycle crashes occur more frequently outside of wintertime in both Europe and the USA. The six months from May to October account for 62% of all bicycle crash fatalities in Europe (2005-2010, CARE) as well as in the USA (2005-2011, FARS). In the latter case, the seasonal demarcation seems less strong but this may also be due to the smaller sample size. Looking only at the distribution of fatal crashes per month by country (Figure 4.3), we see that the pattern is quite similar for the USA and Europe though individual countries (represented by grey bars) display great variations. Because Figure 4.3 reports percentages and not absolute numbers, some of the variations may be due to small sample size in a few countries. However, some countries, especially those with relatively high levels of utilitarian cycling, show a drop-off in fatalities during the summer months which is contrary to the pattern found in aggregate European fatal bicycle crash data (e.g. the case of Belgium in Figure 4.3). This may be due to a drop in overall levels of cycling during the summer holidays in those countries. Questionnaire responses confirmed that the lowest percentage of fatal crashes occurs during winter in every respondent country and, conversely, the greatest percentage of fatal crashes occurs during summer in every respondent country, with the exception of Australia, where it is in autumn, and Belgium, where it is in spring (seen in Figure 4.3).

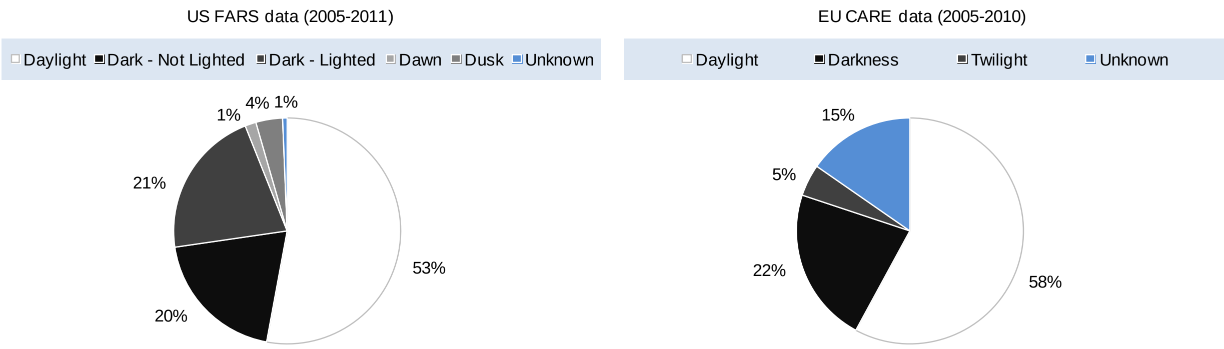
Figure 4.3 **Percentage of all reported fatal bicycle crashes occurring by month, selected European countries.**



Source: EU CARE database, 2005-2010 and USA FARS database 2005-2011

Figures 4.1 and 4.2 reveal an especially prominent pattern of fatal crashes that seem related to dusk and early nightfall for both Europe and the USA. This pattern is visible as a right-facing arrow composed of local maxima in the early evening that evolves over the year according to the length of the day. A reasonable assumption may be that these crashes are at least partially linked to the lack of visibility of cyclists, especially in the early evening hours. Looking at light conditions at the time of fatal crashes (Figure 4.4) we see that while most crashes occur in daylight (when there is likely to be more cycling) a significant share occur in unlit or low light conditions – especially in the USA where these crashes account for nearly half of all fatal crashes. The corresponding share for European countries may be understated as there are a number of fatal crashes for which lighting conditions were not recorded. Certain European countries report a greater share of fatal crashes in darkness and twilight than during daylight (for crashes where this variable was recorded) – e.g. Croatia (52%), the Czech Republic (66%), Ireland (81%) and the United Kingdom (62%).

Figure 4.4 **Cyclist traffic fatalities by light conditions in Europe and the USA**



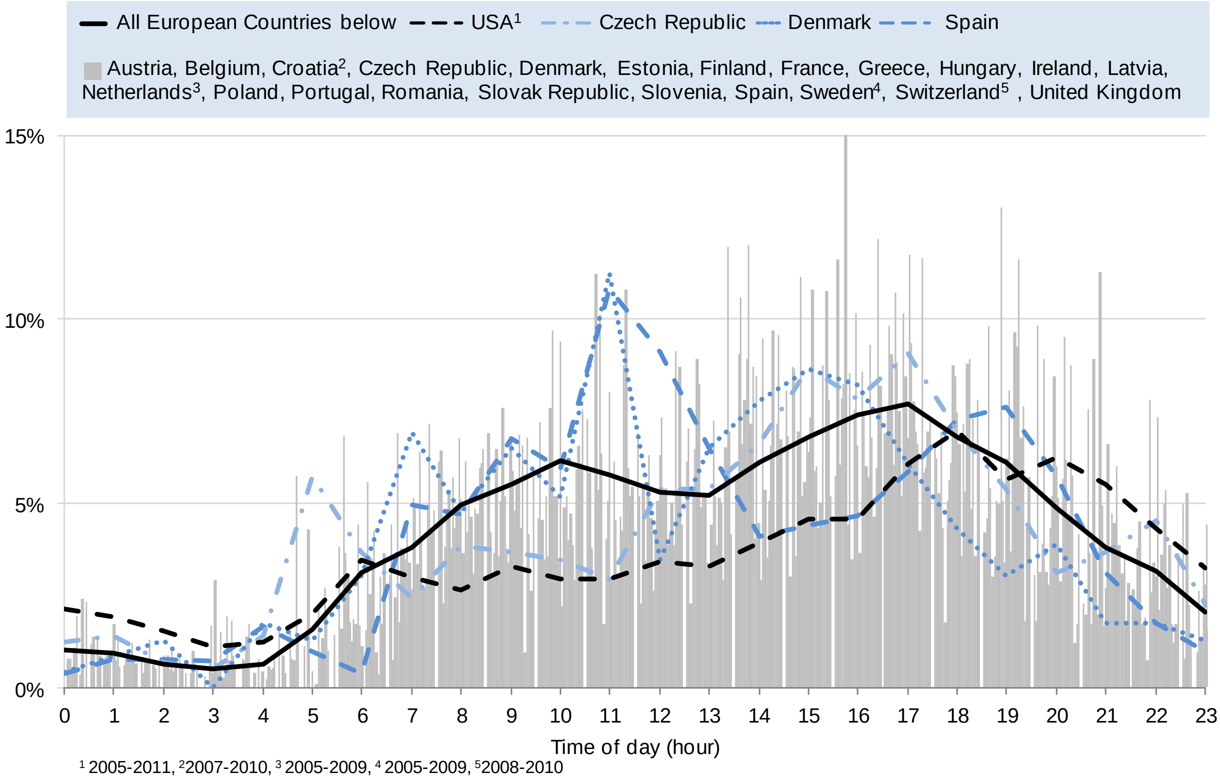
Source: EU CARE database and USA FARS database

A third pattern emerging in Figures 4.1 and 4.2 concerns a clustering of fatal bicycle crashes in the morning and evening. The four hours from 16:00 to 20:00 account for 25% of all fatal bicycle crashes in Europe (2005-2010 CARE) and 27% of all fatal bicycle crashes in the USA (2005-2011 FARS). This pattern seems to be less impacted by season and month of year (and therefore lighting conditions likely play less of a role for these) and seems to occur slightly later in the USA. The distribution of fatal crashes by hour of the day (Figure 4.5) confirms this pattern and the later peak in fatal crashes that occurs in the USA.

A smaller cluster of fatal crashes occurs in the morning. This pattern is more muted in the USA than in Europe where a visible cluster of crashes can be discerned from approximately 08:00-11:00, June-August and Monday-Thursday in Figure 4.2. The period from 06:00 to 11:00 accounts for 26% of all fatal bicycle crashes in Europe (2005-2010 CARE) and 18% of all fatal bicycle crashes in the USA (2005-2011 FARS). Looking at specific European countries reveals a range of patterns that gravitate around the average pattern seen in Figure 4.5.

In the Czech Republic (and the UK, not shown) there is a local peak in the overall percentage of fatalities around 22:00 (Figure 4.5). Spain and Denmark each register a slightly later and higher morning peak (around 11:00) and Spain's (and Romania's, not shown) evening peak is later than average at around 19:00. In some countries, such as Denmark and Australia (as reported in Australia's questionnaire response), the morning peak in fatalities is larger than the afternoon/evening peak. Divergences from the general pattern described above may reflect different work and leisure patterns. Considering that a relatively low proportion of cycling is likely to occur at night, the percentage of fatal crashes that occur at night is fairly high in several countries.

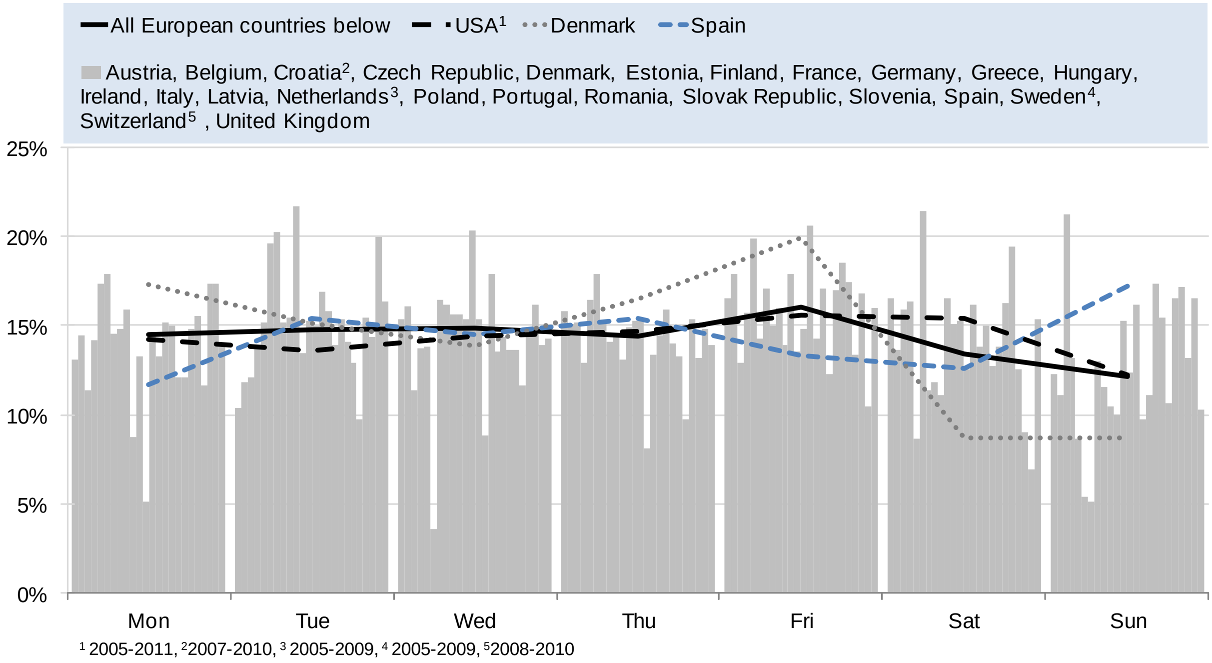
Figure 4.5 **Percentage of all reported fatal bicycle crashes occurring by time of day, 2005-2010**



Source: EU CARE database

The fourth pattern emerging from figures 4.1 and 4.2 concerns the distribution of crashes according to the day of the week. Fatal bicycle crashes in Europe and the USA are more frequent during weekdays (evenings in particular) and seem to drop off slightly on Saturday and even more so on Sunday. Friday accounts for the highest percentage of bicycle fatalities by day of week in both Europe (2005-2010 CARE) and the USA (2005-2011 FARS) – 16% in both instances. The drop-off on Saturday seems more muted in the USA (as confirmed when looking at the distribution of crashes by day of week in Figure 4.6). Australia's questionnaire response, however, reveals a different pattern with fatal crashes appearing most likely on the weekend, with Saturday and Sunday showing an elevated percentage of fatal crashes compared to the weekdays. Both the USA and Europe register a mid-week lull in fatal crashes, though earlier for the former (Tuesday) and later for the latter (Thursday -- Figure 4.6). Denmark's distribution of fatal crashes is loosely representative of the patterns found in many of the countries studied. In Europe, a local maxima can be seen around 08:00 to 11:00 on Sunday mornings in Figure 4.1 – a pattern likely linked to recreational cycling as Sunday mornings is a traditional recreational cycling day in many European countries. Spain's distribution of fatal bicycle crashes illustrated in Figure 4.6 reflects this phenomenon.

Figure 4.6 **Percentage of all reported fatal bicycle crashes occurring by day of week, 2005-2010**



Source: EU CARE database

Figures 4.1 and 4.2 also display bicycle crash fatalities as a percentage of total traffic crash fatalities according to month/day of week and hour. While these figures generally reflect the patterns described above they also display some notable differences. The first is that the share of bicycle fatalities to overall traffic fatalities is highest in the morning in the late spring and summer (extending to the early fall in the USA). Year-round, the highest share of bicycle to all traffic fatalities occurs in the weekday morning peak in Europe whereas in the USA it is in the weekday afternoon/evening peak. The impact of dusk is distinctly visible in Europe as this period consistently accounts for a high share of bicycle-to-overall fatalities throughout the year. The recreational cycling effect described previously is also visible in Europe on Sunday mornings. In the USA, it also becomes visible on both Saturday (a traditional recreational riding day in North America) as well as on Sunday morning.

What role do surface and atmospheric conditions play in fatal crashes?

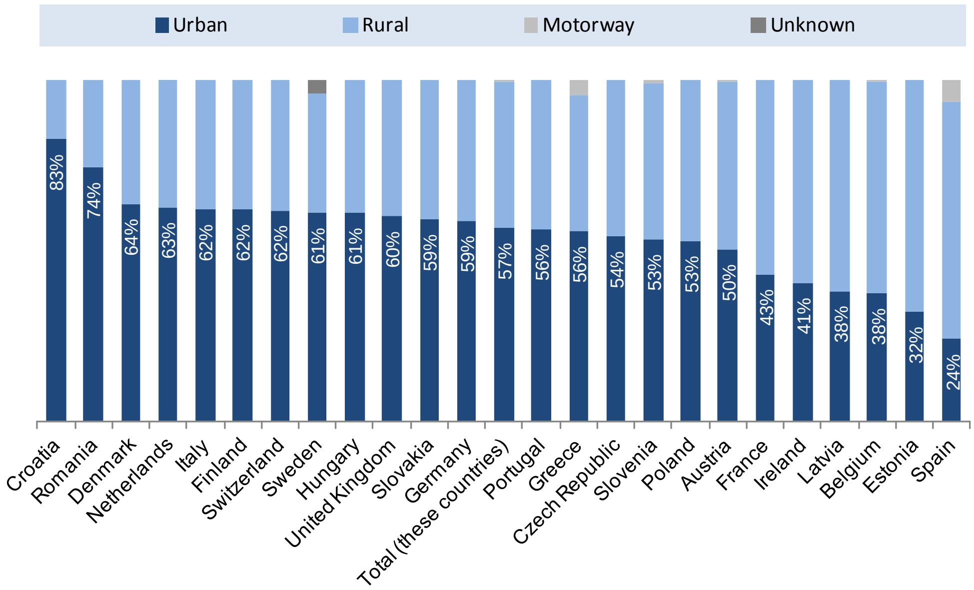
Although wet or icy surface conditions may present a crash risk due to a loss of traction, most fatal crashes occur in dry surface conditions -- most likely because this is when most cycling occurs. CARE data for all reporting EU countries indicates that 82% of fatal bicycle crashes occurred on dry surfaces, 15% on wet or damp surfaces and 1% respectively on slippery and frozen surfaces. Similarly, an overwhelming majority of fatal bicycle crashes occur in dry or clear atmospheric conditions – 94% in the USA and 87% in Europe. Rain is the next most frequent atmospheric condition at the time of a fatal bicycle crash occurring in the case of 5% of all fatal bicycle crashes in the USA and in Europe. Other atmospheric conditions including high wind, fog and snow and sleet occur in 1% or less each of total fatal bicycle crashes although in some countries, this percentage may be higher reflecting local climate patterns. For example, snow, sleet and/or hail account for 4% and 2% of fatal bicycle crashes in Finland and Latvia, respectively.

Where do fatal crashes occur?

Crash location

Figure 4.7 shows the percentage of fatal bicycle crashes occurring in metropolitan versus non-metropolitan in European countries according to CARE data. In addition, Australia and the USA report in their questionnaire responses that 50% and 69%, respectively, of all police-reported fatal crashes occurred in metropolitan areas. In most European countries (21 out of 27), fatal bicycle crashes were as, or more, common in metropolitan areas than in other locations. In 6 countries, fatal crashes were more common in rural areas or on non-metropolitan motorways. One possible reason for this is a high rate of leisure/sport cycling in some of these countries (Spain, France) or because of inter-urban cycling in a relatively dense urban-rural landscape (Belgium).

Figure 4.7 **Percentage of all police-reported fatal bicycle crashes occurring in urban vs. rural areas and motorways, EU**

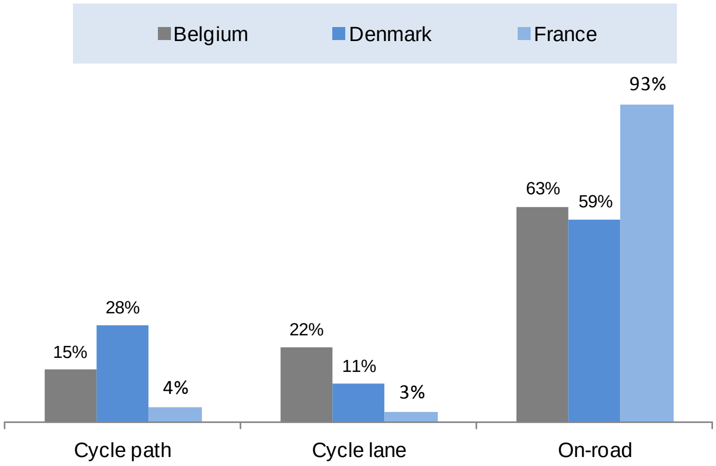


*Croatia(2007-2010), Netherlands (2005-2009), Sweden (2005-2009), Switzerland (2008-2010)

Source: EU CARE database (selected EU countries), 2005-2010*

The CARE database does not specifically account for cycling infrastructure but the working group questionnaire elicited several responses on this topic. In countries that returned questionnaire data on the type of infrastructure where fatal crashes occur (Belgium, Denmark, and France), such crashes were less common on infrastructure specifically designed for bicycles than on roads not marked with bicycle lanes. Arguably, more cycling occurs on cycling-specific infrastructure than on roads in Belgium and Denmark, though perhaps not in France (Figure 4.8). The US FARS database does account for cycling infrastructure for the years 2010 and 2011 (bicycle lanes and greenways) and reports that 2% of all fatal crashes occurred on these infrastructures. This relatively low share in the USA is likely more a testament to the relatively low prevalence of this type of infrastructure than to its safety *per se*.

Figure 4.8 **Percentage of all police-reported fatal bicycle crashes occurring on different types of infrastructure in Belgium and Denmark**



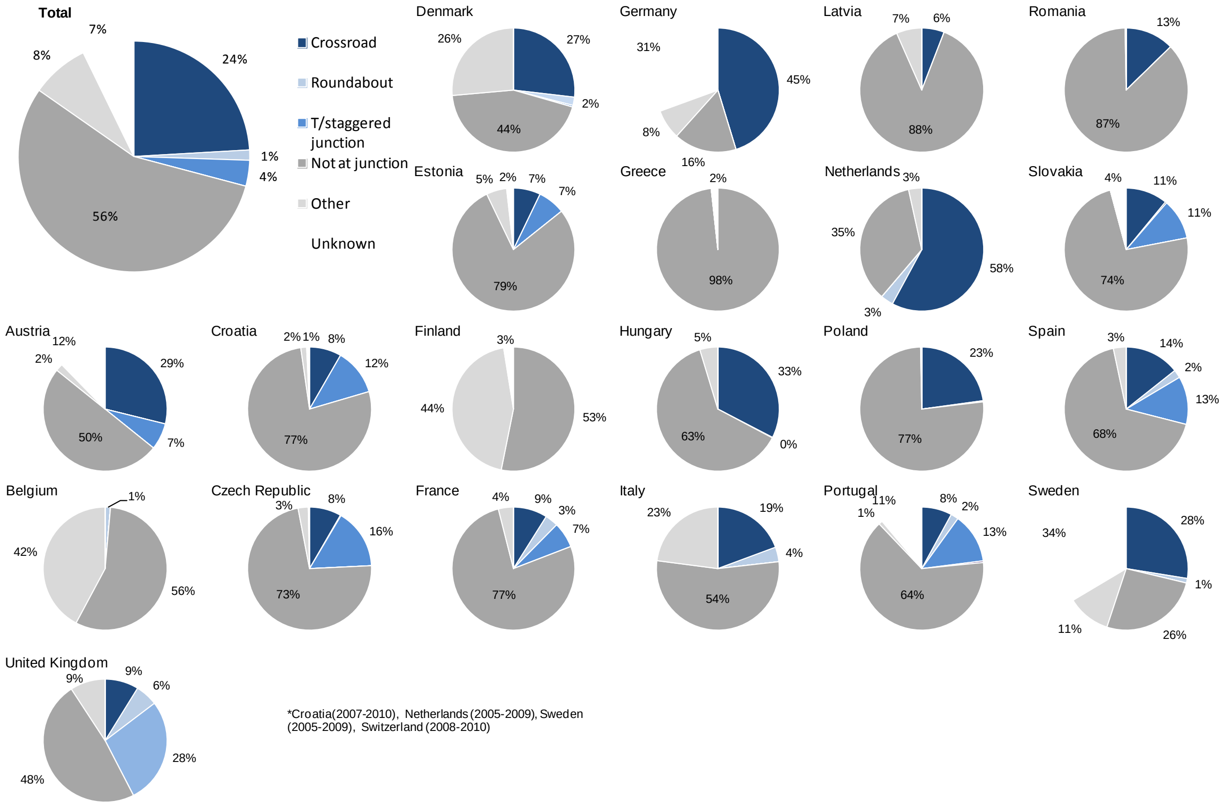
Source: Questionnaire responses

Configuration of infrastructure

For European countries reporting location data to the CARE database, 29% of all fatal bicycle crashes occurred at junctions for the period 2005-2010 though some countries report much lower shares (Figure 4.9). It is difficult to say without further investigation whether extremely low shares of fatal crashes occurring at junctions in some countries (e.g. Greece, Romania, Latvia) reflect reality or are due to mis-reporting or mis-characterisation of crash locations[2]. In Korea, 35% of fatal bicycle crashes occurred in or near a junction and a further 8% occurred in crosswalks (and a further 50% of fatal crashes occurred on the road outside of junctions/crosswalks). In the United States, 36% of all fatal bicycle crashes for the period 2005-2011 occurred in junctions with another 4% in driveways (commercial and private) most likely caused by entering or exiting motor vehicles. Australia reported that only 20% of fatal crashes occurred at junctions which is a relatively low share.

Of fatal bicycle crashes occurring in junctions, most concerned 4-way crossroads in the USA (64% of all junction-related fatal crashes in 2010-2011) and crossroads in Europe (83% of all junction-related fatal crashes, 2005-2010). Roundabouts and traffic circles represented a fairly low share of overall junction-related bicycle crash fatalities (5% in European countries reporting this data and less than 1% in the USA, 2010-2011). Nonetheless, in Ireland, the United Kingdom, Italy and France roundabouts account for a considerably higher share of fatal junction-related bicycle crashes – 10%, 14%, 17% and 18%, respectively for the period 2005-2010. It is not clear whether these elevated percentages reflect increased crash risk in such junctions, or simply the greater number of such junctions, in the countries concerned … or both. Belgium reports an unusually high share of “other” crash locations and an unusually low share of junction-related serious injury crashes – it seems likely that many of the latter are recorded in the former.

Figure 4.9 **Percentage of all police-reported fatal bicycle crashes occurring at different junction locations, EU**



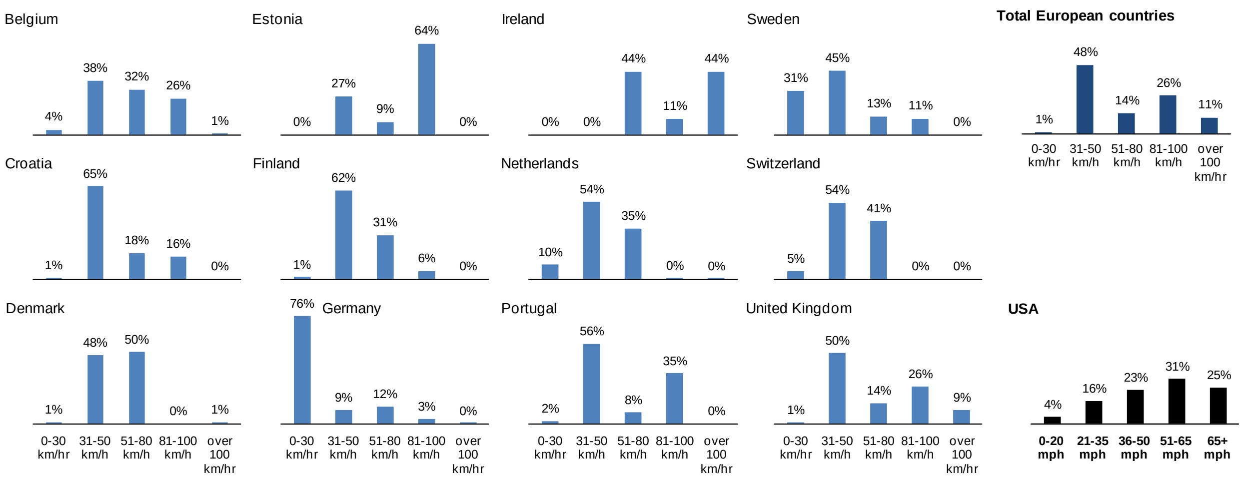
Source: EU Care database, 2005-2010*

Speed limit

Both CARE and FARS databases include data on legal speed limits for the roads on which fatal bicycle crashes occur (Figure 4.10). Approximately half of all fatal police-reported crashes in European countries reporting speed limit data occurred on roads with legal speed limits between 30 to 50 km/hr and about one quarter of all reported fatal crashes occur on roads whose legal speed limit is between 80 and 100 km/hr. The former may account for a large volume of cycling (and thus crashes) while the latter represents roads whose legal speeds greatly increase the probability of fatal outcomes for bicycle-motor vehicle crashes. There is some variability amongst countries with Estonia reporting a disproportionate share of fatal crashes occurring on roads whose legal speed limits are between 80 and 100 km/hr and Germany reporting a disproportionate share of fatal crashes occurring on roads whose legal speed is 30km/hr or less.

US FARS data on legal speed limits for roads where fatal bicycle crashes have occurred is also shown in Figure 4.9. FARS data are reported in miles per hour and are displayed in the figure below in speed bands that are roughly analogous to those used to display CARE data. The USA shows a different pattern than Europe with more than 50% of all fatal bicycle crashes occurring on roads whose speed limit is above 50 miles per hour (80 km/hr) and an additional 23% on roads whose posted speed limit is between 35 and 60 miles per hour (56 and 80 km/hr). Australia reported a relatively even distribution of fatal bicycle crashes in the 40-50 km/hr (25%), 60 km/hr (26%), 70-80 km/hr (23%) and the 100+ km/hr (24%) – the 90 km/hr speed zone only accounted for 2% of fatal crashes.

Figure 4.10 **Percentage of all police-reported fatal bicycle crashes according to the legal speed limit of the main road involved in EU and USA**

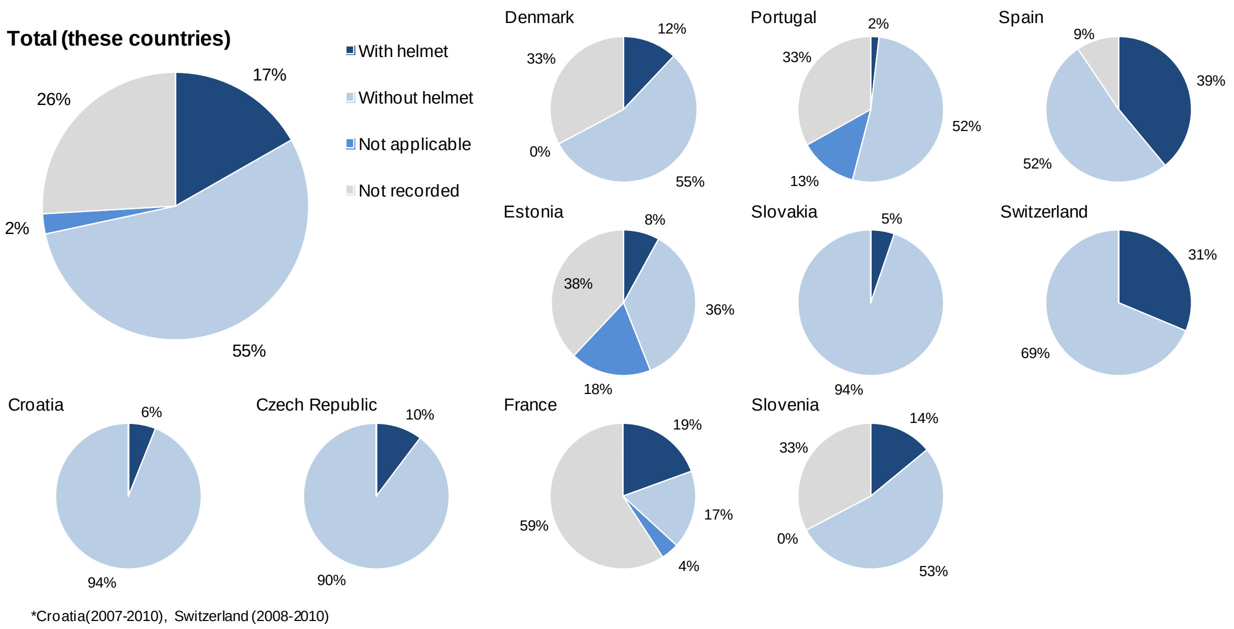


Source: EU CARE database 2005-2010*(Selected countries) and USA FARS database 2005-2009

Use of bicycle helmets

Few countries report the use of bicycle helmets in fatal bicycle crashes. According to the CARE database (for countries reporting this data), only 17% of fatal crashes involved a cyclist wearing a helmet (Figure 4.11). Spain and Switzerland report the highest rate of helmet use for deceased cyclists (39% and 31%, respectively) whereas several other countries report quite low helmet use probably reflecting lower helmet-wearing rates in these countries. Even for those countries reporting on helmet use in the CARE database, helmet use was not recorded for a significant number of fatal crashes (e.g. Denmark, Estonia, France Portugal and Slovenia).

Figure 4.11 **Percentage of all police-reported fatal bicycle crashes occurring with or without helmets, EU**



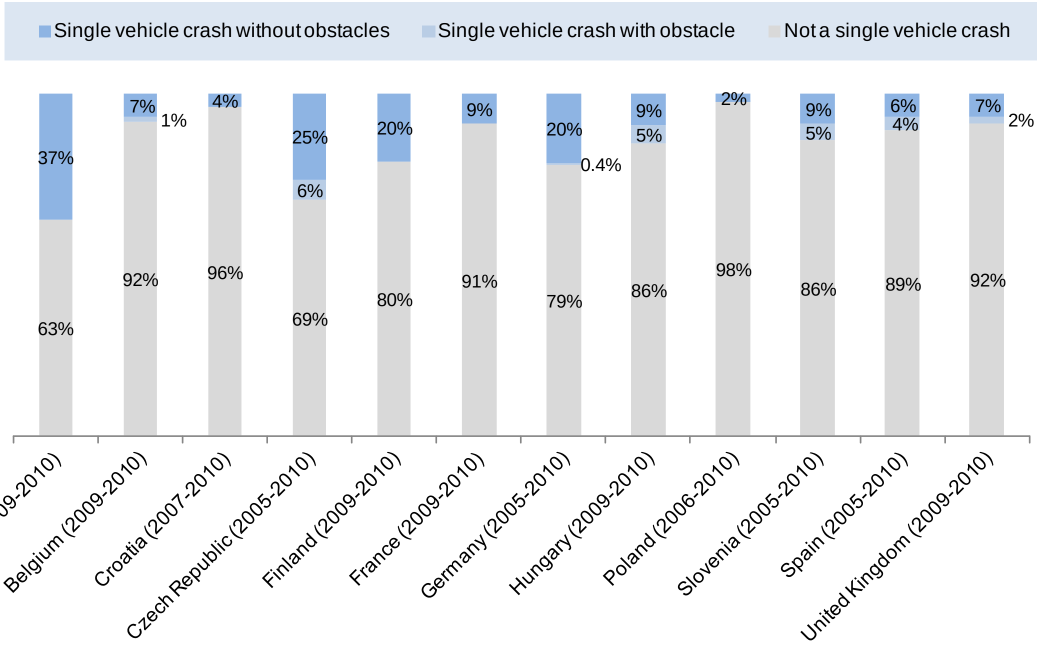
Source: EU CARE database, 2005-2010*

In the United States, 27% of deceased cyclists for which helmet use was recorded wore helmets in 2010 and 2011 (helmet use was not recorded for 14% of all fatal bicycle crashes over the same period). In Australia where helmet use is compulsory, amongst fatal bicycle crash victims for whom helmet use was recording, 63% were wearing helmets.

Crash type

According to questionnaire responses, over 80% of fatal crashes in each country for which data was reported were collisions rather than non-collisions. CARE data on fatal single vehicle collision crashes (e.g. falls or collisions with non-vehicle objects) in Europe confirms questionnaire responses indicating relatively low shares of such crashes with some countries even reporting no such fatal crashes between 2005 and 2009. Figure 4.12 shows the share of single vehicle to non-single vehicle fatal bicycle crashes for a selection of countries. In these countries, most fatal bicycle crashes are not *single vehicle* crashes. For the remainder, most crashes involving no other vehicle also involved no direct collision with an obstacle and therefore presumably resulted from a fall. In some countries, the proportion of fatal single vehicle crashes is relatively elevated as is the case in Austria, the Czech Republic, Finland and Germany. In Australia, single vehicle bicycle crashes accounted for 19% of all bicycle crash fatalities for the years 2005-2012. US FARS data only reports fatal bicycle crashes that result from a motor vehicle collision and thus do not include single vehicle bicycle crashes.

Figure 4.12 **Percentage of all police-reported fatal bicycle crashes occurring with or without a crash opponent, EU**



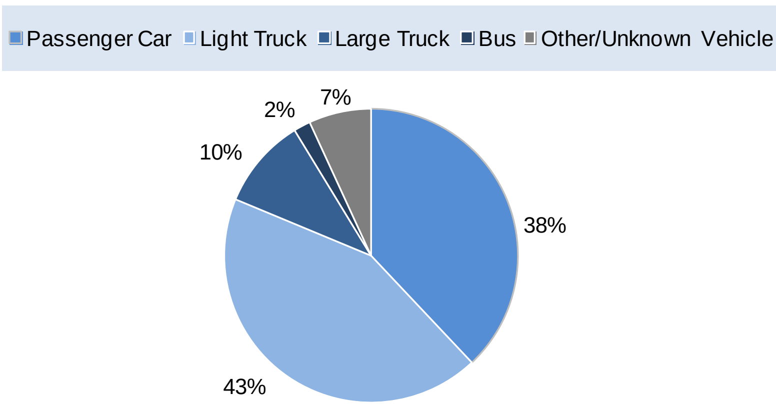
Source: EU CARE database, various year ranges

Collision opponent

Questionnaire responses showed that the vast majority of police-reported fatal collisions are with motor vehicles (e.g. 80-99% of all collision crashes) though in Spain this figure was lower (70%), due in part to a high number of fatal bicycle-train crashes.

In the United States, most fatal bicycle-vehicle collisions involved a passenger car or light truck (Sports Utility Vehicle) though 10% of fatal bicycle collisions involved a large truck (Figure 4.13). In Australia rigid or articulated trucks were involved in 20% of all bicycle crash fatalities for the years 2005-2012.

Figure 4.13 **Fatal bicycle crash victims by crash opponent, USA**



Source: USA FARS database, 2005-2011

Box 4.1 **Evidence and lessons from London on HGV and construction vehicle-related fatal bicycle crashes**

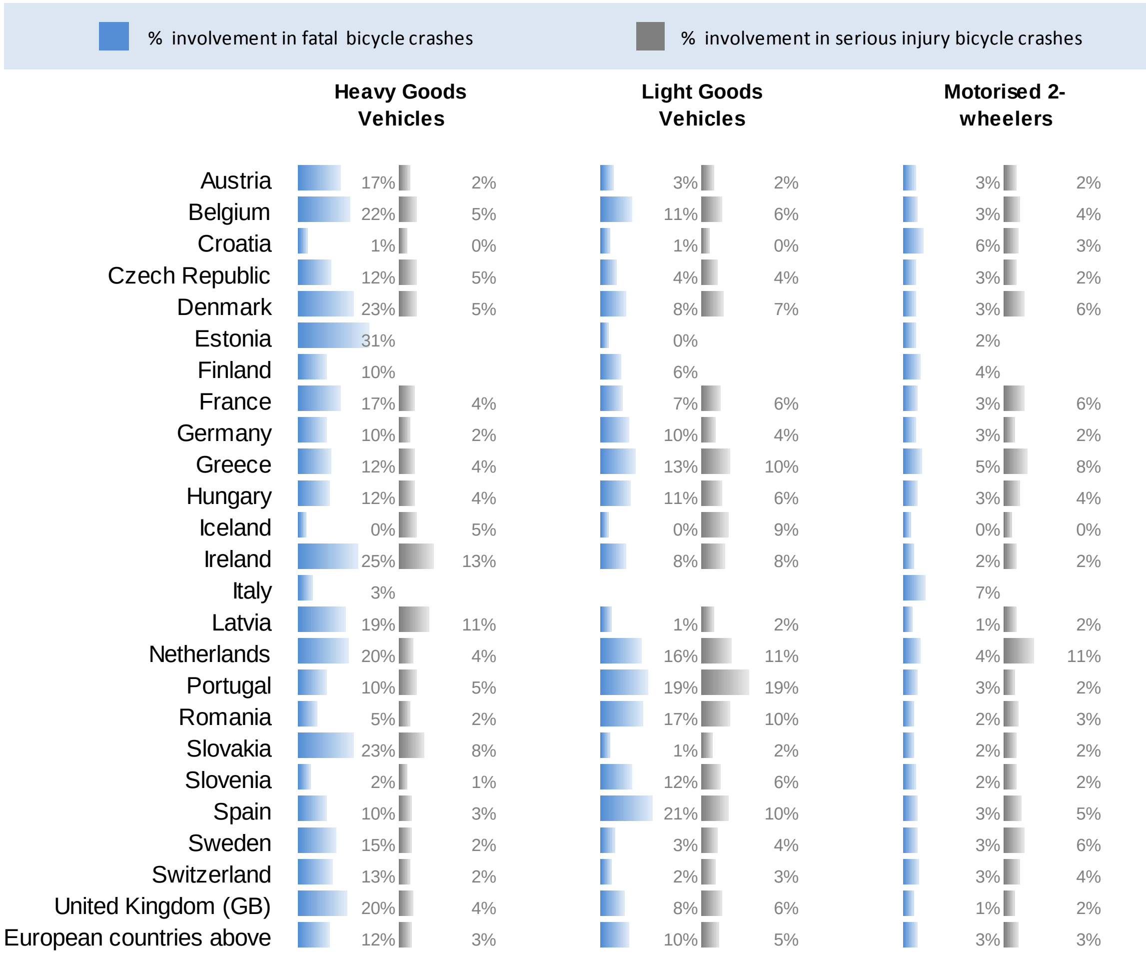
Cycle safety research has highlighted the over-proportional representation of Heavy goods vehicles (HGVs) (including construction-related vehicles) in fatal bicycle crashes in the greater London area. 38% of the 92 police-registered cyclist fatalities in London from 2000 to 2006 were struck by a HGV of over 7 tonnes and a quarter of these crashes involved nearside turns or lane-changing by the HGV. Concerned by this trend, Transport for London (TFL) commissioned a report (Delmonte, et al. 2013) to understand what factors were at play in HGV-cyclist crashes and to identify possible counter-measures.

That report found that *rigid* HGVs were disproportionately involved in fatal bicycle crashes. Rigid HGVs represent 75% of the HGV distance travelled in London and 27% of the tonne kilometers moved by road but account for 89% of fatal HGV-bicycle crashes. The differences between rigid and articulated HGVs are at least partially linked to their respective freight tasks, typical routes and types of journeys as well as to differences amongst the vehicles themselves. One of the key differences between articulated and rigid vehicles in London is that the latter are likely to be involved in servicing construction projects in the city and operate according to different patterns and constraints than typical goods delivery vehicles. Whereas the latter tend to operate habitual services in urban areas or involve drivers that operate exclusively in urban areas, construction-related HGVs serve multiple, constantly changing construction sites and involve drivers who are likely to do most of their driving outside of urban areas. Further, contractors and sub-contractors typically do not extend workplace safety processes to the transport task. These factors, combined with blindspot visibility constraints inherent in HGVs (especially to the front and nearside) that remain even after the installation of extended view mirrors, give rise to an inherently dangerous situation for cyclists (and pedestrians).

Recommended responses include efforts to promote road safety as an integral part of construction industry work safety initiatives and rules, raise awareness of HGV drivers as to the crash risk posed by near-side turning, investigating ways of further reducing HGV blindspots without increasing task complexity, easing time slot constraints for construction site delivery and establish safer construction site access routes that minimise conflicts with cyclists. This initiative is part of a broader effort by TFL to reduce the incidence of HGV-cyclist crashes and builds on other efforts of TFL which include a requirement that all contractors and sub-contractors carrying out TFL business meet TFL’s cycle safety requirements as of December 2012. These include an urban driving safety course for HGV drivers and the installation of side guards, fresnel lenses (or an equivalent side/front view system), class VI mirrors and close proximity warning sensors.

Sources: (Delmonte, et al. 2013), TFL

Figure 4.14 **Fatal bicycle crash victims by crash opponent (excluding passenger cars), EU**



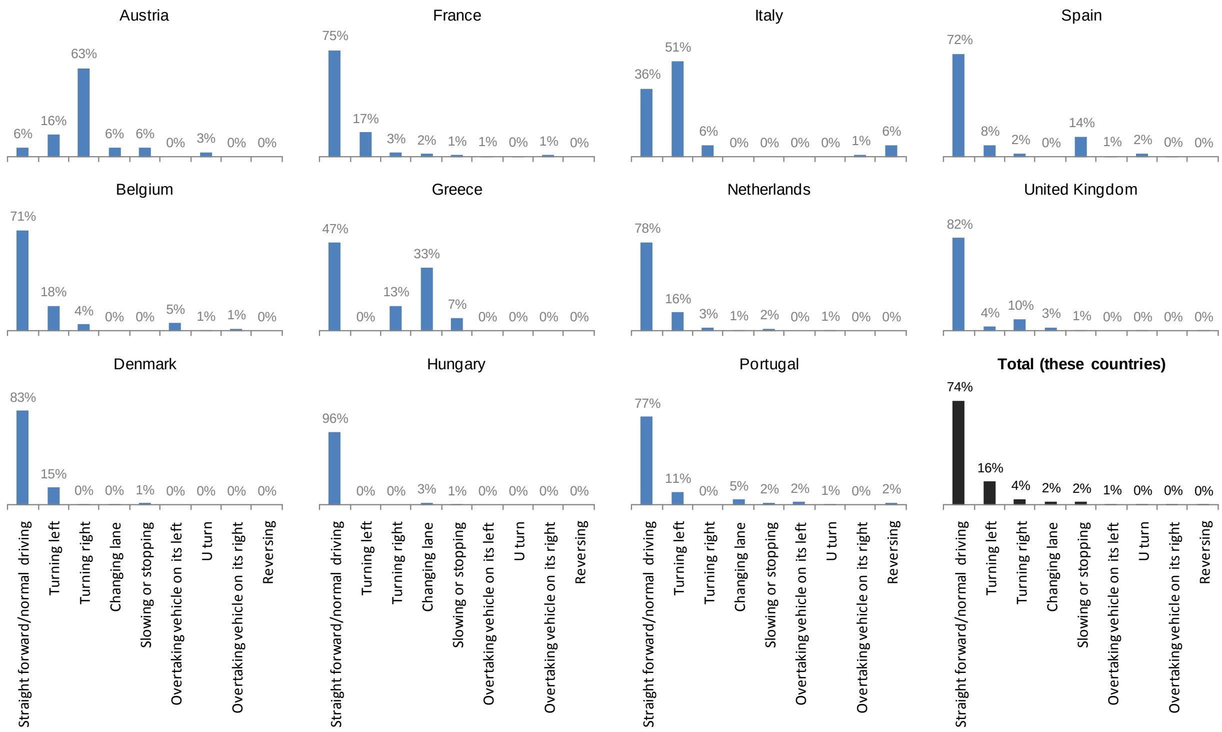
Source: EU CARE database, selected European countries, 2005-2010

Data from the CARE database confirms the significance of heavy goods vehicles (HGV) involvement in fatal bicycle crashes. HGVs were involved in 12% of all fatal bicycle crashes for European countries reporting this data[3] from 2005-2010 (Figure 4.14). For some countries, HGV involvement in fatal bicycle crashes was significantly higher, representing a quarter or more of all fatal bicycle crashes. In almost all countries, HGVs were over-represented in fatal versus serious injury crashes (HGVs were involved in 3% of all serious injury bicycle crashes compared to 12% for fatal injury crashes for European countries reporting this data) highlighting the disproportionate risk of death for cyclists involved in HGV collisions. Light goods vehicles (vans, delivery vehicles, etc.) were involved in a further 10% of all fatal bicycle crashes for countries reporting this data[4] and 5% of serious injury bicycle crashes. Motorised two-wheelers were the third most represented crash opponent involved in fatal bicycle crashes – though in some countries, their crash involvement was higher than that of HGVs (e.g. Italy).

Manoeuvre

The CARE database provides some data on cyclist manoeuvre at the time of a fatal bicycle crash for selected countries (Figure 4.15). This data should be treated with caution and cannot be said to be fully representative for the simple reason that for 55% of fatal crashes, the cyclist's manoeuvre was unknown (or not recorded) and for another 37% of all fatal crashes, the manoeuvre was categorised as "other".

Figure 4.15 **Manoeuvre by cyclist for fatal bicycle crashes where pre-crash manoeuvre was identified and recorded, EU**



Source: EU CARE database, selected countries, 2005-2010

Figure 4.15 shows the distribution of cyclist manoeuvres for those crashes where this data was recorded for countries that consistently have reported this data to the CARE database. In most countries, the deceased cyclist was engaged in straightforward or normal riding (74% of all identified cases on average for these countries). CARE data does not report whether fatal crashes that occurred when the cyclist was underway in a normal or straight manner were caused by a vehicle overtaking from behind. Notable exceptions to the straight-ahead riding majority include Austria where the most common pre-crash manoeuvre by the deceased cyclist was a nearside turn and Italy where, conversely, it was an offside turn. Greece reports a high share of cyclists was changing lanes when fatal crashes occurred.

US FARS data reports pre-crash manoeuvres by cyclists in fatal bicycle crashes for the years 2010 and 2011. According to this data, the two most common cyclist pre-fatal crash manoeuvres were moving along with traffic (38%) or crossing the roadway (34%) – the former includes nearside turns (with traffic) and the latter include offside turns across traffic. 8% of all fatal bicycle crashes involved a cyclist travelling against traffic, another 4% concerned cyclists travelling adjacent to the roadway or in a median area and 2% concerned cyclists travelling on a sidewalk. Unknown or unclassified manoeuvres only account for 6% of all fatal bicycle crashes for these two years in the FARS database.

Incident-level analysis of the United Kingdom's Road Accident and Safety database gives some insight into the combined manoeuvres of both bicycle and the collision opponent in fatal bicycle crashes. For crashes resulting in the death of a cyclist and in which only 2 vehicles were involved (the bicycle and one collision opponent -- 74% of all fatal bicycle crashes in the UK from 2005-2011) either the bicycle (69%) or the crash opponent (59%) was recorded as going ahead in neither an offside or nearside turn. However, in only 44% of all fatal bicycle crashes were both doing the same even though this crash configuration is by far the most common one recorded in the UK data. Approximately half of all fatal 2-vehicle bicycle collisions from 2005-2011 involved a bicycle being hit from behind or by a vehicle attempting to overtake the bicycle on either the street centre side or on the kerbside. A further 16% of all fatal bicycle crashes involved one of the two vehicles turning across the path of its straight-travelling crash opponent.

The above findings generally hold when looking at different types of bicycle crash opponents with the notable exception of very large trucks (over 7.5 tonnes) where only 33% of fatal crashes involved a truck travelling straight ahead and 39% of fatal crashes involved the truck turning into or across the path of a bicycle.

Questionnaire responses provided more detail as to cyclist manoeuvres in fatal bicycle crashes for a few countries. In Australia the most common type of crash in which cyclists were fatally injured was the cyclist being hit from behind by a motor vehicle travelling in the same lane in the same direction. The next most common crash type was the cyclist riding from the footway into a junction or onto a road and being hit by an oncoming motor vehicle (Australian Transport Safety Bureau, 2006).

In Belgium fatal collisions with motor vehicles most often occurred at a junction when the cycle and the motor vehicle were approaching from different streets (13%). The next most frequent manoeuvres were the cycle being hit by the motor vehicle from behind (11%), or being sideswiped during a turn (10%).

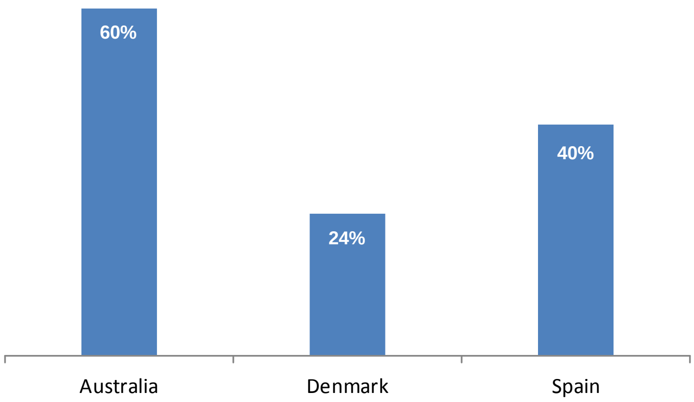
In Denmark, fatal collisions with motor vehicles most often occurred when the motor vehicle was turning nearside and sideswiped the cyclist who may also have been turning nearside or (in most cases) going straight ahead (19%), and at a junction when the cycle and the motor vehicle were approaching the same junction from different streets (19%). The next most frequent manoeuvre was where the cycle was hit by the motor vehicle from behind (13%).

In Korea 52% of fatal bicycle crashes were motor vehicle nearside angle collisions where a motor vehicle sideswiped a bicycle while turning to the nearside.

Contributing actions by cyclists or motorists

The working group questionnaire sought data on which traffic participant (cyclist or other) was deemed to be principally at fault in the crash-related police reports. According to questionnaire responses, cyclists were reported at fault in 60% of fatal crashes in Australia and 40% in Spain (see Figure 4.16). For this variable only, Spanish data were drawn from two provinces. In Denmark, cyclists did not have right of way in 24% of fatal crashes. These findings may reflect different right-of-way rules or practices in effect in different countries with Denmark having relatively more favourable right-of-way rules than either Australia or Spain.

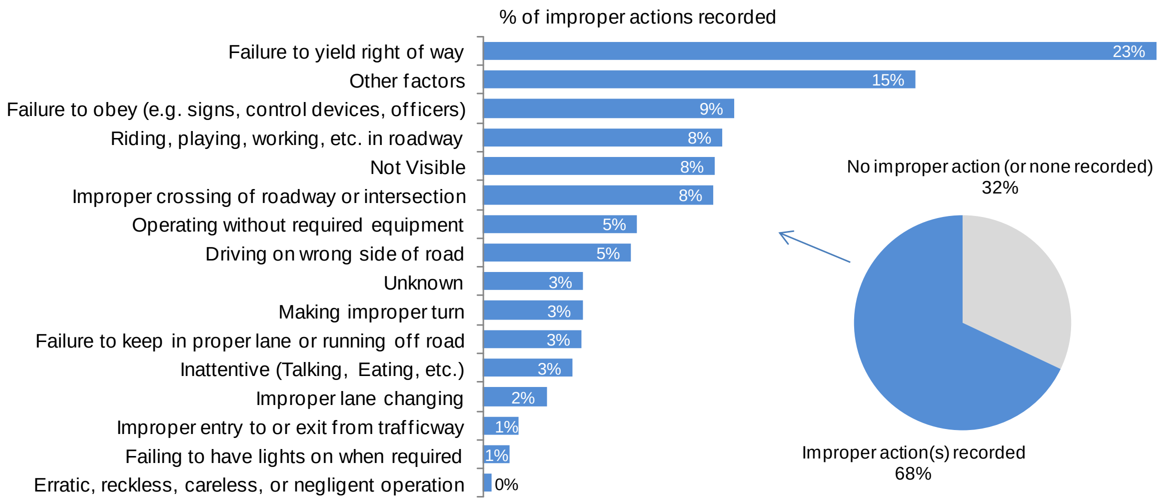
Figure 4.16 **Percentage of all police-reported fatal bicycle crashes classified as cyclist at fault in Australia, Denmark, and Spain**



Source: Questionnaire responses

The US FARS database tracks cyclists' action circumstances at the time of a fatal crash involving a motor vehicle (Figure 4.17). For the years 2005-2011, 68% of fatal bicycle crashes involved no improper action on the part of the cyclist or had no record of an improper action (data from 2010 and 2011 indicate that 76% of those crashes recorded as "no improper action/none reported" specifically noted "no improper action"). Of the remaining 32%, failure to follow traffic rules – e.g. failure to yield right-of-way and failure to obey (traffic signs, control devices, etc.) – was the most significant category of cyclist fault in fatal bicycle crashes accounting for one third of all recorded improper actions undertaken by cyclists in fatal bicycle crashes.

Figure 4.17 **Bicyclist action circumstance at time of crash for fatal bicycle crashes in the USA**

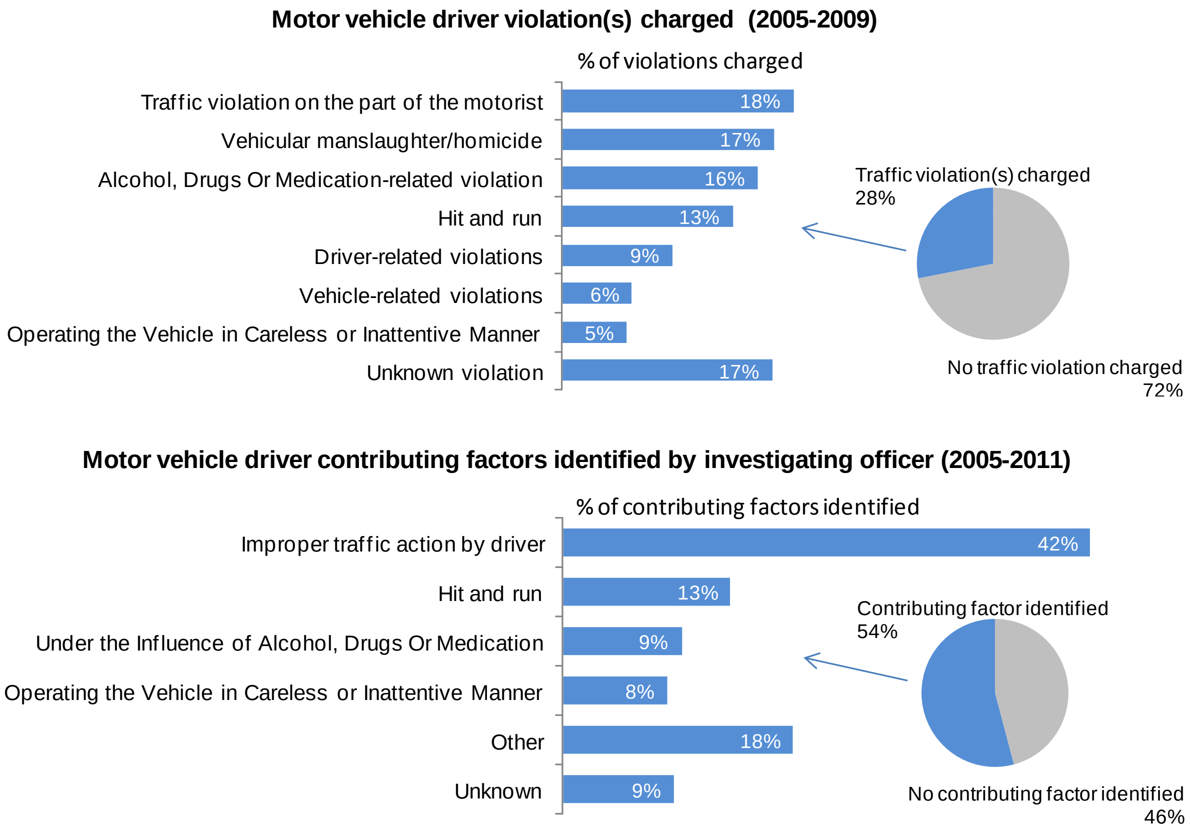


Source: EU CARE database, selected countries, 2005-2010

The FARS database allows a more detailed investigation of contributing actions by *motorists* in fatal bicycle crashes. The first thing that stands out from this analysis is the relatively high incidence of hit-and-run crashes – 17% of all deceased cyclists were involved in a hit-and-run crash in which one (or several) of their crash opponents fled the scene (2005-2011, FARS) – presumably the motorist(s). This is nearly four times the rate of hit-and-run involvement for all recorded traffic fatalities over the same period in the United States (4%).

The FARS database also records the number and type of violations charged to drivers of motor vehicles involved in fatal bicycle crashes as well as a series of (motor vehicle) driver-related factors that played a role in fatal bicycle crashes as recorded by the investigative officer (Figure 4.18). Many contributing factors may have been identified on the scene of the crash that do not necessarily lead to formal charges – the latter therefore provide broader insight into the types of motorist-related contributing crash factors that did not necessarily result in legal charges.

Figure 4.18 **Motorist violations and contributing factors for fatal bicycle crashes in the USA**



Source: USA FARS database

72% of motorists involved in fatal bicycle crashes in the USA (2005-2009) are not charged with a violation. For the remaining 28%, traffic violations (failure to yield right-of-way, speeding, failure to heed signals, etc.), vehicular manslaughter, hit-and-run and alcohol/drug/medication-related violations feature prominently.

Investigating officers on the scene of fatal bicycle crashes in the United States found no contributory factor on the part of the motorist in 46% of cases (2005-2011). For the remaining 54%, the leading contributory factor linked to the driver of the motor vehicle involved was “hit-and-run”, followed by “driving under the influence of alcohol, drugs or medication” and “failure to yield right-of-way”.

In the USA, 27% of all deceased cyclists from 2005 to 2011 were not tested for alcohol and another 11% did not return useable results. Of the remaining 62%, one quarter (25%) returned blood alcohol values above 0.08 mg/ltr which is the drink driving limit enforced by all 50 States. CARE data on alcohol or drug use by deceased cyclists is inconsistent largely due to significant lack of reporting by many European countries.

4.3 Serious Injury crashes

As noted earlier, data on seriously injured cyclists is generally more scarce and more subject to under-reporting than data on cyclist fatalities. Thus, as noted in section 4.1, inter-country comparison of serious injury crash data must be approached with caution. Further, US FARS data is not used in this section because the database is principally a fatality-reporting system.

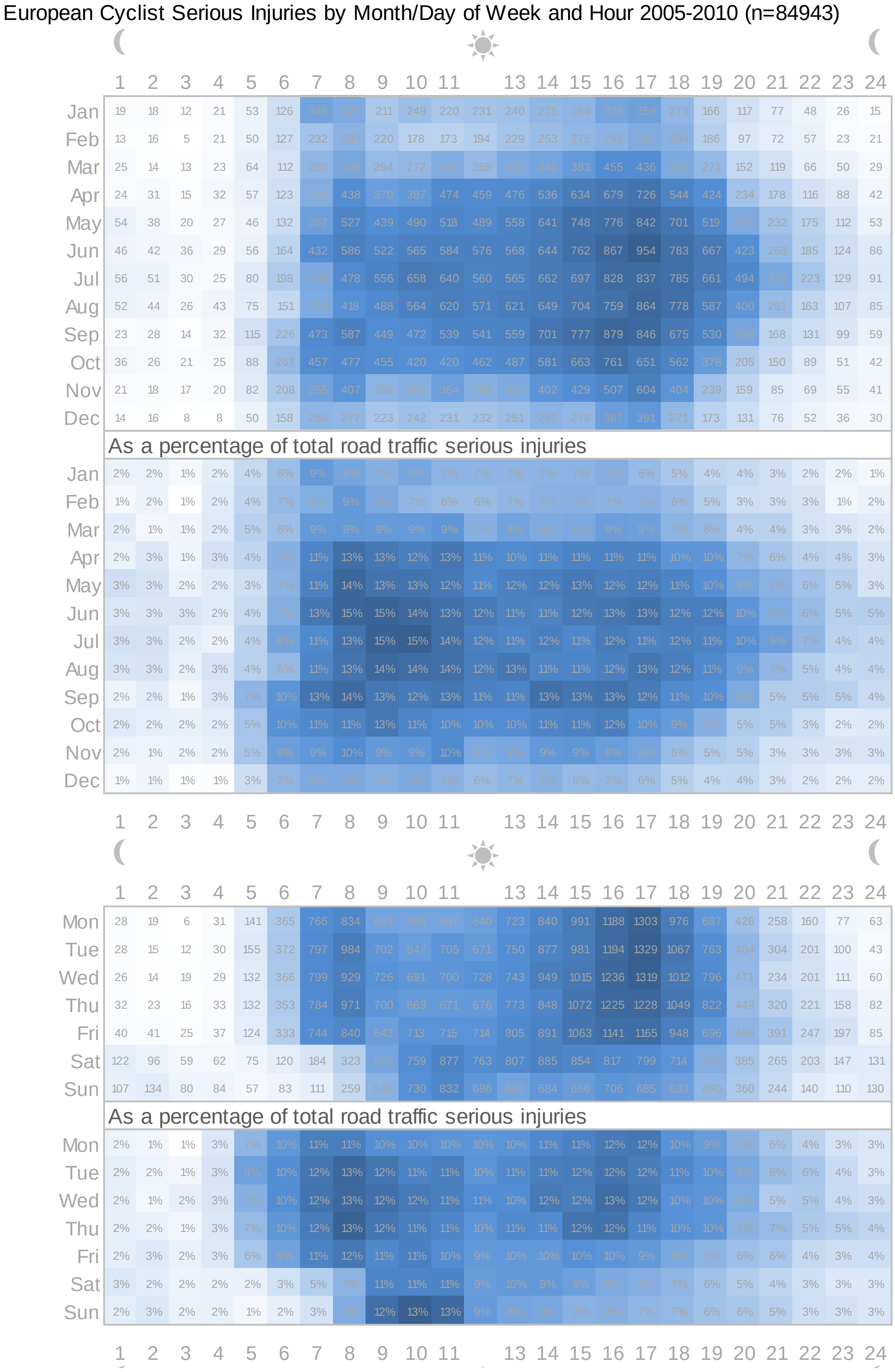
When do serious injury bicycle crashes occur?

The heatmap in Figure 4.19 displays all serious injury bicycle victims by crash hour, month and day of week for European countries reporting this data to the CARE database. Many of the same patterns revealed in Figure 4.1 can also be seen here[5]. One notable exception is that the dusk-related rise in fatalities seen in Figure 4.1 is not mirrored in Figure 4.19. Otherwise, the seasonal pattern (higher numbers of serious injuries reported in late Spring and Summer months) and the diurnal pattern (more crashes in the afternoon-evening with a second local maximum in the morning) are consistent with the pattern of fatal bicycle crashes shown in Figure 4.1. Figure 4.20, showing the range of serious injury crashes by month and by country, confirm these patterns. As with fatal bicycle crashes, countries with a high level of daily utilitarian cycling (illustrated in Figure 4.20 by Belgium, Denmark and the Netherlands) display a more even distribution of serious injury crashes throughout the year and a relative drop in serious injury crashes during the peak summer months – most likely linked to a lower number of work-cycling trips due to annual holidays.

There are also similarities with the diurnal distribution of fatal injury crashes (Figure 4.1) with a double peak, once in the morning and again, but stronger, in the afternoon and early evening (Figure 4.21). The four hours from 16:00 to 20:00 account for 26% of all serious injury bicycle crashes for which the crash time was recorded with the morning period from 06:00 to 10:00 accounting for 22%. Again, countries with high levels of utilitarian cycling (illustrated in Figure 4.21 by Denmark and the Netherlands) show a slightly different pattern in that both morning and evening peaks are more accentuated. As with fatal bicycle crashes, Spain shows a lagged pattern for serious injury crashes in relation to that displayed by most other countries.

75% of serious injury crashes for which light conditions were recorded in the CARE database occurred in daylight and 23% in darkness or in twilight (Figure 4.22). As with fatal crashes, several countries reported an atypical pattern of more numerous darkness/twilight crashes than daylight crashes – e.g. Ireland (77%) and the United Kingdom (62%).

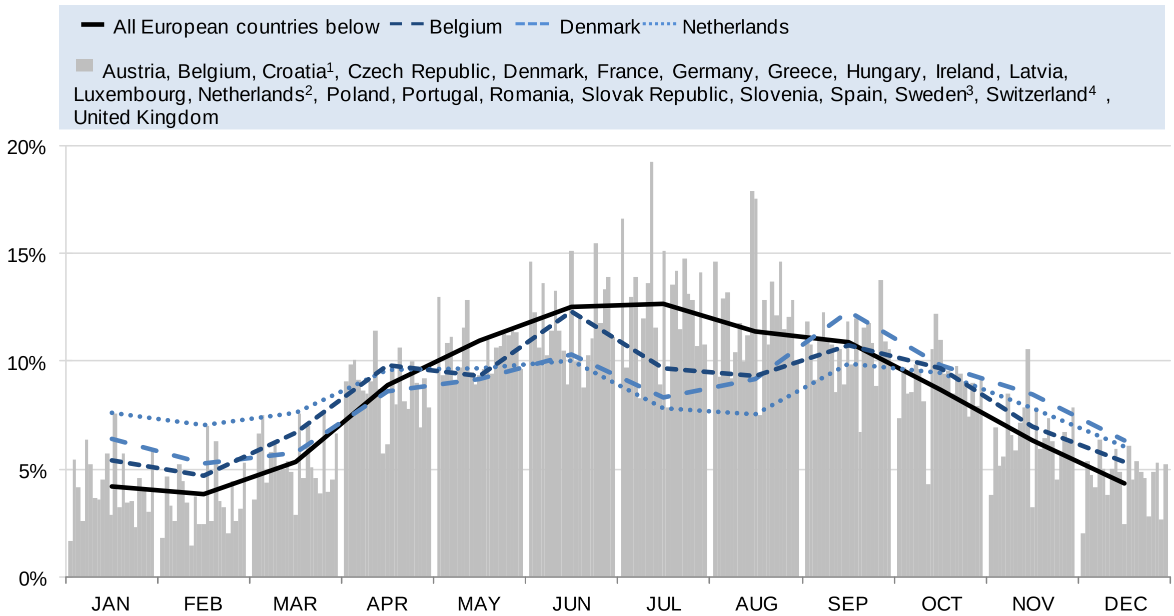
Figure 4.19 **Seriously injured cyclists by month or day of week and by time of day, EU**



Source: EU CARE database (available reports) EU27 countries, Norway and Switzerland, 2005-2010

The weekly pattern of serious injury crashes for European countries displayed in Figure 4.19 is consistent with the weekly pattern for fatal crashes displayed in Figure 4.1. Serious injury crashes are more likely to occur on weekdays (and on weekday evenings in particular). As with fatal crashes, there is a drop-off in serious injury crashes on the week-end as can be seen in Figure 4.23. Denmark and the Netherlands show a steeper drop-off than many other countries whereas Spain shows an atypical increase on the week-end as with fatal crashes – possibly linked to recreational cycling. Unlike the Friday peak for fatal bicycle crashes in Europe, serious injury crashes peak mid-week with Wednesday and Thursday representing 16% of the total each. Questionnaire responses show that for Poland (Warsaw), the peak occurs on Monday. Some countries e.g. Spain and Slovenia register their weekly peak on Sunday -- 16% of all serious injury bicycle crashes occur on Sunday in these two countries compared to 11% for all European countries reporting this data. The recreational riding effect, displayed as a concentration of serious injury crashes on Sunday morning in Figure 4.19 is visible as it is for fatal crashes in Figure 4.1.

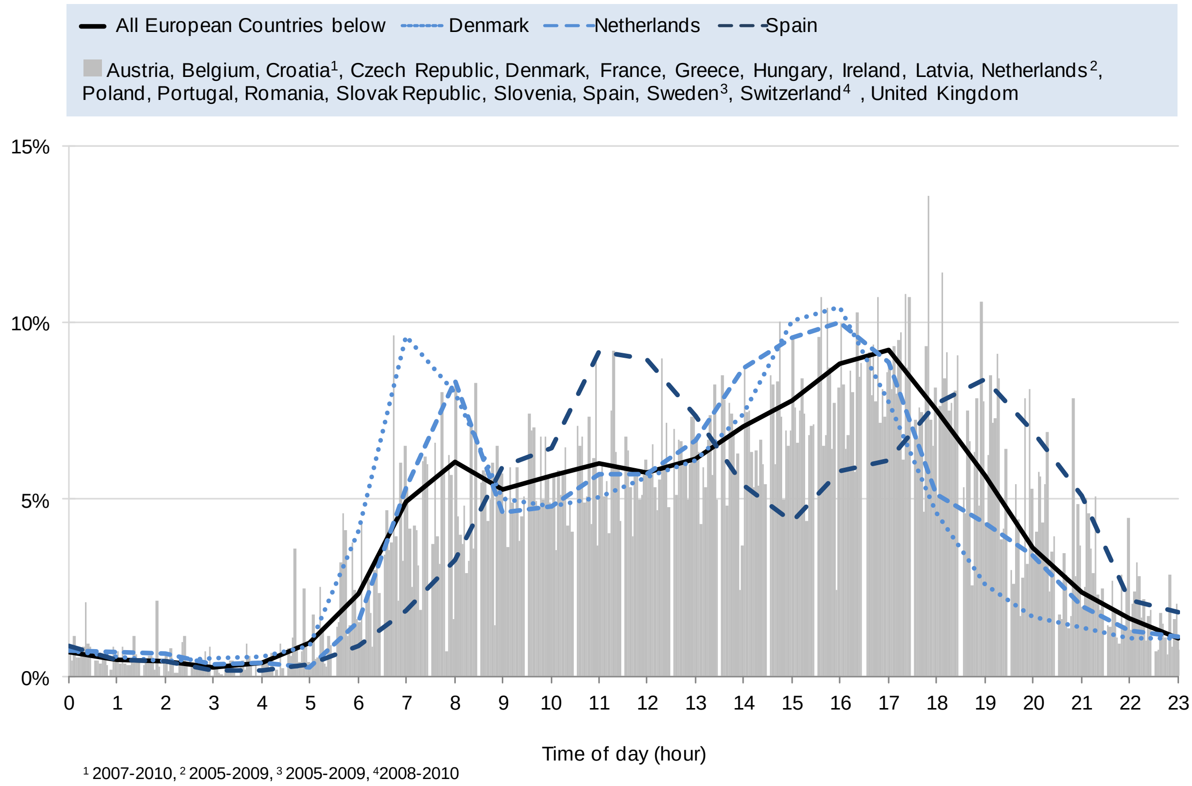
Figure 4.20 **Percentage of all reported serious injury bicycle crashes occurring by month, EU**



1 2007-2010. 2 2005-2009. 3 2005-2009. 4 2008-2010

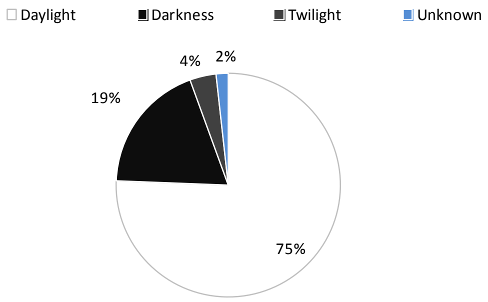
Source: EU CARE database (selected countries), 2005-2010

Figure 4.21 **Percentage of all reported serious injury bicycle crashes occurring by time of day, EU**



Source: EU CARE database (selected countries), 2005-2010

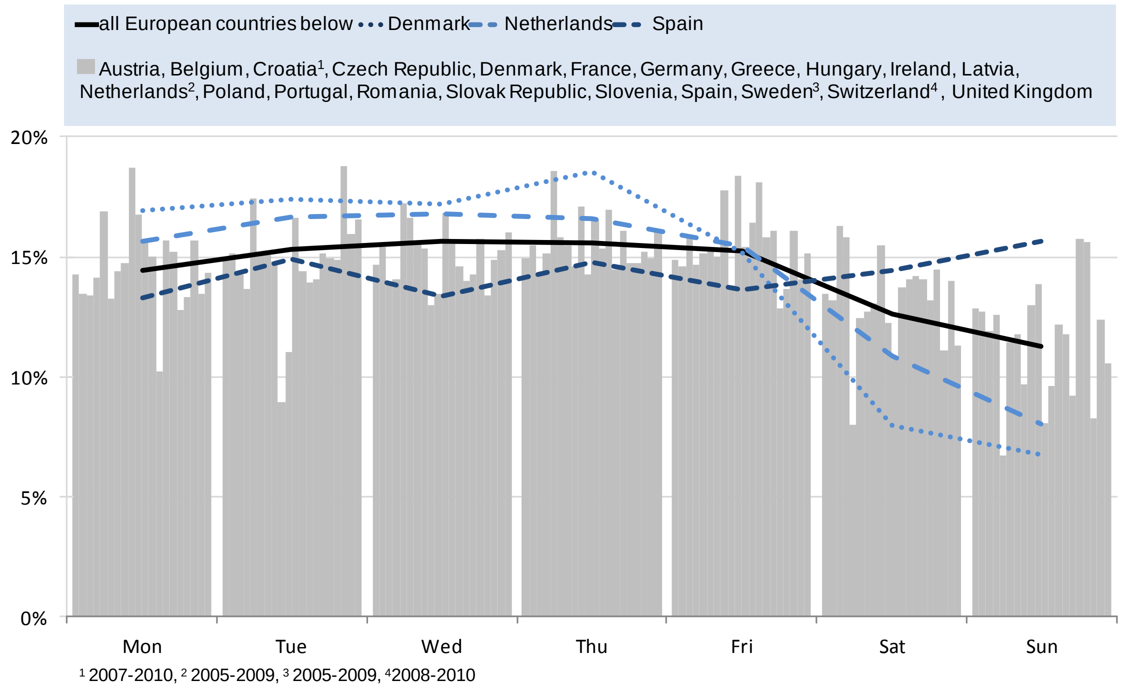
Figure 4.22 **Seriously injured cyclists by light conditions at the time of crash in Europe**



Source: EU CARE database, 2005-2010

Figure 4.19 also displays bicycle crash fatalities as a percentage of total traffic crash fatalities according to month/day of week and hour for European countries. Whereas more serious injury bicycle crashes occur in the late afternoon and evening, the share of bicycle serious injury crashes to total traffic serious injury traffic is highest in the morning – serious injury bicycle crashes in the period from 06:00 to 10:00 account for 11% of all serious injury crashes during the same period whereas the corresponding figure for the period from 16:00 to 20:00 is 9%.

Figure 4.23 **Percentage of all reported serious injury bicycle crashes occurring by day of week, EU**



Source: EU CARE database, 2005-2010

What role do surface and atmospheric conditions play in serious injury crashes?

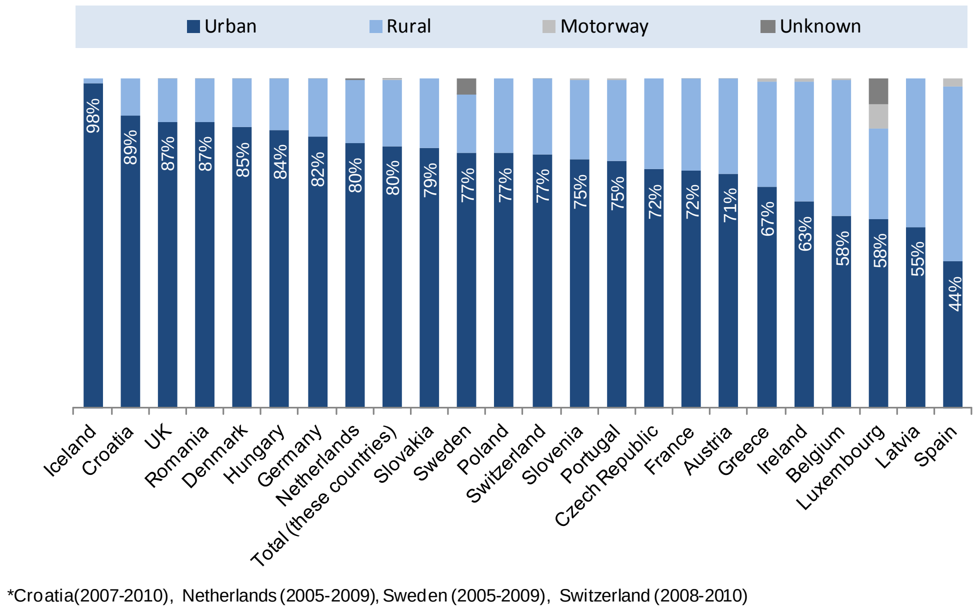
As with fatal bicycle crashes, most serious injury bicycle crashes recorded in the CARE database occur in dry and clear conditions (86%), followed by rain (4%) and sleet (0.8%). Denmark and Netherlands report a much higher share of serious injury bicycle crashes occurring in the rain (10% and 11%, respectively) likely linked to the fact that cyclists continue to ride in these countries, even in rainy conditions.

Where do serious injury bicycle crashes occur?

Crash location

A smaller share of serious injury bicycle crashes occurs in rural areas as compared to fatal injury bicycle crashes (Figure 4.24 and 4.7) and only in Spain do more serious injury crashes occur outside of urban areas than in urban areas. One possible reason lower share of serious injury bicycle crashes occurring outside of urban areas is that motor traffic speeds may be more elevated in rural areas and thus motor-vehicle vs. bicycle crashes there may be more deadly.

Figure 4.24 **Percentage of all police-reported serious injury bicycle crashes occurring in urban vs. rural areas and motorways in selected EU countries**



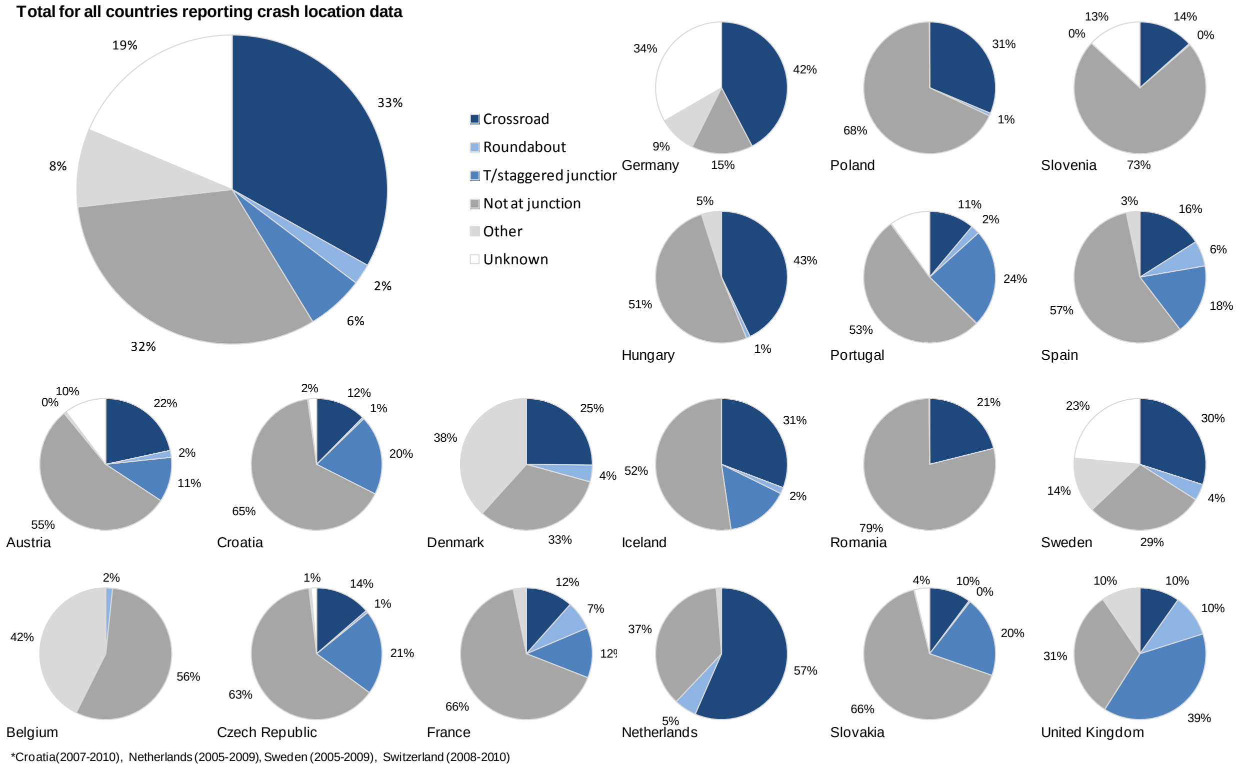
Source: EU CARE database, 2005-2010*

Configuration of infrastructure

In Europe, about as many serious injury bicycle crashes occur inside of as outside of junctions (41% and 40%, respectively) although a relatively small amount of total cycling (kilometres or time) presumably occurs in junctions (Figure 4.25). The share of serious injury bicycle crashes that occurs in junctions is also higher than for fatal bicycle crashes (41% for the former versus 29% for the latter). Some countries report that relatively few serious injury crashes occur in junctions (e.g. Slovenia – 14%) whereas others report more serious injury crashes occurring within rather than outside of junctions (e.g. the Netherlands and the United Kingdom with 62% and 59%, respectively, of all serious injury crashes occurring inside of junctions. In questionnaire responses, Germany reported that only 20% of serious injury crashes occurred in junctions and Denmark over 60%. As discussed previously, Germany likely underreported the number of serious injury bicycle crashes occurring in junctions. In Denmark’s case, many of the crashes categorised as “other” in Figure 4.25 presumably occurred in some form of junction in light of Denmark’s questionnaire response.

Overall, crossroads account for the highest share of junction-related serious injury crashes though in some countries, T-junction (or staggered junction) crashes are more frequent (e.g. in Croatia, the Czech Republic, Portugal, the Slovak Republic, Spain and the United Kingdom). Roundabouts account for a relatively significant share of all serious injury bicycle crashes in France (7%), the Netherlands (5%), Spain (6%) and the United Kingdom (10%). Belgium reports an unusually high share of “other” crash locations and an unusually low share of junction-related serious injury crashes – it seems likely that many of the latter are recorded in the former.

Figure 4.25 **Percentage of all police-reported serious injury bicycle crashes occurring at different junction locations, EU**



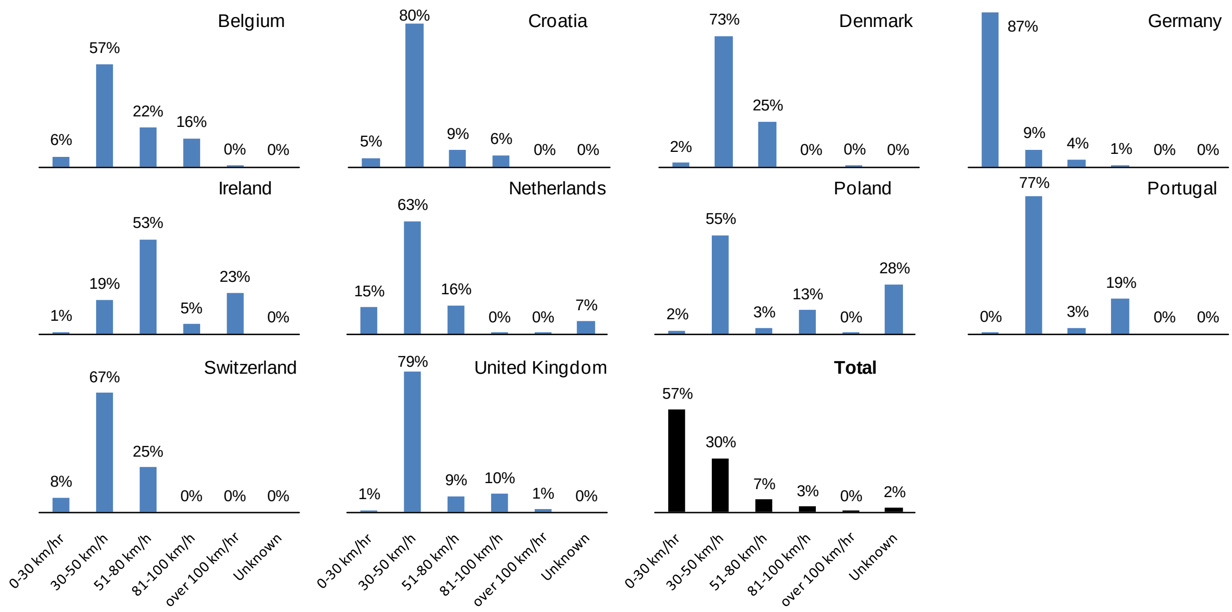
Source: EU CARE database, 2005-2010*

Questionnaire responses addressed serious injury crashes occurring on and off of cycling-specific infrastructure. In Belgium, France, and Poland injury crashes were less common on infrastructure specifically designed for bicycles than on roads not marked with bicycle lanes – although, arguably, more cycling occurs on cycling specific infrastructure. In Denmark, injury crashes were most common on cycling lanes, followed by roads without marked lanes. This too, may reflect that most cycling occurs on cycling lanes in Denmark.

Speed Limit

According to the CARE database, over half of all serious injury bicycle crashes in Europe occur on roads whose legal speed limit is below 30 km/hr (Figure 4.26). However, Germany reports an atypically high share of crashes occurring in this speed limit zone and this may bias the finding for all of Europe since Germany accounts for 64% of all seriously injured bicycle crash victims where speed limits were recorded in the CARE database. Excluding Germany, 67% of all serious injury bicycle crash victims were injured on roads whose legal speed limit was between 30 and 50km/hr. Some countries (Ireland, Netherlands, Portugal and the United Kingdom) report a secondary peak on roads whose speed limits were above 80km/hr – but at lower shares than for fatal bicycle crashes.

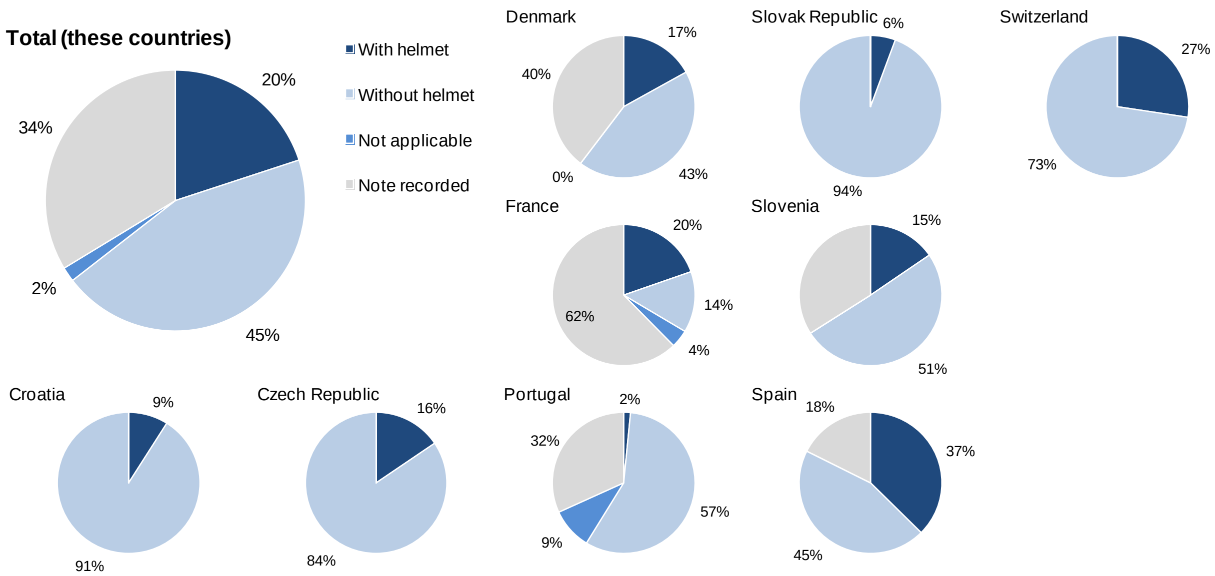
Figure 4.26 **Percentage of all police-reported serious injury bicycle crashes according to the legal speed limit of the main road involved in selected European countries**



*Croatia(2007-2010), Netherlands (2005-2009), Switzerland (2008-2010)

Source: EU CARE database, 2005-2010*

Figure 1. Figure 4.27 **Percentage of all police-reported serious injury bicycle crashes occurring with or without helmets in selected EU countries**



*Croatia(2007-2010), Switzerland (2008-2010)

Source: EU CARE database, 2005-2010*

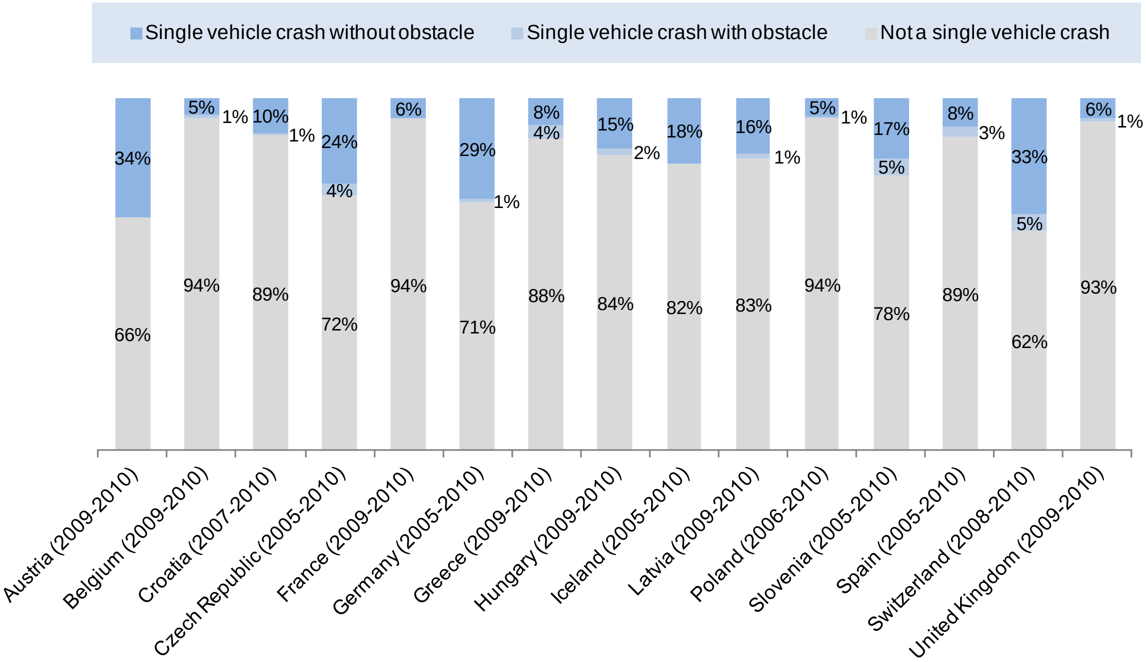
Use of bicycle helmets

Bicycle helmet use was reported by only 20% of all seriously injured cyclists in those countries reporting on crash helmet use in serious injury bicycle crashes (Figure 4.27). Spain and Switzerland reported the highest use of bicycle helmets for seriously injured cyclists (37% and 27% respectively) whereas Portugal, the Slovak Republic and Croatia report the lowest use (2%, 6% and 9%, respectively).

Crash type

As with fatal bicycle crashes, most serious injury bicycle crashes for which crash type was recorded involved another vehicle though some countries report a significant number of single vehicle bicycle crashes resulting in serious injury (e.g. in Austria, the Czech Republic, Germany and Switzerland, single vehicle bicycle crashes result in over 25% of recorded seriously injured cyclists).

Figure 4.28 **Percentage of all police-reported serious injury bicycle crashes occurring with or without a crash opponent, EU**



Source: EU CARE database, various year ranges

Collision opponent

According to questionnaire responses from Belgium, Denmark France (Paris City) and Spain, motor vehicles were the principal crash opponent in a majority of bicycle collisions resulting in serious injury (Table 4.1). Passenger cars dominate motor vehicle collision opponents in serious injury bicycle crashes but goods vehicles (especially light goods vehicles) and motorised 2-wheelers account for a not-insignificant share as well as seen in Figure 4.14.

Table 4.1. **Serious injury cycling collision crash involvement/opponent**

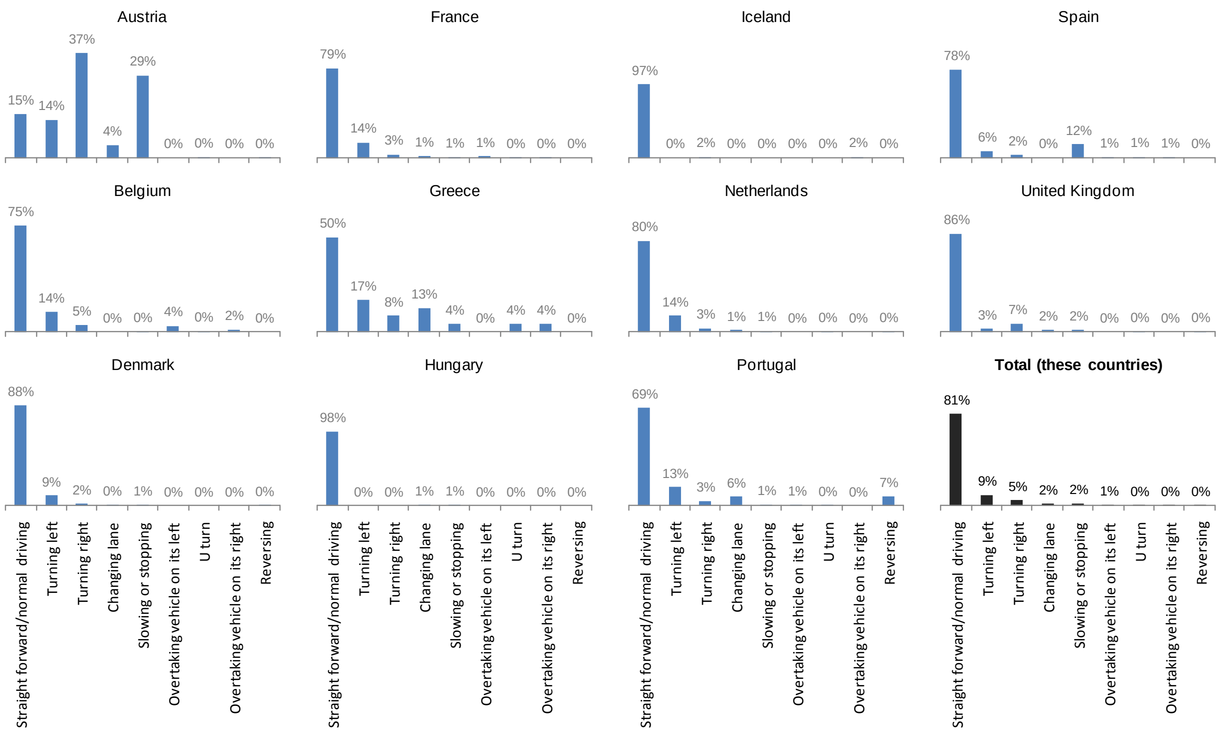
	Motor vehicle	Bicycle	Pedestrian	Animal	Object	Train	Other
Belgium	87%	5%	4%	0%	4%		
Denmark	92%	5%	2%	0%	1%	0%	
France (Paris City)	75%	0%	21%				
Spain	72%	0%	2%	0%	3%		22%

Source: questionnaire responses

Manoeuvre

As with CARE data for fatal crashes, data relating to cyclist manoeuvre for serious injury crashes should be treated with caution since those crashes for which manoeuvre was recorded only account for 29% of all seriously injured cyclists. For crashes where manoeuvre was recorded, most involved a cyclists proceeding straight forward or otherwise riding normally (Figure 4.29).

Figure 4.29 **Manoeuvre by cyclist for serious injury bicycle crashes where pre-crash manoeuvre was identified and recorded, selected EU countries**



Source: EU CARE database, 2005-2010

Questionnaire responses provide further insight into serious injury crash manoeuvre in certain countries. In Belgium injury collisions with vehicles most often occurred in a junction with the bicycle being hit by the motor vehicle during a turn (by the motor vehicle - 13%). The next most frequent manoeuvres were the bicycle being hit when approaching the motor vehicle from a different street (11%) or sideswiped by the motor vehicle during a turn (10%).

In Denmark injury collisions with vehicles most often occurred in a junction when the bicycle or motor vehicle was turning right or left and collided with through-traffic coming from the right or the left (22%). In light of CARE data (Figure 4.29), it seems that in most cases, the motor vehicle was turning at the time of crash (since Denmark reports that relatively few cyclists were turning when the crash occurred). The next most frequent crash-causing manoeuvres were in a junction when the bicycle and the motor vehicle were approaching the same junction from different streets (17%), and when the motor vehicle was turning nearside and sideswiped a cyclist who may also have been turning to the nearside or (in most cases) going straight ahead (13%).

In Paris City, collisions with motor vehicles most often occurred when either the motor vehicle or the bicycle sideswiped the other while travelling in the same direction (26%). The next most frequent manoeuvre was when the motor vehicle was turning to the nearside and sideswiped a cyclist who may also be turning to the nearside or (in most cases) going straight ahead (19%).

Contributing actions by cyclists or motorists

According to questionnaire responses, the cyclist was reported to be at fault in 40% of injury crashes in Spain, whose data are based on two provinces for this variable only, and 31% of injury crashes in France. In Denmark, cyclists did not have right of way in 16% of injury crashes. As with fault in fatal crashes, these figures may be a result of different right-of-way practices and rules in the countries considered.

4.4 Discussion

For many variables, especially those concerning timing of crashes, patterns were fairly consistent across respondent countries. Many exceptions in crash timing data could be understood in terms of different climatic conditions or diurnal patterns in different countries. These findings appear to indicate that a fairly consistent approach can be taken to interventions aiming to improve cycling safety as concerns when crashes occur.

Patterns were also fairly similar for fatal and injury crashes – except for variables which are likely to influence crash severity, such as speed limit zone and crash location (junction vs. non-junction).

Data showed that most crashes occur during daylight, but the rise in fatal crashes at dusk, both in absolute numbers and as a share of overall traffic fatalities, underscores the sensitive nature of this transition period. Better lighting (streets and bicycles) and better conspicuity by cyclists may help in reducing these numbers – as might raising motor vehicle driver awareness.

Unsurprisingly, crashes appear to be more common during peak travel periods (in the morning, middle of the day, and afternoon). For fatal crashes, the afternoon-early evening peak seems to be generally more of a problem in Europe than in the USA but it is the morning period that represents the highest share of bicycle to total traffic fatalities in Europe. Variability amongst countries seems at least partially linked to the amount of utilitarian (and therefore less compressible) cycling that takes place. There are other differences amongst countries as well – for example, in the UK, crashes that occur during the night are more likely to be fatal (Knowles et al., 2009), whereas in Spain, fatal crashes peak later at night than in many other countries (likely reflecting local travel patterns).

Generally, there are a lower proportion of crashes (both fatal crashes and injury crashes) on the weekend than during the week, and this is consistent with recent UK data (Knowles et al., 2009). Key exceptions were that fatal crashes are most common on the Saturdays and Sundays in Australia, and on Sunday in Spain. It is probable that the different pattern in these countries is because cycling is used less as a mode of transport than in the other countries (Loo and Tsui, 2010) and that the crashes involve mostly recreational cyclists. It is also possible that these countries have more of a weekend drinking culture and/or offer a poorer cycling environment which is less forgiving of impairment-related errors.

Box 4.2 **Results from Bicycle Crash Micro-Analysis in Korea**

Under the recent reform of the national traffic safety law in Korea, traffic safety audits have become mandatory on newly constructed roads as well as on existing roads. As part of these audits, a team of researchers from the Korea Transportation Safety Authority investigated detailed bicycle crash data for 30 road sections comprising some form of bicycle infrastructure in 13 municipalities covering the period 2003-2007. Eight bicycle crash "hotspots" were identified and further field studies were undertaken to identify contributory and causal factors.

The review of police records and the field investigation found that most crashes occurred as cyclists were crossing the main road or a side road and identified 5 principal crash-contributing factors and identified crash-reduction actions for each:

- Line of sight obstruction for motorists: Trees, pillars, safety fences, bridge-rails, subway entrances blocked motorists' capacity to detect cyclists. Authorities should inventory visual obstructions that reduce the visibility of cyclists and remove or otherwise alter these.
- Road geometry: wide road curve radii made it hard for motorists to see bicycles. The answer here is to reduce the width of the road (e.g. by installing a traffic island or narrowing the road) or otherwise slow down motor vehicle traffic to allow motorists to see and react to cyclists' presence.
- Poor nightime visibility of cyclists: Lack of illumination and non-reflective attire of cyclists limited motorist's ability to detect cyclists at night. One response is to ensure adequate lighting at bicycle crossings or on routes with high numbers of cyclists. Another is to encourage or mandate the use of lighting and/or reflective clothing at night by cyclists.
- Poor junction recognisability: Cross walks and bicycle crossings may be hard to identify by motorists, especially when they are positioned after a high-speed road segment or a tight curve. Further, bicycle infrastructure lacked roadway markings that would have providing motorists with a visual cue to their presence (see figure below). Adequate Speed management for motor vehicle traffic is called for along with adequate signage and street markings warning motorists of the presence of cyclists.
- Insufficient road crossing infrastructure: Pedestrian and bicycle road crossings often feature traffic islands in the middle to allow non-motorised users refuge while crossing. These were found to be undersized and should be designed to handle more cyclists caught out during short traffic signal cycles.


Before: Discontinuous cycle track marking

Suggested treatment: Mark continuity and increase visibility

Source: CHOE, Byongho, KIM, Hyunjin and JUNG, Minyeong – "Study on improved measures on bicycle safety through accident investigation as presented to KOTI-ITF Bicycle safety Seminar (http://www.internationaltransportforum.org/Proceedings/Cycling2011/Choe.pdf, accessed 24 September 2013)

There is a clear pattern for crashes (both fatal crashes and injury crashes) to be most common in the warmer months, and least common in winter. In Australia the peak for fatal crashes is in spring rather than summer (when it may sometimes be too hot for people to cycle), and in Belgium it is in spring. In Denmark the peak for injury crashes is in autumn. These patterns most likely reflect cycling exposure. Countries with high levels of utilitarian cycling show less month-on-month variability but show a summer-holiday-related drop-off in fatalities and serious injuries.

Although wet or icy surface conditions may present a crash risk, most crashes (both fatal crashes and injury crashes) occur in dry surface conditions, presumably because this is when the most cycling occurs. Bicycle fatalities and serious injuries in inclement weather are highest in countries with high levels of cycling, most likely reflecting exposure.

Fatal and serious injury crashes are typically more common in metropolitan than in non-metropolitan areas. This may be because most cycling takes place in urban areas in most, but not all, countries. For fatal crashes, a minority of countries demonstrated a reversal in this pattern, whereas crashes were roughly evenly distributed across metropolitan and non-metropolitan or more common in non-metropolitan areas. For injury crashes all respondent countries adhered to the general pattern, although some countries, such as Belgium and Spain, have relatively more injury crashes in non-metropolitan areas than other countries. These patterns are likely to reflect where the most cycling occurs, in combination with the density and speed of traffic in these areas. Thus, in Belgium and Spain may have a greater amount of cycling in non-metropolitan areas than other countries, and crashes in these areas might often be fatal due to high traffic speed. For example, in Denmark, Germany, the Netherlands and the United Kingdom, urban areas accounted for 84%, 81%, 79% and 86%, respectively, of combined *killed and seriously injured* cyclists whereas non-urban areas accounted for a disproportionate 36%, 41%, 37% and 40%, respectively, of all *killed* cyclists.

Where it is reported, police-reported crashes are less common on cycling-specific infrastructure than on infrastructure that is not cycling-specific – although arguably the cycling-specific infrastructure carries more cycle traffic, particularly in some countries. This is consistent with the most recent UK data showing that 97% of cyclists involved in collisions resulting in a serious injury or fatality were on the main carriageway and only 2% on a marked cycling lane on the main carriageway (Knowles et al., 2009). Presumably this reflects a safety benefit conferred by various aspects of cycling-specific infrastructure – such as separation from traffic, lower speeds and speed differentials, and fewer junctions (see below). Another possibility untested by the working group is that this finding may also reflect a bias in the police-reported data. For example, in Australia, crashes are only reported to police if they occur on a road (including a bicycle lane on a road). It is noteworthy that in Denmark injury crashes are more common on on-road bicycle lanes than on roads not marked with bicycle lanes – perhaps reflecting exposure. Police-reported crashes generally represent a minority of all injury crashes as discussed in Chapter 1 – given the lack of data on overall injury rates (police reported, hospital recorded and minor injuries), we cannot assume that these findings also hold for mild injury crashes.

The general pattern was for most fatal and injury crashes to occur in low speed limit zones which is likely to reflect greater cycling exposure in these speed limit zones. For fatal crashes in particular, there was a second peak in high speed zones, presumably reflecting higher chance of fatality for crashes occurring at higher speeds. In the United States, the share of fatal bicycle crashes occurring in low-speed zones was lower than in Europe – possibly because low-speed traffic calmed zones are relatively less common in the United States.

About one-quarter of all fatal crashes occurred within junctions for European countries reporting this data though there is great variability amongst countries. Korea and the United States report higher shares of junction-related crashes. Figures from Australia are lower perhaps reflecting the greater share of fatal bicycle crashes in non-metropolitan areas where there are presumably fewer junctions. For Europe, non-junction areas account for a proportionately greater share of fatal (64%) than serious injury bicycle crashes (40%). Likewise junctions account for a smaller percentage of fatal (29%) versus serious injury (41%) bicycle crashes. There are many possible reasons why this should be. The first is that motor vehicle speeds are typically higher outside junctions than in junctions and thus when non-junction crashes occur, the consequences are likely to be more serious for cyclists. There is also the issue of exposure given that more cycling presumably takes place outside of junctions than in junctions. In that respect, however, the significant share of fatal and serious injury crashes that still occur within junctions are significant given that relatively little overall time spent cycling occurs within junctions thus highlighting the *relative* risks posed by junctions.

Research on factors associated with junction versus non-junction crashes highlight a number of other contributory factors. The first is that a great many crashes occurring in junctions can be classified as “looked but failed to see”. There is a significant body of research[6] indicating that motor vehicle operators have a tendency to scan junctions for major dangers to themselves (other motor vehicles) at the expense of more vulnerable users. The greater the approach speed of the vehicle, the stronger this tendency. Internationally comparable data on specific bicycle and collision opponent manoeuvre according to crash location is lacking but it would appear that overtaking and rear-end collisions are a significant problem (Chih-Wei 2011) – e.g. accounting for half of all fatal UK two-vehicle bicycle crashes for the years 2005-2011. A reasonable assumption is that these types of crashes occur more frequently outside of junctions (and in low light conditions) though this is an untested hypothesis.

Differences among helmet-wearing rates for deceased or seriously injured cyclists are likely largely due to national helmet-wearing rates. It is notable that for countries reporting this variable, helmet use among deceased cyclists seems slightly, but consistently lower, than for seriously injured cyclists suggesting the protective effects of helmets. One notable exception is Spain where 39% of deceased cyclists were reported to be wearing a helmet compared to 37% of seriously injured cyclists – reflecting perhaps the fact that many sports-recreational cyclists (more amenable to wearing a helmet) were involved in fatal crashes as suggested by other Spanish data. Rivara, Thompson, and Thompson (1997) report that 51% of cyclists treated in the emergency department or dying from bicycle related injuries in Seattle were not wearing a helmet.

Although most respondent countries reported that the vast majority of fatal and injury crashes were collisions rather than falls, this may partly reflect a sampling bias in the police-recorded data, because collisions are more likely to involve another party. As discussed in Chapter 1, collisions are also more likely to be severe than falls, particularly because collisions are most commonly with motor vehicles.

Heavy goods vehicles were the most common crash opponent following passenger cars for many countries. Comparing the involvement of trucks in fatal versus serious injury crashes reveals the disproportionate risk of death for cyclists in truck-bicycle collisions and the need to address these types of crashes. Light goods vehicles and motorised two wheelers are also significant crash opponents in some countries, in some cases figuring more frequently than heavy goods vehicles.

It is difficult to draw a general conclusion regarding cyclist vs. motorist "fault" in fatal and serious injury bicycle crashes across all countries due to the limited amount of available and comparable data. Cyclists were reported to be at fault in 60% of fatal crashes in Australia, and 40% in Spain. However, these percentages probably exaggerate the role of cyclists, given that the cyclist is not available to give their point of view. In Denmark, where the operationalisation of fault is more objective (not having right of way) the percentage is lower (24%). Rowe, Rowe, and Bota (1995) report that amongst cyclist fatalities in Ontario, bicyclist error was the most common cause of crash for bicyclists aged less than 10 years (79%), bicyclists aged 10 to 19 years (55%) and bicyclists aged 45 years or more (44%), whereas motorist error was the most common cause of crash for bicyclists aged 20 to 44 years (63%).

Data from the United States indicate that cyclists were imputed with an improper action in 68% of fatal bicycle crashes (though, as noted earlier, this may be biased as the cyclist was not able to give their version of events). Of these improper actions, failure to follow traffic rules and yield right-of-way were most commonly cited. Furthermore, one quarter of (deceased) cyclists for which an alcohol test was performed returned blood alcohol values above 0.08 mg/ltr which constitutes a drink-driving offense in all 50 US States.

Motorist fault is also evident in the US data, and the prominent role of hit-and-run crashes involving cyclists (17% of all killed cyclists) is noteworthy. Motorists were charged with traffic violations in nearly one third of all fatal bicycle crashes and investigating officers identified a crash-contributing factor on the part of the motorist in over half of all fatal bicycle crashes.

Most fatal and serious injury crashes in Europe involved the cyclist travelling straight ahead or otherwise riding normally though pre-crash manoeuvre was recorded for only half of all fatal crashes and 29% of all serious injury crashes. Although the order varied slightly for different countries and for different crash severities, the next most common manoeuvres in bicycle crashes involved the bicycle either turning offside (across oncoming motor traffic) or nearside (with traffic). These manoeuvres are roughly consistent with recorded pre-crash manoeuvres in the US. As noted earlier, there is some evidence that overtaking and rear-end collisions are a significant problem as well – especially in low light conditions.

4.5 Limitations

Exposure is not completely controlled (because of inadequacy of exposure data). Whilst presentation of crash numbers as a percentage of all crashes addresses overall participation rates, improving the comparability of different countries, it does not account for different levels of exposure to different conditions. Thus, many of the observed patterns reflect exposure rather than riskiness. For example, we observed a general tendency for more crashes to happen during the warmer months, probably mostly because more cycling happens during the warmer months. In fact, it may be more risky (per kilometre) to ride in winter when roads are icy or wet. Nonetheless, from a problem identification, and resource allocation, perspective, it is arguably most important when/where the most crashes occur.

All countries provide police-reported data, which is unlikely to be representative of all crashes. For some variables in particular there are likely to be strong selection biases. For example, collisions are far more likely to be reported to police than falls.

For some variables, particularly in the case of injury crashes, data was returned by too few countries to draw very broad conclusions. For some variables, aggregate crash databases (e.g. CARE, FARS, UK DFT) are not strictly comparable since data definitions may differ. The cycling environment is undoubtedly very different in different member countries and aggregate databases may not have adequately captured country-level heterogeneity.

For questionnaire responses, even the countries that were able to return data could not return a complete data set – highlighting the importance of improving the collection of information regarding cycling-related crashes worldwide. As already mentioned the availability of exposure information could also be improved.

4.6 Conclusions

Cycling crashes are most likely when exposure is likely to be greatest: during peak travel periods (in the morning, middle of the day, and afternoon), during the week in countries where cycling is a typical mode of transport (and otherwise on the weekend), during seasons when the weather is most conducive to cycling, when the cycling surface is dry, in metropolitan areas, and in low speed limit zones (40-60kmph). The share of fatal and serious injury crashes is relatively more elevated in low-light conditions in the early evening. These crashes are also more common at night than exposure data might otherwise lead one to expect. Addressing urban lighting, cyclist conscipuity and motorist training may be helpful in reducing these crashes. There is an argument for directing resources to improve cycling safety in the situations described above.

There are some important exceptions to this general rule of thumb, with implications for intervention design. Fatal and serious crashes are less common on cycling-specific infrastructure than on infrastructure that is not cycling-specific – indicating perhaps the value of providing cycling-specific infrastructure. A higher proportion of fatal and serious crashes than would be expected on the basis of exposure occur in junctions – indicating the risk posed by junctions and the need for care when designing junctions to be cycling-friendly. There is also some suggestion that fatal crashes are more common in 70-80kmph zones than would be expected on the basis of exposure alone – highlighting the value of speed management as “hidden infrastructure” that protects cyclists.

Collisions appear to be more common than falls, and collisions with motor vehicles most common of all for fatal and serious crashes. Although this is may partly reflect a sampling bias in the police-recorded data, because collisions with motor vehicles are likely to have the most serious outcomes and thus warrant attention in interventions to improve cycling safety. Truck-bicycle crashes are a particularly serious problem in many countries highlighting a need for continued focus on avoiding these crashes and reducing their severity.

Both cyclists and motorists share some level of fault in fatal and serious injury crashes. There may be a bias against adequately reflecting cyclist fault in fatal bicycle-motor vehicle crashes as the cyclist is most likely to be the victim and thus unable to provide essential information. Training of police in crash reporting for bicycle crashes may address this bias if countries determine it exists.

Key Messages

- Patterns timing of crashes were fairly consistent across respondent countries. Many exceptions in crash timing data could be understood in terms of different climatic conditions or diurnal patterns in different countries. These findings appear to indicate that a fairly consistent approach can be taken to interventions aiming to improve cycling safety as concerns when crashes occur.

- Data showed that most crashes occur during daylight and were more common during peak travel periods consistent with the highest volumes of bicycle travel. Likewise, there is a clear pattern for crashes (both fatal crashes and injury crashes) to be most common in the warmer months, and least common in winter. All of these patterns most likely reflect cycling exposure.

- Overall crashes are more common in metropolitan than non-metropolitan areas, reflecting also where most cycling occurs. Some countries report higher rates of fatalities outside of urban areas indicating perhaps greater motor vehicle speeds or greater recreational cycling levels.

- Limited responses from the questionnaire indicate that police-reported crashes are less common on cycling-specific infrastructure than on infrastructure that is not cycling-specific – although arguably the cycling-specific infrastructure carries more cycle traffic in responding countries.

- More fatal bicycle crashes occur outside of junctions than inside ntersections in most countries – this may be linked to exposure (more cycling) or motor vehicle speeds. Nonetheless, a still significant proportion of serious and fatal crashes occur at junctions. This is more than would be expected on the basis of exposure at junctions – indicating the risk posed by junctions and the need for care when designing junctions to be cycling-friendly.

- The general pattern was for most fatal and injury crashes to occur in low speed limit zones (outside of the US, which is likely to reflect greater cycling exposure in these speed limit zones. For fatal crashes in particular, there was a second peak in 70-80kmph zones, presumably reflecting higher chance of fatality for crashes occurring at higher speeds and highlighting the value of speed management as “hidden infrastructure” that protects cyclists.

- Although most respondent countries reported that the vast majority of fatal and injury crashes were collisions rather than falls, this may partly reflect a sampling bias in the police-recorded data, because collisions are more likely to result in serious injury and/or involve another party.

- Insufficient data exists to make a broad finding relating to relative fault though there is evidence that cyclists and motorists both contribute to incorrect crash-causing actions. Lack of cyclist input in fatal bicycle crash investigations may result in biased outcomes.

Notes

1. CARE and FARS report deaths occurring within 30 days of the road crash based mainly on official police records.
2. For example, while Germany indicated only 20% of fatal crashes occurring in junctions in the questionnaire responses, the German police-reported data on crash location often does not specify location. Thus 20% is likely an underestimate. Studies made by BASt (the German Federal Highway Research Institute) suggest that up to 50% of fatal bicycle crashes may occur at intersections. CARE data for Germany reflect this finding.
3. Countries reporting on HGV crash involvement accounted for 82% of bicycle crash fatalities in the CARE database over the same period.
4. Countries reporting on LGV crash involvement accounted for 70% of bicycle crash fatalities in the CARE database over the same period.
5. Full reporting of serious injury crashes in the CARE database is less consistent than that of fatal bicycle crashes – only 11% of fatal bicycle crashes have unknown crash hour or month fields whereas this percentage is nearly 50% for serious injury crashes.
6. See (Chih-Wei 2011) for a discussion of this research.

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5. Review of bicycle safety measures

This chapter investigates the documented safety or safety-related behavioural effects of a number of bicycle safety measures and interventions based on the recent international research.

5.1 Introduction

This chapter reviews a wide range of infrastructural as well as non-infrastructural bicycle safety measures. Whenever it is possible, the estimated safety effect will be presented as a percentage potential crash reduction. The main source of this information is the *Handbook of Road Safety Measures* from the Institute of Transport Economics in Oslo, Norway (Elvik, Høye, et al. 2009). We select this source since it assesses crash-reduction effects on the basis of peer-reviewed literature and comprehensive safety studies. Where applicable, we complement this information with evidence from other research.

We also note a few promising measures that *may* improve bicycle safety but for which the safety-improving effect is undocumented or lacking at present. Also important to note is that many bicycle safety assessments evaluate changes in behaviours that are known or strongly suspected to contribute to increased crashes and injuries (Helman, et al. 2011). These studies may not provide data on crash rates but are helpful nonetheless in detecting risky behaviours that may result in collisions. Where applicable, we highlight these results in this chapter.

Assessment of the effectiveness of safety measures to some extent will depend on local or national preconditions such as:

- Culture and traditions
- Legislation
- Existing infrastructure

Bicycling culture varies from one country to another. In some countries a bicycle is primarily a means of transport, and people bike because it is cheap, or because it is an efficient and easy way of getting to work or to school or going shopping. In other countries cycling is mainly a leisure activity – something cyclists only do on weekends. Likewise the style of biking varies. In some countries cyclists are more sport-oriented and tend to travel very fast on their bikes, while in other countries cycling is slower and more utilitarian. Street environments may also differ across countries, in India (see Annex 2) for instance informal sector stands and activities may dominate street sides whereas in others these activities are uncommon and/or forbidden.

Also, as seen in Chapter 2, traffic rules may vary from one country to another. Safety measures – especially infrastructural measures – showing good results in some countries may not even be possible to deploy on a legal basis in other countries.

In some countries for instance cyclists are allowed to use the sidewalk if there is no bicycle track present, and then bicycles have to give way when descending from the sidewalk (when passing a side road). In other countries bicycles are expected to use the same traffic areas as any other motorised or non-motorised vehicle, if no bicycle track or other designated infrastructure for bicyclists is present, and riding on the sidewalk is strictly forbidden.

Control and enforcement of traffic laws and explicit regulatory treatment of cycling may also differ greatly from city-to-city and between countries. In one country, motor vehicle intrusion onto cycling infrastructure or facilities may be ignored or tolerated by police whereas in others these same practices may result in severe fines or other penalties.

Figure 5.1 **Different types of bicycles – and different types of bicyclists**

Photo credit: Authors

These observed differences should not be exaggerated *in most cases* when measures to improve safety for cyclists are being planned and decided upon. For OECD countries, the bulk of traffic rules pertaining to road use by bicycles are largely harmonised. Bicycles are expected to follow the same traffic rules as any other vehicle and the rules concerning right-of-way for motor vehicles normally apply for cyclists too. However, rules pertaining to the use of, and conduct upon, cycle tracks/paths/lanes may differ as may cyclist and/or motorist familiarity with such infrastructure (see Chapter 2).

What follows in this chapter a description of the documented safety effects of various bicycle safety measures that generally pertain to *most OECD countries.* Many of the examples of safety-improving measures in this section are drawn from European contexts but it is telling that official or informal standards relating to bicycle infrastructure largely build upon European experience (See for example the US National Association of City Transportation Official's – NACTO – Urban Bikeway Design Guide or the Japanese Ministry of Land, Infrastructure, Transport and Tourism and National Police Authority Guidelines for Creating a Safe and Comfortable Environment for Cyclists).

In this chapter we describe the safety effect of *individual* measures. It is not always the case that the effects of individual measures are additive – the ultimate safety effect of multiple measures deployed on one site will largely depend on site-specific interactions. For this reason, the selection and implementation of bicycle safety measures should be based on a site-specific diagnosis and identification of the safety problems to be treated (see section 5.6). Bicycle safety audits as deployed in a number of countries and/or cities can be helpful in this respect (see Box 5.1).

It is also important to note that the aggregate safety effects of an extensive segregated bicycle infrastructure network may contradict the evidence of the safety performance of its component parts (Reid and Adams 2010). For instance, the Netherlands and Denmark have both deployed extensive networks of segregated bicycle tracks (along with other bicycle infrastructure types) which, according to some evidence on the safety impacts of segregated bicycle tracks, might result in lower bicycle safety due to conflicts at junctions. Yet the evidence regarding aggregate levels of bicycle safety in these (and other countries having deployed similar networks) indicates that these countries typically have (much) better bicycle safety performance than countries lacking such networks (see, for example Figure 3.12). Why this should be is not clearly evident from the study of the safety impacts of individual measures and there are few peer-reviewed studies looking to explain this phenomenon. Those that do, for example, (Pucher, Dill and Handy, 2010) (Pucher and Buehler 2008) (Ligtermoet 2009) and (Pucher, Buehler and Seinen 2011), note that the aggregate bicycle safety performance of these countries is based on the interaction of a number of factors, including:

- Political willingness and a regulatory environment that prioritises bicycle traffic.
- Sustained investment in a *complete network* of high quality bicycle facilities over several decades.
- Traffic calming and speed control on residential streets.
- Supportive land use planning.
- Extensive and early traffic training on the use of bicycle facilities and the rules governing bicycle-motor vehicle interactions.
- Timely and targeted interventions to address safety blackspots.
- Coordinated policies that increase the numbers of cyclists while increasing their safety.

These factors should be borne in mind when reading through this chapter. It is unlikely that implementing only one type, or a limited set, of the measures described in the following pages will raise aggregate bicycle safety measures – but the coordinated, targeted and extensive deployment of many bicycles safety measures, along with other interventions as described above, can result in better system-wide bicycle safety performance.

5.2 Key considerations regarding the assessment of safety measures

Before discussing individual measures, it is worth addressing a few key issues that should be borne in mind when assessing the safety effect of individual measures. These relate to the presence of confounding factors impacting safety, the implications of behavioural responses to safety-improving measures and the need to differentiate between safety-improving measures and those that increase the perception of safety.

Box 5.1 **Example of bicycle road safety audit and prompt lists (US Federal Highway Administration)**

Several countries and cities have developed guidelines for bicycle-specific Road Safety Audits (RSAs) to help ensure that cycling-specific concerns are addressed in road design or modification interventions. According to the United States Federal Highway Administration,

> *"RSAs can be used to help address the safety of cyclists by improving the understanding of both the characteristics of cyclists and the factors that affect cyclist safety. An RSA is a formal safety examination of an existing facility or future roadway plan or project that is conducted by an independent, experienced, multidisciplinary team. RSAs are a cost-effective method to proactively identify factors affecting safety and make suggestions on strategies and facilities to improve cyclist safety and support a truly multimodal street network for all types of facilities."*(Nabors, et al. 2012)

Below is the RSA prompt list suggested by the United States Federal Highway Administration:

	Road safety audit intervention zone				
	A. Street/path	B. Structures	C. Junctions, crossings and interchanges	D. Transitions	E. Public Transport
1.	Presence and availability				
	Are cyclists accommodated?				
2.	Design and placement				
	Are design features present that adversely impact the use of the facility by cyclists?	Are bridges/ tunnels designed with adequate bicycle accommodations on both sides? Does the gradient of the cycling accommodations impact the use of the facility?	Are junctions/ interchange accommodations designed to reduce conflicting movements and communicate proper bicycle positioning through the crossing?	Are transition areas designed with logical termini or do they end abruptly, potentially contributing to sudden and difficult merges, midblock crossings, or behaviors such as wrong way riding?	Are public transport facilities designed and placed to minimize conflicts with other modes?
3.	Operations				
	Are there suitable provisions for cyclists given the characteristics of the roadway or path (speed, volume, traffic, and functional classification)? Do access management practices detract from cycling safety?		Do traffic operations (especially during peak periods) create a safety concern for cyclists?	Do shared roadway geometries change substantially or frequently?	Are public transport facilities designed and placed to minimize conflicts with other modes?
4.	Quality and conditions				
	Is the riding surface smooth, stable, and free of debris and is drainage adequate? Are drainage grates designed for cyclists?	Is the grating/bridge surface designed for cyclists? Is drainage adequate to accommodate bicyclists? Are there longitudinal or transverse joints that may cause cyclists problems?	Are there any obstacles at crossings? Are the manhole covers properly designed?	Is there an abrupt change in riding surface?	Are public transport stops maintained during periods of inclement weather?

5.	Obstructions				
	Are there any horizontal or vertical obstructions (incl. temporary) along the facility?	Is there adequate horizontal and vertical clearance?	If bollards or other physical terminal devices are used, is the risk of occasional motorized vehicles greater than the risk of a fixed object within the travel way?		Is the waiting area free of temporary/ permanent obstructions that constrict its width or block access to the bus stop?
6.	Roadside				
	Is the clear zone for cyclists' operating space adequate?	Are railings, guardrail, and/or parapets and other structures installed at an appropriate height and shy distance?	If bollards or other physical terminal devices are used, is the risk of occasional motorized vehicles greater than the risk of a fixed object within the travel way?		Are bicycle accommodations connected and convenient for public transport users?
7.	Continuity and connectivity				
	Are bicycle accommodations continuous? Do bicycle accommodations provide adequate connectivity to major destinations?	Are bicycle accommodations continuous, or do they end abruptly at bridge/tunnel crossings?	Are bicycle accommodations continuous, or do they end abruptly at crossings/ junctions/ interchanges?	Is there a safe way for cyclists from both directions to access connections or continue to other destinations along the street network?	Are crossings convenient and free of potential hazards for cyclists?
8.	Lighting				
	Is the riding surface adequately lit?	Are bridges and tunnels adequately lit?	Are the junction/transition and paths leading to the transition adequately lit?		Are transit access ways and facilities adequately lit?
9.	Visibility				
	Is the visibility of cyclists using the facility adequate from the perspective of all road users?	Can cyclists see approaching vehicles/ pedestrians, and vice versa?	Can cyclists see approaching vehicles/ pedestrians at all legs of a junction/ crossing, and vice versa?	Is the visibility of cyclists as they make the transition from one facility or roadway geometry to another adequate from the perspective of all road users?	Is the visibility of cyclists using the facility adequate from the perspective of all road users?
10.	Signs and pavement markings				
	Are signs and markings along the riding surface visible, wellmaintained, easily understood, and adequate?	Are adequate warning signs posted at entrances?	Do signs and markings along the cycling facility clearly indicate the cyclist path and right-of-way at junctions?	Are signs and markings at transition areas appropriate?	Are signs and markings at designated areas for cyclists using transit appropriate?
11.	Traffic signals				
	If bicycle traffic signalization and detection are present, are they properly positioned, functioning, and effective? Does the traffic signal design accommodate all users?				
12.	Human factors/bevaviours				
	What are all roadway users (vehicles, bicyclists, pedestrians, transit, etc.) doing with regards to bicycle traffic, and vice versa?				

Source: (Nabors, et al. 2012)

Accounting for confounding factors

There are multiple confounding variables that may have an impact on observed safety outcomes that may not be captured in ex-ante or ex-post evaluation of bicycle safety measures. “Safety in numbers”, as discussed in Chapter 1, is one good example. Does safety result from the presence of numerous cyclists or are numerous cyclists evidence of a safe cycling environment? Alternatively, does the assessment of a bicycle safety measure account for the generalised road safety improvement that can be observed in many countries? Robust assessment methodologies and ensuring relevant temporal or spatial coverage of bicycle safety measures should reduce the risk of missing confounding variables. Without these, there is a risk that safety policies lead to unintended and possibly deleterious consequences.

Accounting for behavioural responses to safety measures

Road safety policy, especially that targeting infrastructure, has typically assumed a deterministic and fixed response to road safety interventions wherein road users have a single and predictable response to changes in infrastructure design or a new policy (Noland 2012). For instance, the typical assumption would be that improved sightlines on roads would simply allow traffic users to better detect potential obstacles and avoid them in time and thus reduce the number and severity of crashes. However, a likely response to such an intervention is that road users increase their speed. Why this would be the case has been the focus of much recent research in the traffic safety field and though debate is ongoing, there is broad (but not unanimous) support for theories relating to *risk compensation* or *risk homeostasis*. These approaches assume that road users explicitly or implicitly make decisions on the basis of a target or acceptable level of risk or otherwise trade off risk for other desirable outcomes (shortened travel time, thrill of speed, etc.)[1].

For cycling safety policy, this means that behavioural responses to safety policies must be accounted for in policy development and assessment. For instance, will riding in a cycle lane or wearing a helmet increase the propensity for motorists to pass cyclists more closely? Alternatively, will providing dedicated cycling infrastructure or helmet-wearing increase risk-taking on the part of cyclists? While it seems unlikely that behavioural responses will negate the safety-improving effect of most safety interventions, the potential for reduced benefits is important and this may affect the outcome policy appraisal. We highlight some of the behavioural response aspects of the measures described in this chapter where research is available.

Differentiating between safety and the perception of safety

We should also make clear that the discussion of “bicycle safety” itself is not a unitary concept. There are actions that demonstrably reduce the material risk of crashes or attenuate their severity – these types of measures have a direct impact on the safety of existing cyclists. There are also measures that reduce the perception of crash risk by cyclists – e.g. measures that increase the perception of safety. In some cases, this perception may not reflect actual crash risk and in most cases, is highly dependent on the level of experience of cyclists themselves (see for example Box 5.2). A classic example is the heightened perception of safety attributed by many cyclists to separated cycle tracks even though actual crash risk at road- cycle track junctions may in fact be higher when these junctions are poorly designed. It may seem that improving perceived safety is an unimportant distraction that may result in negative outcomes but improving the perception of safety may attract new cyclists and thus deliver the very strong overall health benefits discussed in Chapter 1. This is especially important if groups currently under-represented in cycling populations are to be encouraged[2]. Authorities seeking to maximise the benefits stemming from cycling will have to address both material and perceived safety simultaneously and they should do so with the understanding that what is perceived as safe will differ among different groups of existing or potential cyclists.

Box 5.2 **Perceived Safety and Route Choice Preference: Evidence from India and Korea**

Studies looking at perceived safety and cyclist route preferences have tended to be based on research based in OECD countries, notable Europe and North America. Cycling mode shares in non-European countries can be elevated – e.g. in many Indian and Chinese cities cycling mode shares are much higher than in similarly sized European or North American cities though cycling is losing ground to motorized two and four-wheeled vehicles as incomes rise in these and other developing countries. Korea has reached a more advanced stage of economic development and a relatively high motorization rate although efforts are underway to promote cycling there as a way of increasing health and promoting less environmentally harmful transport. In the course of this working group, members contributed findings from two recent research projects aiming to gauge cyclists perception of safety and route preference in India and Korea – these may be found in Annexes B and C.

Evidence from India (Annex B):

Cycling mode shares are relatively elevated in a number of medium to large cities though most Indian cyclists are “captive” riders who bicycle out of necessity as no other viable (and affordable) mobility options are available to them. One study looking at perceptions of such “captive” riders as compared to a group of not yet riding (potential) riders (short trip makers) found that the perception of risk among captive riders and potential riders does not show much difference contrary to what was expected. Both captive riders as well as potential cyclists focus on physical safety and the difficulties in crossing junctions. Differences among these two populations arise, however, in their perception of comfort / attractiveness and identification of barriers. Pedestrians / bus commuters waiting at the curb side lane are considered as predominant barriers (about 28%) by potential cyclists while captive riders are more tolerant to them. Results indicate that perception of safety and comfort are not related to type of zone and distance travelled. The presence of informal sector on the street side is social security element and was considered attractive for captive cyclists, especially as they use these services. Potential cyclists, however, consider the informal sector as a barrier to riding. Results show potential cyclists perceive slope as bigger barrier to riding as compared to captive riders. Captive riders prefer wider arterial roads against the narrow roads preferred by potential cyclists.

Evidence from Korea (Annex C):

Unlike the situation in India, evidence indicates that most cyclists in Korea ride for health and leisure and not for transport purposes. Korea has seen an increase in the number of bicycle crashes and injuries though deaths have remained relatively constant. One study looking at Korean cyclists’ perception of safety found that segregated facilities enhanced current cyclists’ perception of safety – but not nearly as much as reducing motor traffic speed did.

5.3 Non-infrastructural measures

Many non-infrastructural measures have been subject to research studies, but only a small number of those studies base their conclusions on actual crash data. Instead the major part of these studies estimate changes in risk factors – such as behavioural changes, changes in stopping distances (brakes) or detection distances (reflectors). This is especially the case for *safety equipment*. It seems that use of bicycle helmets is the only type of protective device which has been subject to evaluation studies based on actual crash data. Where relevant, we note the basis for the safety evaluation of the following measures.

Safety Equipment and Vehicle design

Reflectors, lamps, brakes, handlebars and gears on bicycles

Note: None of the measures in these categories have been evaluated by use of actual crash data.

According to (Elvik, Høye, et al. 2009) the most important types of safety equipment are:

- Pedal reflectors
- Tail light
- Brakes on both wheels (vs. back wheel only)
- Synthetic brake blocks (vs. rubber)
- Rim brakes vs. hub brakes

These five measures all contribute to a major (and statistically significant) improvement in the risk factors *detection distance* and *stopping distance*.

Daytime running lights on bicycles

New types of bicycle lights – permanently fixed to the bike, powered by magnetic induction from magnets fixed to the spokes – have made daytime running lights on bicycles a realistic option. The first generation of these lights only came as flashing lights – making them illegal in some countries – but within recent years a number of manufactures have also launch steady light versions.

The safety effect of daytime running lights on bicycles was tested in a Danish study in 2005 (Madsen 2006). Nearly 2,000 cyclists in the town of Odense used the new induction lights (flashing type) for one year with, while 2,000 others continued with ordinary bike lights, which were only switched on during dark hours. The accident frequencies of the two groups (based on self-reported accidents) were then compared and analysed.

Figure 5.3 **Tail and front lights (from two different manufacturers) powered by magnetic induction.**

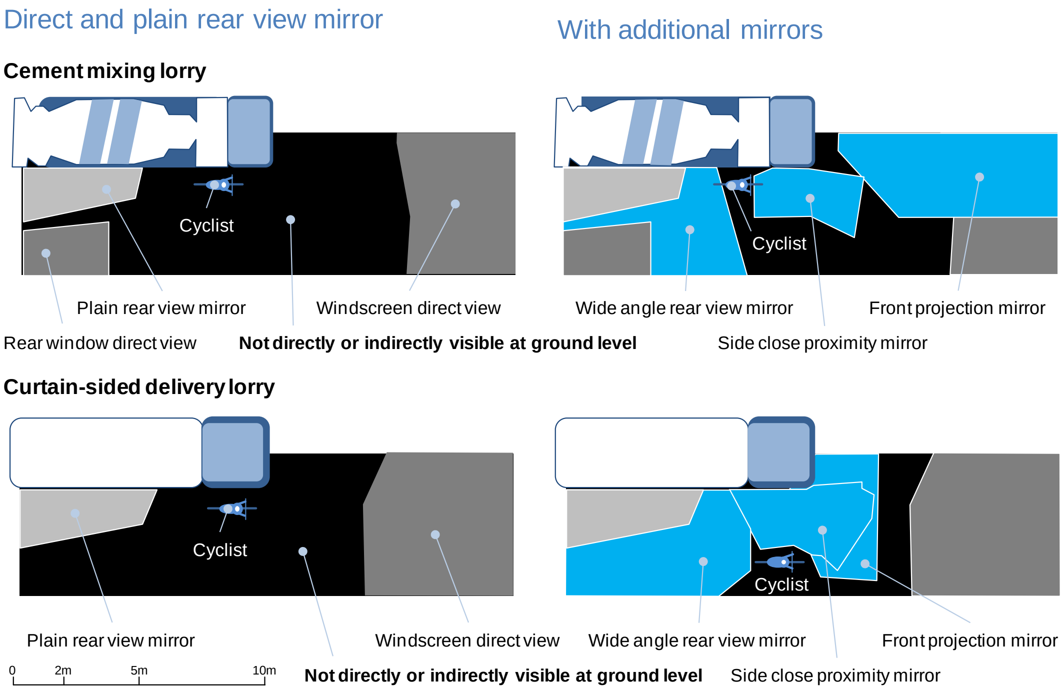
Photo credit: Authors

The main result was that use of daytime running lights was associated with a reduction of the number of crashes by more than 30%. The number of *related crashes* (crashes in daylight and with a counterpart) decreased by 50% approximately. Both results are statistically significant. There are indications that the study may have not controlled for all factors – for instance it is unclear to what extent the control group's crashes included single vehicle crashes (this type of crash is hardly influenced use of induction lights). Also, the study makes no finding as to the safety effect of flashing versus steady lights.

Blind spot mirrors on trucks

Heavy goods vehicle (HGVs)-bicycle collisions are less common than car-bicycle collisions but they are especially deadly (See Chapter 4). One of the main sources of danger is the limited visibility of cyclists to HGV drivers. Because of the elevated driving position and blind spots caused by structural elements of the driving compartment (including mirrors themselves), a significant portion of the area to the front and on the nearside of HGVs is shielded from the driver's view at ground level (Figure 5.4). Cyclists within these blind zones are invisible or only partially visible to HGV drivers and thus at risk of being struck, especially in nearside turning manoeuvres. In order to counter this threat, the EU has introduced legislation requiring truck manufacturers to fit mirrors or equivalent systems to extend sideways and rearward vision (Directive 2003/97/EC8). Accompanying legislation requires HGVs registered after January 2000 to be retrofitted with such devices (2007/38/EC9). Following the enactment of these two pieces of legislation, the number of vulnerable road users killed in HGV crashes has dropped significantly but at the same time all traffic fatalities dropped even more sharply so it is difficult to isolate the specific safety impact of the two directives (Knight 2011). It should also be noted that even with additional and extended vision mirrors, blind spots remain – mirrors can reduce the risk of cyclist non-detection by HGV drivers but they do not eliminate it altogether.

Figure 5.4 **Ground-level blind spots for HGV/Construction equipment drivers and the impact of additional mirrors**



Source: (Delmonte, et al. 2013)

Previously, blind spot mirrors had been made mandatory on all Dutch trucks by the end of 2003. No studies evaluating the safety effect of blind spot mirrors have been found. Crash statistics from Netherlands show that for a short period of time (2002-2003) the number of related fatal accidents decreased, but from 2004 the numbers were back on the same level as before (SWOV 2009)

As a result of an in-depth accident study the Danish Road Traffic Accident Investigation Board recommends front projection mirrors on trucks (HVU 2006) in order to diminish the .blind spot directly in front of the vehicle (see Figure 5.4). Mirrors are only useful if they are indeed used by HGV drivers and there is some indication that the multiplication of mirrors may in fact be a distraction to drivers and limit their effectiveness (Knight 2011). For this reason, the Danish Road Traffic Investigation Board recommends that mirrors be clustered together (e.g. on common masts) to make the mirrors easier to use rather than multiplying the number of mirrors.

Other on-vehicle measures targeting HGV blind spots have also been proposed and implemented in some cases. These include onboard indirect vision aids (cameras and displays) and onboard sensors and warning devices.

Low level windows on trucks

No studies evaluating the safety effect of low level windows have been found (see Figure 5.5). Nonetheless, the measure was recommended by the Danish Road Traffic Accident Investigation Board following an in-depth study of truck-bicycle crashes with trucks turning nearside and bicycles going straight ahead (HVU 2006). One of the main conclusions from the study was that drivers either failing to look or see a cyclist were contributory factors in all 25 crashes analysed.

Figure 5.5 **Truck with low level windscreen and side windows (Copenhagen)**

Photo credit: Authors

The in-depth study also found that in many crashes with nearside turning trucks, the lower edge of the windscreen or the side windows of the truck was more than 2 m above the road surface. To be able to see bicyclists positioned near the nearside front corner or along the nearside of the truck the driver then had to rely 100% on the mirrors and remember to use each of them. This finding is consistent with some of the analysis of EU Directives 2003/97/EC8 and 2007/38/EC9. Despite the use of all recommended mirrors, some blind spots for detecting cyclist still remain (Knight 2011). Low level windows could help drivers to be more aware of cyclists on the non-driver side and could improve the chances of drivers perceiving cyclists in their path before initiating a turn.

Protective devices -- Bicycle helmets

One area that has received vigorous research focus is the safety impact of bicycle helmet use and of helmet-wearing mandates. Studies addressing the safety impact of helmets can generally be split into two groups: those that focus on the way in which bicycle helmets change the injury risk for individual cyclists in case of a crash and those that focus on the generalised safety effect of introducing measures (typically campaigns and/or legislation) to increase helmet use among cyclists. These two approaches and their results must be treated separately.

The first group generally finds that wearing a bicycle helmet reduces the risk of sustaining a head injury in a crash (head injuries are among the most severe outcomes of cycle crashes). Meta-analysis of the quantified safety effects of bicycle helmet use in (Elvik, Høye, et al. 2009) finds the following:

Effects of wearing *hard* shell bicycle helmet in case of an accident:

- Risk of sustaining head injuries in general will *decrease* by 64%
- Risk of sustaining facial injuries will *decrease* by 34%
- Risk of sustaining neck injuries will *increase* by 36%

Effects of wearing *soft* shell bicycle helmet in case of an accident:

- Risk of sustaining head injuries in general will decrease by 41%
- Risk of sustaining facial injuries will increase by 14% (not significant)

A comprehensive Australian synthesis of 16 peer-reviewed studies in which the odds ratio for different types of head injuries was calculated using meta-analyses (Attewell, Glase and McFadden 2001) found similar results to those presented above. A subsequent re-analysis of this study controlling for publication bias found the safety-improving effect to be less pronounced and principally evident only in older studies (Elvik 2011).

To be clear -- these studies indicate that helmets reduce the risk of fatal and non-fatal head injuries for a single cyclist in case of a crash[3]. These are important benefits and greatly reduce the negative outcomes of crashes involving head contact. Furthermore, helmet technology has advanced considerably since the meta-analyses cited above – it is not clear that these findings reflect the safety effects of the latest generation of cycling helmets.

These safety effects, however, must not be mistaken for the aggregate *health* effects of mandatory helmet legislation or other measures to increase helmet use which must take into account the impact on overall numbers of cyclists. The health and safety effect of *mandatory* helmet legislation has been evaluated in far fewer studies than the individual risk in case of a crash. The effect of mandatory helmet legislation is a result of a series of sometimes conflicting factors:

- Reduced injury risk (due to increased helmet use)
- Increased crash risk (due to change in behaviour amongst cyclists who take up wearing helmets)
- Changes in the composition of the cycling population due to the mandate (e.g. cautious cyclists no longer riding because of perceived risk due to helmet mandate)
- Less cycling (leading to a reduced number of accidents and injuries, possibly contributing to a higher crash risk for those who still bike as discussed in Chapter 1 and, a potential reduction of overall health due to less physical exercise)

That helmet use decreases head injuries seems clear but other injuries may increase if helmet-wearers display riskier cycling behaviour. Changes in the composition and characteristic of the cycling population after helmet mandates are rarely controlled for in evaluation studies though this could be an important determinant of crash rates and severity (Robinson 2007). Whether cyclists change behaviour when they start to use a bicycle helmet seems very uncertain (and difficult to prove) but there is evidence in support of this (Elvik, Høye, et al. 2009) (Fyhri, Bjørnskau et Backer-Grøndahl, 2012) (Fyhri et Phillips 2013) (Phillips, Fyrhi et Sagberg 2013). It seems plausible that mandatory helmet use may dissuade new cyclists and possibly reduce the overall number of existing cyclists though there is conflicting evidence on this point. Those that are left, e.g. those that choose to cycle under mandated helmet use, might display a behaviour which is different from the behaviour of those who stop cycling (Fyhri, Bjørnskau et Backer-Grøndahl, 2012). Even under helmet use mandates, some cyclists will continue to ride without helmets and there is evidence that these cyclists display riskier behaviour than the remaining helmeted riders (Bambach, et al. 2013). All of these factors interplay but are rarely explicitly accounted for in research investigating the impact of mandatory helmet use. There is also evidence that motorists behave differently in the presence of helmeted riders for example by passing these cyclists more closely than non-helmeted riders (Walker 2007). This may have an incidence on crash numbers in the presence of increased helmet use.

(Elvik, Høye, et al. 2009) seek to quantify the impact of each of the factors cited previously while trying to control for the different dynamics described above. They find that helmet use mandates have the following effects:

- *Injury risk*: head injuries are reduced by 25% (increased helmet usage)
- *Crash risk*: all injuries increase by 14% (change in behaviour)
- *Number of cyclists*: all injuries are reduced by 29% (less cycling)

Overall, they find the effect of mandatory helmet legislation is a *reduction* in all injuries by 22% but they do not quantify the health impact resulting from the reduced number of cyclists. This is a crucial point because as discussed in Chapter 1, evidence suggests that the health benefits from cycling far outweigh the aggregate health and safety disbenefits.

One study (de Jongh 2012) seeks to address the overall health impact of mandatory bicycle helmet laws. He finds that in jurisdictions where cycling is relatively safe, helmet mandates are likely to have large unintended negative health impacts due to a drop in the number of cyclists. Furthermore in areas where cycling is already unsafe, helmet mandates will in most cases do little to improve safety and only under the most extreme assumptions will overall societal health improve. These are contestable findings as the ongoing debate around helmet use mandates would seem to suggest but it seems clear from a policy perspective that several key factors must be considered when considering such legislation. These include the impact of the mandate on the size and composition of the cycling population (and their risk profiles), the overall impact on health (and not just safety) and the need to address confounding factors and behavioural responses in ex-post evaluation.

5.4 Infrastructural measures

General design considerations

Premises for planning and geometric design

Regardless of local or national traditions and legislation it is important to keep in mind, that a bicycle is a vehicle. Just like any other motorised or non-motorised vehicle, a bicycle moves at a certain speed, which means that the cyclist needs time to react and brake or change direction if an obstacle or an unpredicted situation occurs. In practice, this means that on two-directional bicycle tracks or paths (green ways) the geometric alignment must meet physical parameters for sight distances to prevent head-on collisions between cyclists or between cyclists and moped riders (if moped riders are allowed on the bicycle track). This is especially important in curves at the end of a downhill section and/or where the bicycle track bends into tunnels/underpasses. In some countries these issues have been addressed by describing design speeds, sight/brake distances and minimum radii of horizontal curves in road standards or design guidelines. The tables below show some examples from the United Kingdom.

Table 5.1 **Recommended minimum stopping sight distances (UK)**

Off-Carriageway Cycle Routes (UK)	**Design Speed**	**Preferred Minimum Stopping Sight Distance**	**Preferred Minimum Radii (horizontal)**
Acceptable minimum (over short distances)	10 km/h	10 m	4 m
General off-carriageway cycle route provision	30 km/h	30 m	25 m

Source: UK Design Manual for Roads and Bridges (http://www.dft.gov.uk/ha/standards/dmrb/, accessed September 23, 2013)

Steep gradients can lead to relatively high speeds for descending cyclists or very low speeds for climbing cyclists – both can create hazards – thus gradients should be kept to a minimum. Stopping distances also increase significantly on downhill gradients in excess of 5%, and obstacles and sharp bends at the top or bottom of steep and/or long gradients should be avoided. In general a maximum. gradient of 3% is recommended in road standards from a number of countries. In Danish road standards the recommended maximum gradient depends on the distance travelled, which is shown in the following table.

Table 5.2. **Recommended gradients (Denmark)**

Gradient	Max. distance	Vertical height
5,0% (1:20)	50 m	2,5 m
4,5% (1:22)	100 m	4,5 m
4,0% (1:25)	200 m	8,0 m
3,5% (1:29)	300 m	10,5 m
3,0% (1:33)	500 m	15,0 m

Source: Danish Road Administration

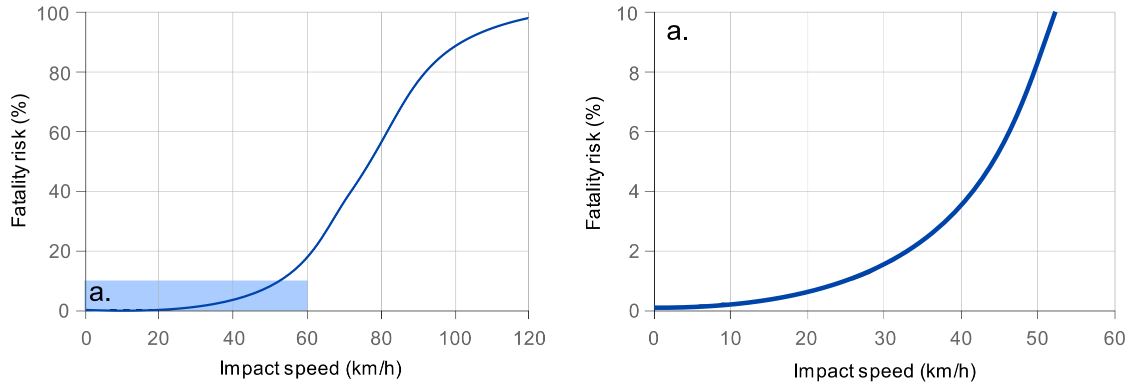
Separation or integration

Separating bicycle traffic from motor vehicle traffic is often regarded as an obvious measure to improve safety for bicyclists. As discussed in Chapter 1, separation of vehicles of different mass, different speed and different capabilities is one of the precepts of the ”Safe System” approach. This approach has largely guided bicycle safety planning in a number of European countries that display high numbers of cyclists and good safety performance. Nonetheless, separation has not been universally accepted as a desirable bicycle safety strategy – notably in the United States where there has been a historically significant movement in support of ”vehicular cycling” which advocates full mixing of bicycles in traffic and ensuring that cyclists behave in the same manner as other (motorised) road users. Support for vehicular cycling in the United States and elsewhere appears to be waning as municipalities there adopt the principal of segregated facilities as a way to ensure safety and attract new cyclists who would otherwise be intimidated in traffic. Recent research on the safety of cycling on segregated facilities vs. in mixed traffic in North America indicate that the former is safer (and is perceived as safer) than riding in mixed traffic (Teshke, et al. 2012) (Lusk, et al. 2011). A recent literature review also finds a safety-improving effect for segregated bicycle facilities (Reynolds, et al. 2009). This is somewhat in contradiction with some research from countries with extensive bicycle facilities and elevated cycling mode share that report elevated crash risks at junctions associated with bicycle tracks.

Bicycle traffic can be separated from motor traffic by installing separate areas designated for bicycles. Such areas may be part of the carriageway (paved shoulder or bicycle lane), separated from the carriageway by verge or kerbstones (bicycle track or bicycle path), or may not be part of a road at all (green ways).

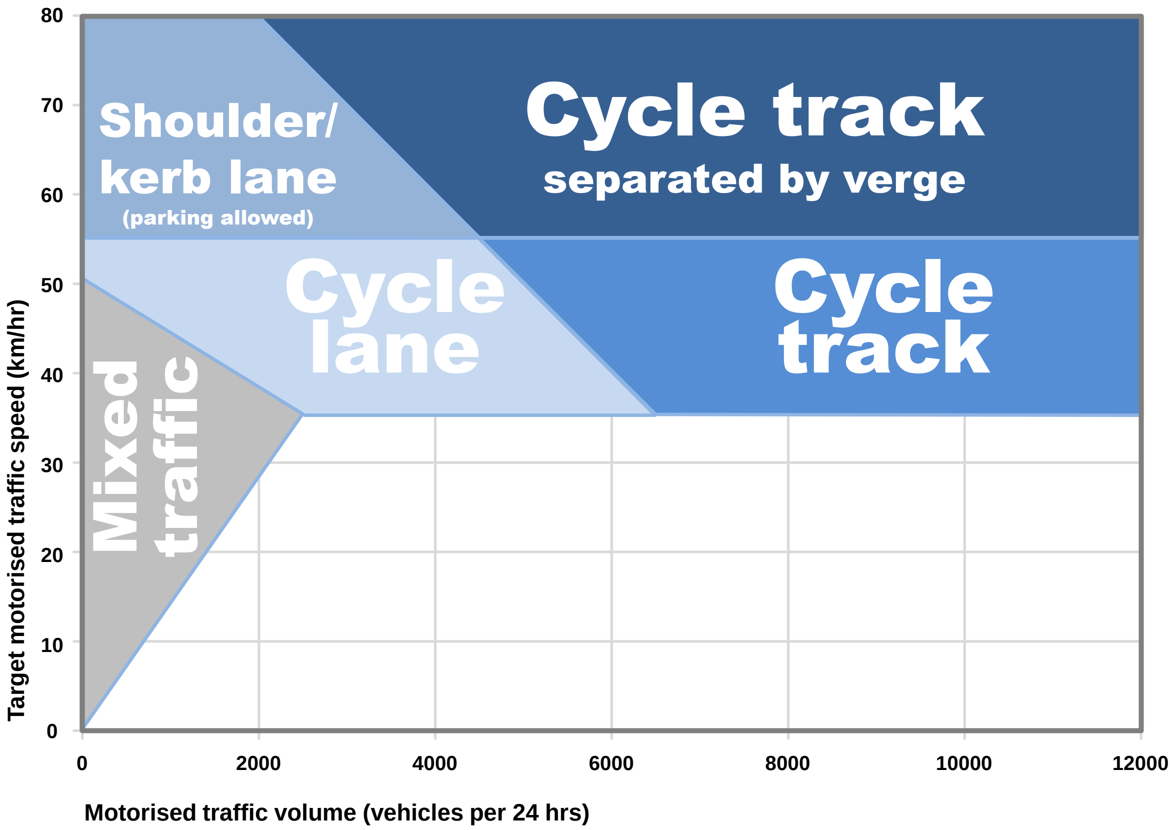
In this matter motor vehicle speed is a very decisive factor. The fatality risk for vulnerable road users as a function of crash opponent speed is well-studied and documented (Figure 5.6) (Rosen, Stigson et Sander 2011) (Teft 2011) . It should be noted that the speed-fatality (or speed-serious injury) relationship is nearly always based on analysis of pedestrian fatalities. Cyclists display different speed profiles as compared to pedestrians and this is likely to modify to some extent the motor vehicle-cyclist fatality relationship by an unknown but likely small extent. Crash outcomes at a given motor vehicle speed will differ among motor vehicles of different mass and cyclists of different ages (Teft 2011). Generally however, cyclists’ exposure to fatal and serious injury crashes rises exponentially with collision speed – reducing this exposure calls for separating bicycle traffic from motor vehicle traffic on roads and in areas where motor vehicle speed is as low as 30 km/h.

Figure 5.6 **Pedestrian fatality risk as a function of car impact speed**



Source: (Rosen, Stigson et Sander 2011)

Figure 5.7 **Guide for planning bicycle facilities on all-purpose roads (Denmark)**



Source: Cycling Embassy of Denmark, 2012 (Andersen, et al. 2012)

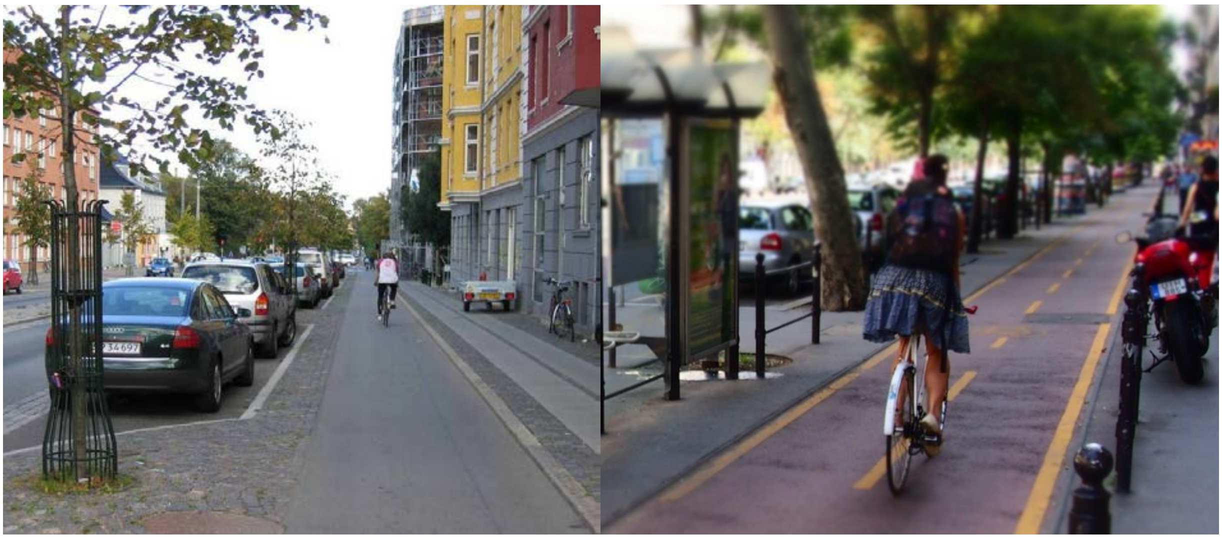
In most countries the situation on the road network is very far from the "Safe System" ideal of mass and speed-based separation. Where this is the case, emphasis should be put on separating bicycles from motor vehicles on the roads with highest speed levels and the highest traffic volumes, and slowing down speeds at junctions. Figure 5.7 illustrates a general approach to aligning bicycle infrastructure design to traffic speed and volumes as suggested by the Danish Cycling Embassy. It should be noted that in some countries applying a strict ”Safe System” approach such as the Netherlands, allowing bicycles adjacent to high speed motor traffic (upper left-hand side of figure 5.7) should never be allowed, despite low traffic volumes.

Linear facilities on all-purpose roads

A bicycle track/path may be designed either as a one-directional bicycle track – and is then normally installed on both sides of road – or as a two-directional bicycle track – which is installed only in one side of the road (Figure 5.8).

Findings on the safety impact of cycle tracks are mixed. Generally speaking, bicycle tracks reduce the number of head-on collisions and rear-end collisions involving bicycles on links between junctions (as might be expected due to the segregation of traffic). At the same time, however, the number of crashes involving bicycles in junctions have been seen to increase in some, but not all studies. Studies finding an increase in junction crashes do not give an indication of crash severity at junctions though crash reduction on linear tracks is an important result as rear-end and overtaking crashes (typical of non-junction mixed traffic bicycle crashes) are often relatively high-speed crashes and therefore likely to have severe outcomes.

Figure 5.8 **Bicycle Tracks**



Left – One-way bicycle track with “buffer” zone (cobble stones) to prevent collisions between bicycles and opening car doors (Copenhagen), Right – 2-way bicycle track with separation from pedestrians and parked cars (Budapest) Junction treatment of two-way bicycle tracks is particularly delicate as such infrastructure gives rise to non-conventional traffic manoeuvres.

Photo credit: Authors

If bicycle tracks are installed as a crash reduction measure, it is important to identify the actual safety problems on the road to determine whether a bicycle track is actually the right measure to mitigate those problems. In particular special attention needs to be paid to safe layout in junctions. Traffic authorities should also be aware that:

- Conflicts can occur at bus stops and where vehicles are parked on or beside cycle lanes.
- Fewer serious accidents involving personal injury occur on cycle tracks than on cycle lanes.

- Bi-directional cycle tracks along roads invariably lead to non-conventional manoeuvres at junctions and where such tracks terminate. These situations entail a significant risk of crashes. Two-directional cycle tracks along roads generally should be avoided, unless the advantages are very clear or the space constraints for two unidirectional tracks insurmountable.

Bicycle tracks marked directly on the sidewalk might be the easiest and cheapest way of providing bicycle infrastructure (Figure 5.9), but conflicts between bicyclists and pedestrians are inevitable for this configuration and in general it should be avoided.

Figure 5.9 **Left: Bicycle track (barely) marked on the sidewalk (Germany)**
Right: Bicycle track marked on the sidewalk (Faroe Islands)

Photo credit: Authors

One-way systems should normally only apply to motor vehicular traffic in dense urban street networks; the inconvenience of permitting bidirectional cycle traffic - with appropriate markings and protection - is usually less than the inconvenience of compelling cyclists to take a diversion or of having them ride in contravention of the rules. Contra-flow cycling on low-speed streets has been deployed in a number of countries. This measure requires clear entry and exit markings and surface treatments to alert motor vehicle drivers of the possibility of oncoming cyclists (Figure 5.10). (Mairie of Paris, 2012) has evaluated the before and after safety impact of contra-flow cycling on a number of one-way (for cars) streets in Paris. They find that the implementation of contra-flow cycling significantly increased overall bicycle traffic on the streets in question and also resulted in a drop in average motor vehicle speed (the streets in question were all limited top 30km/hr though actual motor vehicle speeds were sometimes higher). At the same time, there was no increase in cycling crashes (despite higher numbers of bicycles) and that those crashes that occurred did not significantly diverge in nature from the pre-contra-flow situation (e.g. most crashes were due to car-door collisions and failure to cede right-of-way in the motor-vehicle direction of travel. The study found that the incidence of post-contra-flow frontal bicycle-car collisions was extremely low (1 in fact over the one year post-implementation study period though this had been cited as one of the major risk factors) as was the crash's severity (possibly a consequence of reduced motor vehicle speed). The study's findings did highlight the risk for pedestrians in mid-block crossings. These findings provide a snapshot of the early effects of the implementation of contra-flow cycling just as motorists and cyclists are adapting to the new street configuration – it may be expected that crash risk and severity may further decrease as road users become habituated to the new configuration.

Figure 5.10 **Contra flow streets in Strasbourg (left) and St. Germain-en-Laye (right)**

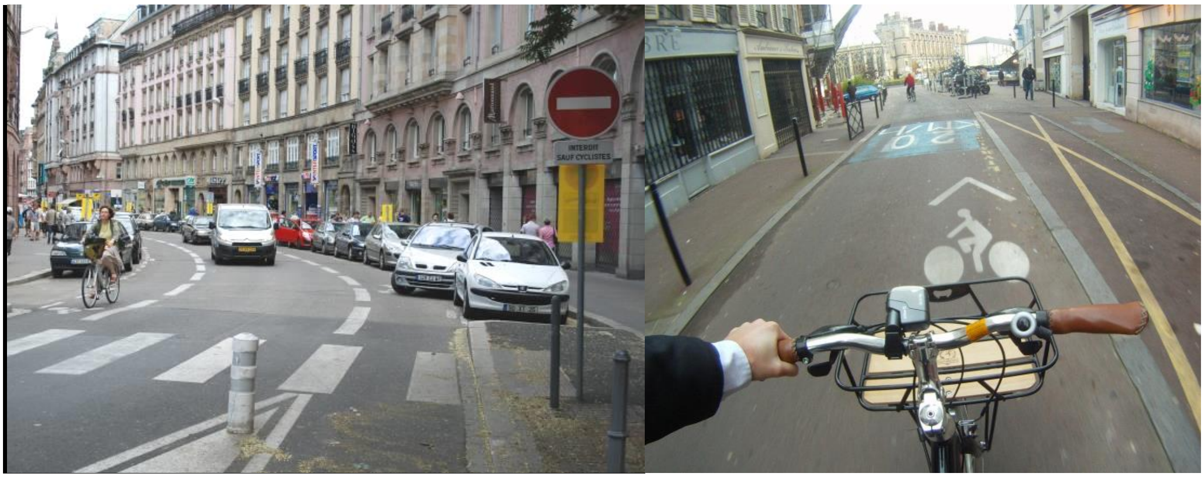


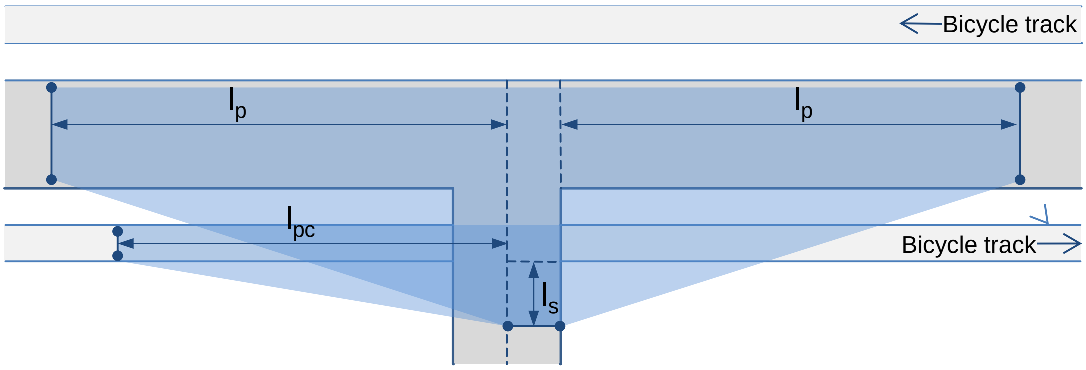
Photo credit: Authors

Junction design

In priority-controlled junctions, visibility splays must be provided for bicycle lanes, tracks or paths, if they continue through the junction.

The figure below (Figure 5.11) shows the visibility splays in a priority-controlled T-junction, where there are bicycle tracks along the primary road, and traffic from the side road has to yield for cyclists on the bicycle track as well as for motorised vehicles on the main carriageway.

Figure 5.11 **Visibility splays in priority controlled T-junction**
(with one-directional bicycle paths on main road, right-hand drive)



L_p : sight distance to vehicles on primary road
L_{pc} : sight distance to cyclists on bicycle track (along primary road)
L_s: eye point distance from give way line

Source: Danish Road Administration

Junction design is critical for improving cycling safety. Many potential treatments exist in order to ensure that poor visibility or sight lines do not impede safety:

- At priority-controlled junctions, the number of crashes involving cyclists decreases when the cycle track continues all the way through the junction.

- At signalised junctions, the installation of blue bicycle crossings can reduce the numbers of cyclists killed or injured, especially in connection with accidents when turning offside.

- Advanced stop lines at signalised junctions exert an influence on crashes occurring between vehicles turning to the nearside and cyclists travelling straight ahead, when these accidents occur at the start of the green period.

- Truncated cycle tracks at signalised junctions also result in fewer accidents involving vehicles turning to the nearside, although some cyclists may consider this approach unsafe.

Roundabouts

Roundabouts can play an important role in limiting the number of casualties at junctions and have been deployed in many jurisdictions. However, according to a great number of research studies from different countries, roundabouts do not seem to reduce the number of crashes involving cyclists. For example, (Elvik, Høye, et al. 2009) reports that several studies have shown little or no reduction in the number of bicycle crashes, when junctions are changed into roundabouts.

Many attempts have been made to find differences in the level of safety for cyclists in roundabouts with different types of layout. So far the results are not very clear, with the exception that roundabouts with more than one lane are associated with a higher incidence of bicycle crashes and should not be used by cyclists. Separate bicycle path systems – preferably with grade-separated cycle crossings – should be established for bicycle traffic at such roundabouts.

There are four types of roundabout design that are relevant in connection with safety for cyclist:

- One lane roundabout without any bicycle facilities.

- One lane roundabout with a bicycle *track* in the roundabout (next to the outer edge of the circulatory carriageway).

- One lane roundabout with a bicycle *lane* in the roundabout (on the outer edge of the circulatory carriageway).

- One lane roundabout with bicycle tracks recessed from the roundabout and cyclists having duty to yield when crossing the road arms.

Recent Belgian, German and American studies indicate that bicycle tracks or bicycle lanes in the roundabout (at the outer edge of the circulatory carriageway) are the worst solutions concerning safety for bicyclists (De Brabander, Nuyts and Vereeck 2005), (Daniels, et al. 2008). A recent Danish study also indicates, that the number of bicycle crashes is correlated with the speed of motor vehicles in the roundabout (Hels and Møller 2007).

Figure 5.12 **Small roundabout (mini roundabout) with raised (blue) bicycle lane (Copenhagen)**

Photo credit: Authors

A special type of roundabout is shown in Figure 5.12. Car speed is reduced by raising the bicycle lane a few centimetres above the normal road surface, so cars entering and leaving the roundabout have to pass a sort of “road hump” when they cross the bicycle lane. This has the advantage of strongly signalling the potential presence of cyclists to motorists but there are as of yet no studies quantifying the safety impact of this roundabout treatment.

Maintenance and Enforcement

While not strictly design principles, the effectiveness of safety-improving infrastructure treatments relies on ensuring that these operate as intended. In order to do so, bicycle infrastructure must be maintained to a standard such that the condition of the infrastructure does not contribute to crashes. This means ensuring that potholes and other running track irregularities are quickly repaired, that surfaces are swept of debris regularly and that bicycle facilities are kept clear of snow or standing water. Failure to do so might provoke crashes as cyclists hit, or alternatively, swerve to avoid obstacles or as bicycles lose traction due to poorly maintained or slippery surfaces. Maintenance may be particularly effective in reducing single bicycle crashes and falls since it corrects many of the contributory factors in these types of crashes (Reid and Adams 2010) (Schepers and Klein Wolt 2012).

Motor vehicle encroachment onto bicycle infrastructure causes cyclists to swerve to avoid and/or make their way past illegally parked or positioned motor vehicles (Figure 5.13). In addition, many jurisdictions stipulate minimum passing distances for cyclists (in mixed traffic) and have established right-of-way rules that govern cyclist/motor vehicle interaction at non-signalised junctions. Effective enforcement of these rules may avoid potentially dangerous conflicts that could result in injury crashes.

Figure 5.13 **Motor vehicle encroachment onto cycling infrastructure can contribute to crash-causing manoeuvres**

Photo credit: Authors

Enforcement of (or abiding by) traffic rules for cyclists – especially at signalised junctions **--** may also avoid situations where cyclists and motor vehicles come into conflict. Red light running by cyclists, for instance, is an often-cited contributory factor in fatal and serious injury bicycle crashes (at least in the United States as discussed in Chapter 4, and likely elsewhere as well). For instance, (District of Columbia Department of Transportation 2012) reports that 40% of cyclists observed in an evaluation study in 2012 disobeyed signals at signalised junctions. Non-compliance was highest at junctions with low volumes of conflicting traffic or long signal delays. In the latter cases, enforcement may be challenging as cyclists may feel that signal timing and traffic volumes do not account for bicycle traffic.

Accident reduction measures for road sections

Bicycle paths/tracks along roads

The safety effect of building bicycle paths or tracks along roads (Figure 5.14) has been subject to a great number of research studies within the last 30-40 years. In general the studies show, that building bicycle paths/tracks along a road reduces the number of head-on collisions and rear-end collisions involving bicycles on road sections between junctions (as expected) and there are some indications of reduced crash severity as well. However, the number of accidents involving bicycles in junctions (and in some cases at bus stops) are likely to increase as discussed earlier.

Figure 5.14 **Typical bicycle paths/tracks alongside roads**

Left: Typical Danish one-directional bicycle track in urban area separated from the carriageway by kerbstones (Copenhagen). Right: Two-directional bicycle path in urban area separated from the carriageway by a verge (Warsaw).

Photo credit: Authors

According to the meta-analysis in (Elvik, Høye, et al. 2009), the overall safety effects of bicycle paths/tracks in relation to injury crashes involving bicycles are:

- A statistically significant *increase* of 24% in junctions.
- A statistically significant *decrease* of 11% on road sections (mid blocks).

On average the overall result is a non-significant *increase* of 7% for injury accidents involving bicycles according to (Elvik, Høye, et al. 2009). It should be added that the installation of bicycle tracks will make *all* injury accidents (not only bicycle accidents) *decrease* by 2% according to the same source.

A Danish study (Jensen,) sheds additional light on which crash types have increased and which have decreased following the installation of bicycle tracks on 20,6 km of roads and streets in the city of Copenhagen. In brief, it finds:

- In *junctions*: crashes with cyclists being hit by cars turning left or right will *increase*, while crashes with cars hitting offside-turning cyclists will *decrease*.
- On *sections:* crashes with cyclists hitting other cyclists or pedestrians (mainly bus passengers) will *increase*, while accidents with cyclists being hit by cars from behind and accidents with cyclists hitting parked cars will *decrease*.

Despite the high number of studies showing similar results, the safety performance of bicycle tracks and in particular the increase in number of crashes observed on this type of infrastructure is disputed and the results stated above have often challenged. It is true that some of the studies are quite old and that many of the studies are from a limited number of northern European countries with a well-established tradition for bicycling and crowded bicycle facilities. Furthermore, the results of many of the studies are not adjusted for changes in bicycle traffic volumes.

It may be that the safety effect of separated cycle tracks may be different in different contexts as well. Recent studies from North America do not find a similar increased crash and injury risk associated with separate bicycle tracks -- (Lusk, et al. 2011) report that the relative risk of injury on a bicycle track was 0.72 as compared with riding on parallel reference streets in Montreal and (Teshke, et al. 2012) report a relative risk of 0.11 for riding on a cycle track as compared to a similar reference street in Toronto and Vancouver. Unlike the northern European cycling environments that served as the backdrop for studies finding increased (junction-related) crash risk for cycle tracks, the Canadian traffic situation that sets the context for the two aforementioned studies is characterised by lower numbers of cyclists and a much lower cycle infrastructure density. It is unclear from these studies if these factors had an impact on study results[4].

Most of the studies contributing to the results in (Elvik, Høye, et al. 2009) address the effect of building bicycle paths/tracks in urban areas. According to a recent Danish synthesis bicycle paths in *rural* areas show far better results (Jensen, Andersson and Herrstedt 2010). The total number of injury crashes involving bicycles (and mopeds) *decrease* by 62% (average for sections *and* junctions) when bicycle paths are installed along roads in rural areas. For fatalities the effect is even higher (80% decrease overall). A possible explanation to this very high effect is the speed level in rural areas and the subsequent benefit of separating bicycle and motor vehicle traffic.

According to (Elvik, Høye, et al. 2009) and (Jensen, Andersson and Herrstedt 2010) it is not possible to identify specific results for *two-directional bicycle paths*. Despite the absence of specific results in terms of overall safety effects, experience has shown some specific safety problems connected to two-directional bicycle paths:

- Head-on collisions between cyclists or between cyclists and moped riders.
- Collisions with cars from the side road in priority junctions (car drivers not paying attention to cyclists from the “wrong” direction on the bicycle track).

Despite the counter-factual evidence from North America cited above, the observed increase in crash risk associated with cycle tracks in northern European countries is problematic since many countries are seeking to increase this type of bicycle infrastructure. What then are possible explanations for this phenomenon and how can they be addressed by policy? A number of theories have been outlined to explain why bicycle paths and tracks lead to an increasing number of bicycle crashes at junctions. A generally accepted theory is that the physical separation on the road sections makes bicyclists and car drivers pay less attention to each other when they approach junctions. This is likely to especially be the case where the design of the bicycle track “hides” the cyclist from turning cars (Figure 5.15).

Figure 5.15 **Some bicycle track designs (verges with trees, lamp posts etc.) may "hide" bicyclists from turning cars**

Photo credit: Authors

Another possible explanation is that the installation of a bicycle track changes the lateral position of the bicycles towards the edges of the cross section, thus making cyclists less visible for car drivers coming from a side road or turning offside into a side road.

In the Danish study (Jensen 2006), a third possible explanation is suggested: When a bicycle track is installed, it is often necessary – in order to make space for the bicycle track – to ban parking on the road. As a result more car drivers will turn in to the side roads to look for parking space, and therefore the number of crashes in junctions – especially in the minor, priority controlled junctions – will increase simply because of increased traffic volumes to and from the side roads.

Figure 5.16 **Left: Pedestrians crossing a bicycle track. Right: Conflicts between pedestrians and cyclist on a bicycle track**

Photo credit: Authors

The increased number of pedestrian crashes found in some studies is often explained by lack of awareness or detection of cyclists by pedestrians who are more concerned about cars on the carriageway Figure 5.16). They don't consider bicyclists "dangerous" and forget to look out when crossing the bicycle track. In some cases the design also may contribute to this lack of awareness, for instance if it is difficult for pedestrians to see a distinction between sidewalk and bicycle track.

Figure 5.17 **Bicycle-pedestrian interaction zones at bus stops**

Left: Bicycle track with speed hump at bus stop. Right: Bus stop with pedestrian island between bus bay and bicycle track.

Photo credit: Authors

It is also important to remember that the installation of bicycle tracks will generate new conflicts at bus stops, since bus passengers now have to cross the bicycle track to get from the sidewalk to the bus or reverse. Possible counter measures include speed bumps on cycle tracks slightly before the bus stop or a refuge island between cycle track and bus bay to shelter passengers boarding or alighting from the bus (Figure 5.17).

Bicycle lanes in urban areas

The safety effect of marking bicycle lanes on the carriageway has also been subject to a number of research studies within the last 30-40 years. Most of the studies address bicycle lanes in urban areas (Figure 5.18). In general the studies find that bicycle lanes reduce the number of crashes involving bicycles on sections (mid-blocks) *as well as in* junctions.

Figure 5.18 **Typical bicycle lanes**

Left: Bicycle lane in Norway (Oslo). Right: Bicycle lane in Denmark (Copenhagen).

Photo credit: Authors

According to (Elvik, Høye, et al. 2009), the average safety effects on injury crashes involving bicycles are

- A statistically significant *decrease* of 25% in junctions.
- A non-significant *decrease* of 19% on road sections (mid blocks).

On average the overall result for both sections and junctions is a *decrease* of 9% for injury crashes involving bicycles. This overall result is based on many more studies than the specified effects for junctions and sections (which explains why the overall effect is not somewhere between 19% and 25%).

The results found in (Elvik, Høye, et al. 2009) are all based on studies of "pure" bicycle lanes (no shared lanes of any kind). There is little research on the safety effects of shared lanes or "suggested" lanes (see glossary). One study, however, finds a relative risk of 1.99 for suggested bicycle lanes or "sharrows" as compared to a reference street with no infrastructure in two Canadian cities (and also finds a relative risk for a painted bicycle lane to be 0.86) (K. Teschke 2012). It is also worth mentioning that the results from the different studies analysed in (Elvik, Høye, et al. 2009) in relation to bicycle lanes are less consistent than the results of studies examining the safety impacts of bicycle tracks. For instance the results from (Jensen 2006) are quite different from the overall results in (Elvik, Høye, et al. 2009). In the former study, an increase in number of bicycle crashes was found on sections *and* in junctions. On the other hand, this study was based on results from one city only (Copenhagen).

Though the results in (Elvik, Høye, et al. 2009) are all based on studies of "pure" bicycle lanes (no shared lanes of any kind), there are still differences in the layout of bicycle lanes – not only from one country to another but also within a country or city (Figure 5.19). Differences in layout could be part of the explanation to why the results in (Jensen 2006) are very different from the results in (Elvik, Høye, et al. 2009). For instance, bicycle lanes in Copenhagen are often placed between the sidewalk and a parking lane, and therefore cyclists are "hidden" from cars turning cars at side roads (Figure 5.19 - right).

Figure 5.19 **Bicycle lanes and car parking**

Right: Bicycle lane on the left side of car parking zone with door-opening buffer (Paris), Left: Bicycle lane between a parking lane and the sidewalk (Copenhagen).

Photo credit: Authors

The effects presented in (Elvik, Høye, et al. 2009) are only for crashes without reference to crash injury severity. Other studies have found, that bicycle crashes on roads with bicycle lanes are more severe than crashes on combined road/bicycle track facilities (depending on speed level) (Jensen, Andersen, et al. 2000). One contributing factor may be the propensity for motorists to pass cyclists in a bicycle lane more closely (Walker 2007) (Parkin and Meyers 2010) which may be explained by the fact that motorists position themselves with respect to the painted bicycle lane margin and not the cyclists within the bicycle lane.

(Turner, et al. 2011) undertook a before-and-after safety impact evaluation for bicycle lanes in a number of Australian and New Zealand cities. They found that bicycle lanes built to high standards improve safety while, conversely, cycle lanes built to low standards degrade safety. Taking this into account, they found the overall safety impact of the lanes studied to be neutral. They also found that providing sufficient space in an approach lane or for the combined bicycle lane and adjacent traffic lane is more important that delimiting a bicycle lane within available (sometimes too little) space – overall wider cycle lanes (between 1 to 1.8 metres) had beneficial safety impacts. Better driver behaviour was also observed when cycle lanes were painted in colour.

Paved shoulders

Paved shoulders are often used by cyclists as bicycle lanes on rural roads with no designated bicycle facility (Figure 5.20). The paved shoulders are separated from the carriageway by either broken or solid – profiled or non-profiled – edge lines, depending on national or local regulation. The width of the paved shoulder might be very different from one road to another.

The safety effect of paved shoulders has been subject to a number of research studies. In general the studies find that roads with paved shoulders (up to approximately 1 metre wide) have lower overall (motor vehicle and bicycle) crash rates than roads without paved shoulders (Elvik, Høye, et al. 2009).

This overall result applies to bicycle crashes as well (Rosbach 1984) – but most of the studies do not estimate specific effects for bicycle crashes. To be clear, allowing cyclists onto paved shoulders in itself violates one of the principles of "Safe System" approach discussed in Chapter 1 – notably the separation of high mass and high speed traffic from cyclists -- but wide shoulders serves as an imperfect proxy for separation where fully separated facilities are not felt to be justified.

Figure 5.20 **Paved shoulders on rural roads (Denmark)**

Photo credit: Authors

Paved shoulders may be provided by adding the paved shoulder to the existing road width (widening the paved width) or by narrowing the traffic lanes to make space for hard shoulders within the existing paved width. Most of the studies find that widening the paved width will reduce the number of crashes, but when the paved shoulders are provided within the existing road width, results are very inconsistent and no clear recommendations can be given. Rumble strips should not be placed in the paved shoulder if it is supposed to be used by bicyclists.

Parallel access roads

A parallel access road is a lower speed road placed alongside a higher speed main road. It is meant to be used by vulnerable road users and slow moving (agricultural) vehicles and to provide access to private properties (Figure 5.21).

According to Dutch road design guidelines (CROW 2002) and based on a comparative (not before-and-after) study, the accident risk for *all vehicles* travelling distributor roads with a parallel access road is 55% lower than the accident risk for all vehicles travelling on a distributor road with a parallel bicycle path. The size of the difference and the specific incidence of bicycle crashes for the two designs are not quantified. However, the perception of safety for cyclists may be higher on a separate bicycle track as parallel access roads carry traffic and have numerous entries and egresses.

Speed management

Reducing speed – either by means of speed limits or by physical measures – may be used to enhance bicycle safety (and that of pedestrians) (Figure 5.21). These measures may be deployed:

- As a single site treatment (for crash reduction).
- As part of a traffic calming scheme (area wide or on a specific road) where the objective is to direct through traffic to more suitable roads.
- As part of an "environmental road" where the objective is not to redirect traffic, but to ensure that through traffic pass through in a safe way.

The general safety effects of speed reducing devices are well-documented. Studies find that speed reducing is a very efficient safety measure showing good results worldwide, whether it is used for traffic calming, for environmental roads or just as a single site measure for accident reduction (Elvik, Høye, et al. 2009). However, some studies looking specifically at bicycle crashes find that traffic calming schemes generate an increasing number of crashes involving bicycles and other two-wheelers.

Figure 5.21 **Road hump with kerbed islands and bollards**

The islands protect bicyclists from being squeezed by cars trying to avoid the hump, but the islands also constitute a hazard for bicyclists.

Photo credit: Authors

One of latest studies to show this phenomenon is Danish and was published in 2007 (Jensen 2007). The study found like many other studies a reduction in the total number of crashes, especially pedestrian crashes, but also a (non-significant) 10% increase in the number of bicycle and moped crashes. The study does not analyse potential causes for the increase in bicycle and moped crashes, but similar results were found in the evaluation of the first environmentally adapted through roads in Denmark where it was found that cyclists were crashing with sign posts, bollards etc. put up as part of the traffic calming scheme. It is therefore important to ensure that the deployment of speed reduction devices, signage and other traffic-calming measures does not create new hazards to cyclists on speed-controlled streets or in traffic calmed zones.

Figure 5.22 **Spherical road hump without any vertical hazards for bicyclists**

Photo credit: Authors

Bicycle streets or Bicycle boulevards

Bicycle boulevards or bicycle streets combine aspects of traffic calming and speed management resulting in streets with relatively low motor vehicle traffic and attractive cycling conditions. Few studies have looked at the safety impacts of such streets as a whole though many studies have looked at the impacts of the specific speed control and traffic calming strategies employed (see above). One study did investigate the relative safety of bicycle boulevards compared to adjacent reference arterial streets in Berkeley, California and found that collision rates on bicycle boulevards were two to eight times lower (though no difference was found in the share of severe injuries) (Minikel 2012).

Crash reduction measures at cycle track crossings

Refuge / central islands

Central islands are commonly used at pedestrian crossings and are normally regarded as useful safety measures, but no evaluations estimating a specific safety effect for bicyclists have been found (Figure 5.23). Evidence from Korea indicates that under-dimensioned refuges may pose a safety hazard for cyclists due to insufficient marshalling space for bicycles at central islands installed at bicycle crossings.

Figure 5.23 **Central island at bicycle crossing on urban road**

Photo credit: Authors

Speed reducing measures on bicycle path / greenway

In some countries bars or barriers across the bicycle path are often used to make cyclists slow down and, in some cases, dismount before crossing a road (Figure 5.24). From a safety point of view this is not an ideal solution. Bars are rigid obstacles constituting a hazard to cyclists and many cyclists will try to avoid passing through the bars, which might lead to hazardous situations.

A Danish behavioural study in the town of Odense did find, that speed reducing measures (humps) on the bicycle path in combination with right-of-way markings might be a better and more safe alternative to bars, where greenways cross roads (Jensen 2003).

Figure 5.24 **Speed reducing measures on bicycle paths or greenways**

Left: Bicycle path with hump and rumble strips on the approach to a bicycle crossing (where bicyclists have to yield). Right: Traditional bicycle crossing with bars.

Photo credit: Authors

Measures in priority junctions

Bicycle crossing with priority

Our review has not found any evaluation of the safety effect of giving cyclists priority at road crossings though this is the practice in many countries in line with efforts to structure priority from the most vulnerable road users to the least vulnerable (at least on minor roads in urban areas) (Figure 5.25). Such priority should only be installed on minor roads, where speeds are relatively low or can be reduced to a suitable level. In addition, it is important to ensure clear sight lines onto the bicycle infrastructure from the motor vehicle operator's seat.

Figure 5.25 **Bicycle crossing on raised plateau and with right of way for bicyclist (Denmark)**

Photo credit: Authors

Recessed bicycle track

A recessed bicycle track may be used in priority junctions on major roads (Figure 26). The 5-7 m deflection of the cycle track makes it possible for passenger cars to stop between the bicycle track and the main road carriageway. The car drivers then will be able to fulfil their obligations to yield in to bicycle traffic which in theory should improve safety. Only one evaluation study of this measure was found in our review though it did not find any conclusive safety effects (Andersen, Nielsen and Olesen 2004).

Figure 5.26 **Recessed bicycle track**

Photo credit: Authors

Continuing bicycle track

Continuing bicycle tracks may be used in priority junctions on minor or major roads (Figure 5.27). Normally the continuing bicycle track is combined with a continuing sidewalk (sometimes called *exit construction*).

Figure 5.27 **Continuing bicycle track (and sidewalk) in a priority junction**

Photo credit: Authors

A few evaluation studies have been carried out. According to (Elvik, Høye, et al. 2009), the overall safety effect of continuing bicycle track in a priority junction is a 13% (non-significant) reduction in the number of bicycle crashes compared to a situation where the bicycle track (and the sidewalk) is interrupted at the junction. According to (Jensen 2006), the safety benefits of continuing bicycle tracks are more pronounced for 4-armed junctions than in T-junctions.

Side road entry treatments

Side road entry treatments (SRETs) consist of a flat-topped raised platform across the mouth of a side-road junction with a main carriageway (Reid and Adams 2010) (Figure 2.28). SRETs are not strictly cycle-specific infrastructure as they were designed primarily for pedestrians but studies have found a safety-improving effect for bicycles. (Wood, et al. 2006) report a statistically significant 20% reduction of bicycle collisions due to SRETS though the overall number of collisions remained essentially unchanged (motorised two-wheeler collisions increased) within London. They also report a statistically significant 51% decrease of bicycle collisions (and an estimated 21% reduction of all collisions) in outer London.

Figure 5.28 **Side road entry treatment (SRET) with contra-flow bicycle lane (Paris)**

Photo credit: Authors

Storage lane for offside turning bicyclists

No studies evaluating the safety effect of storage lane for offside turning cyclist have been found in our review (Figure 5.29). The measure, at least in theory, offers a solution to a well-known problem which has recently been highlighted in a Danish in-depth study on severe bicycle accidents in priority junctions (HVU 2008). The study found that a significant number of crashes result from a cyclist (often elderly) failing to look back when turning offside (across oncoming traffic) to a side-road. This type of crash is most likely to happen on roads with no bicycle tracks, and in rural areas the outcome is likely to be a severe – often fatal – casualty due to motor vehicle speed. Storage lanes on the nearside of the road mitigate this problem by providing an area where the cyclist may slow or dismount and undertake a full scan back before crossing the road.

Figure 5.29 **Bicycle storage lane (Denmark)**

Bicycle storage lane (on the nearside of the carriageway) providing a protected area where offside turning bicyclists may wait for safe passage.
Photo credit: Authors

Measures in Signalised junctions

Designated signals / separate phases / pre-green stage

Traffic signals (Figures 5.30, 5.31) and different ways of upgrading existing signalised junctions have been subject to a fairly high number of evaluations and research studies. Unfortunately only very few of the studies have presented quantified results for reductions of bicycle crashes. (Elvik, Høye, et al. 2009) presents the safety effects of a great number of upgrading measures for signalised junctions. Three measures are found to be especially likely to be relevant for reducing bicycle crashes, even though their effects are not quantified in that review. Those measures are:

- Extended all-red traffic light phase
- Conflict-free phase changes
- Separate offside turn phases

Figure 5.30 **Different types of designated bicycle signals**

Photo credit: Authors

Extended all-red phases reduce the overall crash risk in signalised junctions by 55% according to (Elvik, Høye, et al. 2009). This result is statistically significant, and it is plausible that cyclists also benefit from the result. On the other hand, some of the studies that have contributed to this finding are relatively old, were carried out on junctions with particular accident problems (black spots) and/or did not control for regression to the mean. It is hardly possible to obtain the same result in a modern signalised junction with optimised time settings etc.

Conflict-free phase changes decrease injury crashes by 75% according to (Elvik, Høye, et al. 2009). As noted above, some of the studies contributing to this finding are old and some caution should be exercised in interpreting this finding. However, one of the studies explicitly looked at impacts on bicycles and mopeds, confirming the crash-reduction effect (Bach and Jørgensen 1986). The result was not statistically significant, but otherwise very clear (almost a 70% reduction).

Separate offside-turn phases reduces the number of offside-turn crashes in signalised junctions by 58% according to (Elvik, Høye, et al. 2009). This effect is likely also to apply to crashes with bicycles (especially accidents where bicycles are hit by offside turning cars from the opposite direction). It should be mentioned that separate offside-turn phases are likely to cause a minor increase in other types of crashes – including crashes involving bicycles. If separate offside-turn phases are introduced in a junction where offside turn crashes only account for a minor share of overall crashes, there is a risk that the decrease in offside turn crashes will be outnumbered by an increase in the number of other types of crashes.

Figure 5.31 **Bicycle-specific traffic signal phases**

Left: Pre-green stage for bicyclists (Copenhagen). Right: Separate phases for nearside turning cars against bicycles travelling straight ahead (Copenhagen).

Photo credit: Authors

Other measures to reduce the number of nearside turn crashes in signalised junctions – such as *pre-green stages* for cyclists and *separate phases* for nearside turning cars against bicycles – are commonly used in some countries, but no specific evaluation of the safety effects have been found.

Advanced stop line

On streets and roads with bicycle tracks or bicycle lanes, differentiated bicycle versus car stop lines may decrease bicycle crashes (Figure 5.32). The advanced bicycle stop line may be placed ahead of the stop line for cars in order to prevent crashes between nearside-turning cars and bicycles travelling straight ahead at the beginning of the green stage.

Figure 5.32 **Advanced stop line in signalised junction (Copenhagen)**

Photo credit: Authors

According to (Elvik, Høye, et al. 2009), advanced stop lines reduce the number of injury crashes with cyclists by 19% (compared to a situation with stop lines next to each other). This result is not statistically significant.

According to the Danish synthesis (Jensen, Andersson and Herrstedt 2010), advanced stop lines reduce two specific injury crash types by 35%:

- Car turning to the nearside in front of bicycle going straight ahead
- Car turning to the nearside in front of pedestrian walking straight ahead

The Danish Road Traffic Accident Investigation Board recommends that the distance between the two stop lines is kept at exactly five metres to make it possible for truck drivers waiting at the stop line for cars to observe bicyclists waiting at their stop line (HVU 2006).

This treatment augments cyclists’ perception of safety at signalised junctions (as opposed to other treatments such as the truncated bicycle track) as well as contributes to crash reduction. According to (Jensen 2006), advanced stop lines are the safest solution for cyclists in signalised junctions if combined with a separate nearside turn lane for cars. If a separate nearside turn lane cannot be provided, the use of a truncated bicycle track is safer. It should be noted, however, that these findings were based on crash investigations in only one city (Copenhagen).

If advanced stop lines are installed in existing signalised junctions, it might be necessary to adjust the timing of the signals.

Bicycle box

The bicycle box is a reservoir for cyclists placed in front of the stop line for cars at signalised junctions and might be regarded as an alternative version of the advanced stop line (Figure 5.33). Like the advanced stop line the purpose is to prevent accidents between nearside turning cars and bicycles travelling straight ahead at the beginning of the green stage.

Figure 5.33 **Bicycle boxes**

Left: Bicycle box, signalised 3-armed junction (Edinburgh). Right: Bicycle box in signalised 4-armed junction (St. Germain-en-Laye).

Photo credit: Authors

The bicycle box is used and recommended in many countries, but studies quantifying their safety effect are lacking. For instance, while a number of behavioural studies have been published none of them indicate a decisive safety effect (Elvik, Høye, et al. 2009). Nonetheless, studies such as (Dill, Monsere and McNeil 2012) observe that bicycle boxes reduce behaviours that contribute to crashes.

Narrow bicycle lane

The narrow bicycle lane is most often used as a way of continuing an interrupted bicycle track or a normal bicycle lane right up to the stop line in signalised junctions (Figure 5.34). The narrow bicycle lane may also be used on roads with no bicycle facilities – then it is only marked on the last 10-15 m before the junction.

The theory is that cyclists travelling on a narrow bicycle lane instead of a bicycle track or a normal bicycle lane will adjust their behaviour and pay more attention to cars, when they approach the junction. This is supposed to reduce the risk of cyclists being hit by nearside turning cars. A Danish study on narrow bicycle lanes in 12 signalised junctions in Copenhagen did not find any significant changes in overall crash risk (Jensen 2010).

Figure 5.34 **Narrow bicycle lanes**

Left: Narrow bicycle lane at the end of an interrupted bicycle track (Denmark). Right: Narrow bicycle lane installed only at the junction (Denmark).

Photo credit: Authors

Truncated (interrupted or dropped) bicycle track

A truncated bicycle track stops approximately 20 metres before a junction forcing cyclists to merge into the nearside lane with nearside-turning cars (Figure 5.35).

Figure 5.35 **Truncated bicycle track in signalised junction (Copenhagen)**

Photo credit: Authors

According to (Elvik, Høye, et al. 2009), truncated bicycle tracks reduce the number of injury crashes with cyclists by 31% compared to a situation where the bicycle track continues right up to the junction (without advanced stop lines). This result is statistically significant.

A number of theories have been put forward to explain why truncated bicycle tracks perform better in terms of crash reduction than many alternative treatments. One possible and often quoted explanation is that cyclists and car drivers pay more attention to each other in mixed traffic and that cyclists are feeling more unsafe (and thus more cautious in their behaviour at the junction) (Elvik, Høye, et al. 2009). For that same reason, many cyclists (and especially new or inexperienced cyclists) perceive truncated bicycle tracks to be less safe than they actually are.

There are other, possibly more obvious, explanations. When the bicycle track is truncated, cyclists have the possibility of placing themselves on the offside side of nearside-turning cars as they would in free traffic conditions. When cyclists chose place themselves so, conflicts at the stop line are replaced by merging manoeuvres at the beginning of the nearside-turn lane. Here cyclists and cars arrive randomly and each can stage themselves irrespective of signal phases whereas conflicts at the stop line are concentrated within the green signal phase.

According to (Jensen 2006), truncated bicycle tracks are the second-best solution for cyclists in signalised junctions (on roads with bicycle tracks), and should be used if it is impossible to combine an advanced stop line with a separate nearside turn lane for cars. As noted earlier, however, this study bases it findings only on results from one city (Copenhagen).

Truncated bicycle tracks are a suitable solution where bicycle traffic is moderate. If bicycle traffic volumes are very high, it becomes difficult for nearside-turning car drivers (and for cyclists) to merge with the cyclists and congestion may occur (Figure 5.36).

Figure 5.36 **Truncated bicycle track at a crowded signalised junction (Copenhagen)**

Bicycle traffic volumes make it difficult for car drivers to mix with bicycles in the nearside turn lane.

Photo credit: Authors

Central bicycle lane or "pocket lane"

A central bicycle lane is a lane for cyclists travelling straight ahead (or turning offside) in a signalised junction (Figure 5.37). The central lane is placed between the nearside turn lane and the other car lanes. The start of the lane may be painted in blue or another contrasting colour in relation to the carriageway to make nearside turning car drivers aware that they are crossing a bicycle lane – and to direct the bicycles travelling straight ahead into the central lane.

The central bicycle lane is closely related to the truncated bicycle track and works well with the latter. While the truncated bicycle track makes it possible for the cyclists to place themselves on the offside side of nearside turning cars, the central bicycle lane forces them to do so.

Figure 5.37 **Central bicycle lane**

Left: Central bicycle lane in a signalised junction in Norway (Oslo). Right: Central bicycle lane in a signalised junction in Denmark (Copenhagen).

Photo credit: Authors

A few research studies have been undertaken in order to estimate the safety effects of the central bicycle lane. In general the number of bicycle crashes in these studies was too small to produce a significant result, but there are indications that the measure improves safety for cyclists (Sørensen 2011).

Coloured bicycle crossings at junctions

Coloured cycle crossings at junctions (Figure 5.38) serve two purposes:

- They indicate to cyclists where they should ride through a junction.
- The warn car drivers look out for cyclists when they crossing the coloured marking.

According to (Elvik, Høye, et al. 2009), coloured bicycle crossings in signalised junctions reduce the number of injury crashes involving cyclists by 22%. This result is statistically significant, but findings in (Jensen 2006) indicate that the effect depends on the complexity of the junction and the number of coloured crossings in the junction. According to that study, the best results are obtained in junctions with only one coloured cycle crossing.

Figure 5.38 **Coloured bicycle crossings at junctions**

Left: Blue bicycle crossing in Copenhagen. Right: Green bicycle crossing in Strasbourg.

Photo credit: Authors

Refuge cycle track or shunted track

Refuge or shunted cycle tracks (Figure 5.39) allow cyclists to turn to the nearside in a protected space so as to remove potential conflicts with nearside-turning motor vehicles. Bicycle-motor vehicle conflicts are thus removed but conflicts with pedestrians may emerge if nearside turning is allowed irrespective of pedestrian crossing signals. We are not aware of studies that have specifically documented the safety impact of refuge cycle tracks.

Figure 5.39 **Refuge or shunted cycle track (nearside turning - Copenhagen)**

Photo credit: Authors

5.5 Other Measures

Cycle lanes in the middle of the road

Cycle lanes in the middle of the road (Figure 5.40) are currently implemented or about to be implemented in several European countries, in one-way but also in two-way streets. We have found no evaluation studies examining the safety impacts of these facilities. According to their proponents, the following improvements are expected:

- Better mutual perception between cyclist and car driver
- Prevents from accidents when people open their car doors
- Decrease of accidents at junctions
- More convenience for the cyclist
- Traffic calming
- Better safety for pedestrians crossing streets as the cyclist isn't hidden by parked cars

Figure 5.40 **Cycle path in the middle of the road**

Photo credit: Direction General del Transporte, Spain

Off-side cycle lanes

Off-side cycle lanes (Figure 5.42) can be seen in several countries though we could not find evaluation studies assessing their safety impact. Designers of off-side cycling lanes expect the following results[5]:

- Better visibility — Drivers are better able to see bicyclists in the driver's side mirror than on the passenger side. There is also a large blind spot on the passenger side of most vehicles.

- Fewer truck conflicts — Since most loading zones are on the near side of the roadway, there are fewer delivery trucks crossing the bike lane on the off side of the roadway.

- Fewer door incidents — Since most commuters drive alone there are relatively few passenger doors swinging open. Having the bike lane on the off side may reduce cyclist's chance of being hit by a door when cars are parked on the off side of one-way streets and thus facing the same direction as cycling traffic.

Figure 5.42 **Offside cycle lane (St. Germain-en-Laye, France)**

Photo credit: Authors

Cyclist airbags

Two types of airbags for cyclists have been studied and prototyped though their commercial prospects are unclear at present – especially given that there is no mandate for their use (unlike passenger airbags in cars). The first relate to airbags fitted on the exterior of cars set to deploy in car-pedestrian or cyclist collisions. The second is an experimental airbag worn by cyclists that deploys in a collision thus mimicking the use of a helmet.

Following the development of car passenger (interior) and pedestrian (car exterior) airbags, some research has looked at the development of car exterior airbags for cyclists. Research from the Netherlands Organisation for Applied Scientific Research (TNO) indicates that cyclists often benefit little from experimental airbag systems developed specifically for pedestrians. In a collision, pedestrians end up with their heads on the hood or the lower part of the windscreen. Cyclists' heads often hit the upper part of the windscreen or even the hard metal window stiles in the event of a frontal collision with a car. Suggestions are for cars to have exterior airbags fitted so that the majority of the windscreen on the outside of the car is covered. One automobile manufacturer (Volvo) has announced that they will deploy bonnet-airbag technologies on some vehicles commencing in 2013.

The second type of airbag for cyclists under study (and early commercial prototyping) is intended as a replacement for the bicycle helmet. A collar complete with battery-powered motion detectors inflates automatically in a collision once a certain acceleration threshold is met.

Cyclist detection and warning system (infrastructure)

In order to reduce the risk of crashes between nearside turning motor vehicles and cyclists, some authorities have experimented with external cyclist detection systems – the most basic being roadside-mounted “Trixi” mirrors. These convex mirrors provide car and truck drivers with a view of their nearside blindspot at junctions. Another alternative approach trialled in Copenhagen involves sensors that detect and trigger a set of embedded LED lights that warn HGV and car drivers of the presence of cyclists on the adjacent cycle track (Figure 5.4) in their nearside blindspot (Figure 5.43). We are not aware of studies documenting the crash reduction effect of such external cyclist detection devices.

Figure 5.43 **Sensor-activated LED lights warning nearside turning motorists of presence of cyclist in near-side bicycle lane (Copenhagen)**

Photo credit: Authors

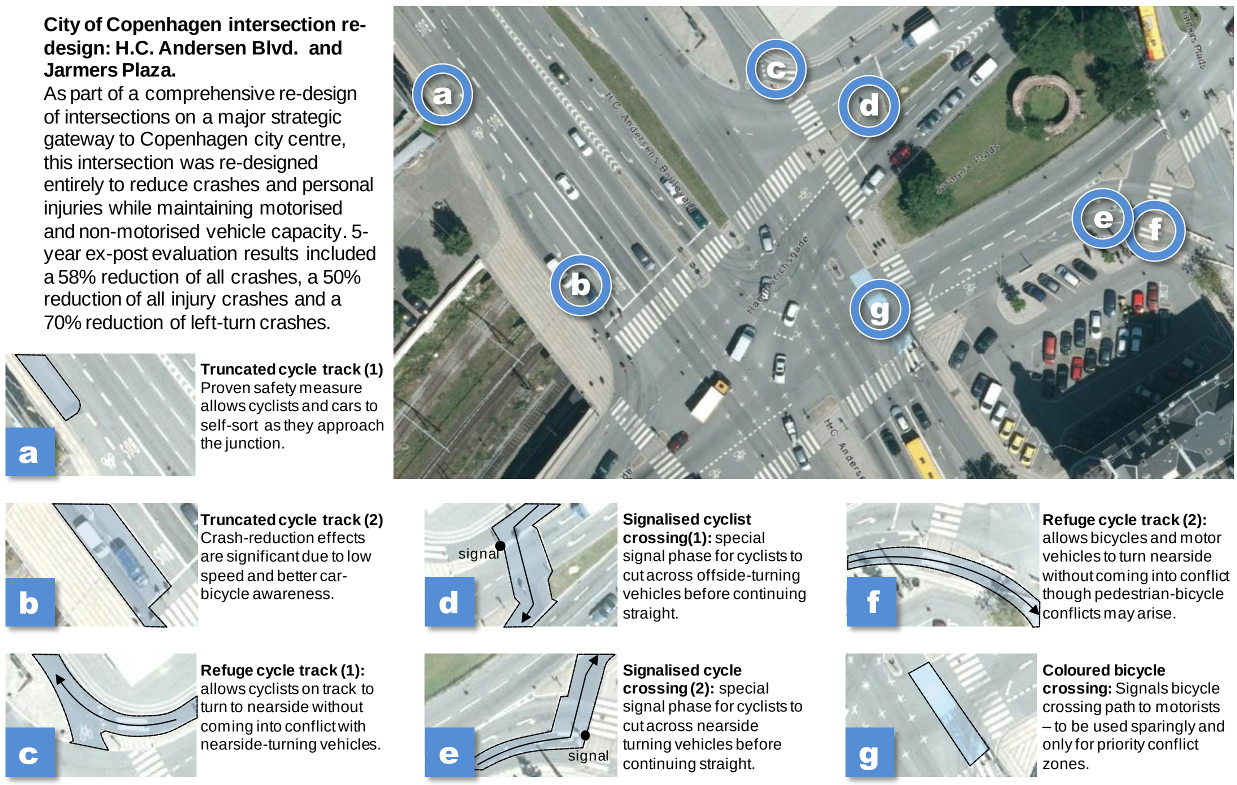
Cyclist collision threat detection and response systems (vehicles)

Building on pedestrian collision threat detection and response systems available on some car models since 2010, one manufacturer (Volvo) has announced the deployment of cyclist detection, alert and response systems to be deployed as an option on some car models starting in 2013. These radar-based systems detect the sudden presence of cyclists in the car’s trajectory, alert the driver and deploy the brakes. As in the case of cyclist airbags, the availability of cyclist collision threat detection and response systems is a promising development. Nonetheless, it is unclear at this stage what the overall safety impacts of the large-scale deployment of such systems may be given that drivers may modify their behaviour in the presence of such technology.

5.6 Diagnosis and implementing safety measures

Countries and cities that have successfully improved bicycle safety have done so via a coordinated set of policies and measures at both the tactical (design of specific safety interventions) and strategic ("safe system" approach) levels. Success requires coordinating both of these approaches in a supportive regulatory environment. On the tactical level, diagnosis of safety improvement targets must be built on crash and traffic monitoring so that effective responses may be designed and implemented. Rarely will isolated safety interventions satisfactorily improve safety and in some cases, uncoordinated responses might make things worse. Figure 5.43 illustrates how safety improvements may result from wholesale re-design of critical elements of the traffic environment – in this case, a series of complete junction re-designs along a major thoroughfare entering the Copenhagen city centre. Here only one of several treated junctions is shown but similar results were found for other junction re-designs in the project – e.g. 39-64% reduction for all crashes, 39-78% reduction for all injury crashes and 64-76% reduction in offside-turning crashes.

Figure 5.43 **Safety improvement from complete re-design of complex junction (Copenhagen)**



Source: City of Copenhagen

Improving bicycle safety requires building on proven interventions and adapting them to local conditions. The trouble-shooting table that follows is based on the findings detailed in the previous sections. It should be seen as an indicative guide to potential infrastructure-related solutions to commonly found bicycle safety problems. These are not prescriptive (indeed, they could not be given that implementing all of these would lead to conflicting traffic situations) but serve as a guide to understanding possible solutions for particular, oftentimes site-specific, bicycle safety hotspots.

Accident problem	Hypothesis	Possible solutions
Road sections		
Accidents with bicyclists being run over from behind	Speeds are too high	Speed reducing measures Narrowing of lanes with edge line
	Narrow, dense traffic	Bicycle lanes/bicycle and pedestrian path
	Darkness, moist weather	Road lighting Campaigns on the use of bicycle lights
	Road side parking	Prohibit parking/stopping
Accidents with bicyclists hitting parked cars	Narrow roads	Markings (parking lane) Prohibit parking
Accidents with bicyclists hitting pedestrians	Accidents concentrated	Refuge/verge Raised pedestrian crossing
	Wide street, accidents spread out	Center island
Entrances to private properties		
Bicyclists on bicycle path are hit by cars from the entrance	Sight distance from stop position not enough	Close entrance Improve sight distance
	Bicyclists are overlooked/lack of attention because of dense and fast traffic	Close entrance Speed reducing measures, reduce number of lanes
	Bicyclists go in the wrong direction	Sight distance improved in both directions
Nearside turning cars/lorries hit bicyclists going straight ahead on bicycle path	No sight distance in mirrors	Prohibit nearside turn Prohibit stopping Remove trees and other obstacles from verge Remove or narrow verge Close entrance
Priority junctions in general		
Accidents with offside turning vehicles hitting bicycles driving straight on bicycle path	Sight distance; check parked cars along bicycle path	Sight distance along bicycle path improved Prohibit offside turn Prohibit stopping
	Insufficient orientation	Blue bicycle markings Speed reducing measures
Roundabouts		
Bicyclists are hit by entering vehicles	Too high speeds	More narrow design
	Problem with sight distance/Signs and other obstacles are blocking view	Improve sight distance Replace signs and obstacles
	Bicyclists are overlooked	Bicycle markings on road Change of roundabout design/priority
Bicyclists are hit by vehicles leaving the roundabout	Too high speeds	More narrow design
	Problem with sight distance/Signs and other obstacles are blocking view	Improve sight distance by removing verge Replace signs and obstacles Bicycle markings on road Change of roundabout design/priority

Signalised intersections		
Turning cars hit bicyclists	Bicyclists are overlooked	Cross-junction bicycle markings Avoid pre-green for nearside turning vehicles
Right-angle collisions in far end of big junctions	Insufficient clearance phase for slow bicyclists	Increase amber phase
Bicyclists turn offside in front of straight going traffic	No waiting area or signal for cyclists	Establish waiting area Separate signal/phase for bicyclists
Bicyclists cross on red	Long waiting time	Retime signal
Nearside turning cars/lorries hit straight going bicyclists	Not sufficient sight in mirrors	Staggered stop line for cars Remove verge Cut back bicycle track
	Sight OK, but insufficient orientation	Separate regulation Cut back bicycle track Pre-green stage for cyclists Avoid pre-green for nearside turning cars

Key Messages

- Assessment of the effectiveness of safety measures will depend to some extent on local or national preconditions such as culture and traditions, legislation, existing infrastructure but there are commonalities with regards to safety-improving strategies that should not be ignored. The former should not be seen as barriers to implementing safety measures that have proven successful.

- The safety impacts of individual measures are not necessarily additive – the ultimate safety effect of multiple measures deployed on one site will largely depend on site-specific interactions. The selection and implementation of bicycle safety measures should be based on a site-specific diagnosis and identification of the safety problems to be treated. Bicycle safety audits as can be helpful in this respect.

- The aggregate safety effects of an extensive segregated bicycle infrastructure network may contradict the evidence of the safety performance of its component parts. Why this should be is not clearly evident from the study of the safety impacts of individual measures but it has been the experience of many countries that the coordinated, targeted and network-wide deployment of many bicycle safety measures along with sustained policy support and training of all road users contributes to high levels of bicycle safety.

- Authorities should recognise that cyclists are heterogeneous and have different skills and perceptions of safety. These perceptions will have to be addressed alongside actions to materially improve safety if authorities are to be successful in preserving or increasing levels of cycling.

- Safety measures for cycling can be broadly categorised as those measures seeking to reduce the negative outcomes of crashes (e.g. vehicle design and helmets) and those that seek to avoid crashes. These are not incompatible but implementing the latter is likely a necessary pre-condition for increasing cycling levels.

- Because of the severity of truck-cyclist turning collisions, efforts should be made to eliminate truck nearside and frontal blind spots through, for example, the use of mirrors or advanced stop lines for cyclists. External detection and warning devices may also prove helpful though their safety effects remain undocumented.

- Helmets are effective at reducing serious or fatal head injuries in the event of a crash but may contribute to (generally less serious) neck and facial injuries. On the other hand, their use may give rise to riskier behaviour on the part of cyclists (and motorists) and thus increase the incidence of crashes. Crucially, mandating their use may suppress cycling participation and thus possibly erode societal health benefits derived from physical activity.

- The effectiveness of safety-improving infrastructure treatments relies on ensuring that these operate as intended. In order to do so, bicycle infrastructure must be maintained to a standard such that the condition of the infrastructure does not contribute to crashes. This also requires that rules and regulations regarding motor vehicle encroachment on bicycle facilities and governing bicycle-motor vehicle interactions are enforced.

- Speed management is a critical and effective tool to avoid or otherwise reduce the severity of bicycle-motor vehicle crashes. Where appropriate (e.g. where authorities wish to increase cycling densities, where cycle traffic is concentrated and in distributor road networks in urban areas) speeds should set to 30km/hr and lower for mixed bicycle-motor vehicle carriageways.

- In speed-control or traffic-calmed areas, care should be given to the design of speed-control devices (humps, bollards, signage, etc.) as these may constitute hazards to cyclists.

- Where speeds cannot be lowered, or where justified by traffic densities, authorities should seek to separate bicycle and motor traffic when feasible.

- Separated bicycle tracks are an attractive option in that they generally produce fewer and less severe crashes in their linear sections – however this safety effect may be compromised at junctions where crashes may increase unless specific counter-measures are undertaken. These countermeasures should remove conflicts and reduce speed differentials among motorised and non-motorised users.

- Crash risk at bicycle track/road interfaces is exacerbated by poor sight lines, un-conspicuity of cyclists to motorists and uncertain expectations of cyclists *vis-à-vis* motorists and vice-versa. Proper design of junctions that eliminate sight barriers, clearly signal likely cyclist behaviour (e.g. cross-junction bicycle markings), physically demarcate cycling space (e.g. continuous raised cycle track across side roads), separate and give priority to cyclists at junctions (advanced stop line, bike boxes) or harmonise behavioural expectations (e.g. truncated bicycle track) all contribute to lower crash risk.

- Roundabouts and rural (high speed) roads are two other bicycle crash black spots that should be addressed by authorities.

Notes

1. See (Noland 2012) for a discussion of this research.
2. See (Garrard, Rose et Sing 2008), (Lawson, et al. 2012) and (Møller et Hels 2008) for a discussion of cyclist perception of risk for different facilities, road environments and among different groups.
3. And, incidentally, increase the risk of neck injury in the case of hard shell helmets and facial injury in the case of soft-shell helmets.
4. These studies do, however, seem to refute the view that "European-style" bicycle infrastructure would necessarily decrease safety in a North American context.
5. See for example www.bicyclinginfo.org

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Annex A. Working group questionnaire on bicycle safety and crash characteristics

All Working Group member countries were sent a questionnaire asking for the number of crashes for different levels of each of the crash characteristics listed below.

- Time of day
- Day of week
- Season
- Surface conditions
- Location
- Cycling infrastructure type
- Speed limit
- Configuration of infrastructure
- Use of bicycle helmet
- Crash type
- Road-user/object involved
- Fault
- Manoeuvre

Member countries were asked to complete the questionnaire at the national level four times:

- For fatal crashes between 2005-2009
- For injury crashes between 2005-2009
- For fatal crashes for the most recent year (specifying which year)
- For injury crashes for most recent year (specifying which year)

We asked for crash numbers, because most countries do not have reliable exposure information, with which to calculate rates. Population-based rates are not very useful, given the vastly different cycling participation levels and patterns in different countries, as discussed in Chapters 1 and 3. Because our main concern is to consider crash patterns, and to compare these across countries, we present our data in terms of the percentage of all cycle crashes represented by each level of each characteristic. This accounts to some extent for cycling exposure *per se*. It does not account for exposure to different levels of each characteristic, so that, for example, the greatest proportion of bicycle crashes occur during the day simply because more cycling occurs during the day. Nonetheless, for the purposes of designing and targeting policy and interventions, arguably what is important is that greatest proportion of bicycle crashes occur during a day (even if this is due to exposure).

We recognized that not all countries have the information requested at the national level, and so we asked that such countries provide the information at the highest level available (e.g. at a city level). We also identified that we would accept data for fatal and injury crashes together (e.g. from police-reports), or for a different year range, if nothing else were available.

We understood that different countries have different ways of categorising particular variables (e.g. time of day, location), and asked that countries use their own categorization while providing us with their definition of the categories.

Finally we asked that countries provide us with information about the source of the data (e.g. police-report versus hospitalization), and the criteria for inclusion in the dataset. This allows consideration of the likely biases in the data.

Questionnaire Results

We assumed that when questionnaire cells, or a whole table, were left empty, then the data were not available. Table A.1 summarises the data we received back from the member countries. Most data were reported at the national level. Exceptions are indicated in Table A.1. We also received separate input from Korea (from the Korean Transportation Safety Authority) – this data is included in the discussion of the questionnaire results where appropriate. Detailed findings from crash microanalysis in Korea are presented in Box 4.2.

We received more complete questionnaire data for the year range (2005-2009) than for the most recent year, and could supplement with data from Australia (Australian Transport Safety Bureau, 2006), the UK (Knowles et al, 2009) and the US (NHTSA 2009) for different year ranges (where indicated in Table A.1). We also considered year range data to be more reliable. Thus, we have reported the year range data in preference to the data from the most recent year, except in the case of Poland for which we only received data from the most recent year (2010).

Table A.1. **Questionnaire responses for data on cycling crash characteristics**

2005-2009 Year range	**Fatal**							**Injury**						
	Australia	Belgium	Denmark	France	Germany	Poland	Spain	Australia[a]	Belgium	Denmark	France[b]	Germany	Poland[c]	Spain
Time	Y	Y	Y	Y*	..	..	..	..	Y	Y	..	..	..	..
Day	Y	Y	Y	Y	Y	..	Y	..	Y	Y	..	Y	..	Y
Season	Y	Y	Y	Y	Y	..	Y	..	Y	Y	..	Y	..	Y
Weather	Y$^{\#}$	Y	Y	Y	Y	..	Y	..	Y	Y	..	Y	..	Y
Location	Y$^{\#}$	Y	Y	Y	Y	..	Y	..	Y	Y	..	Y	..	Y
Infrastructure	..	Y	Y	Y	..	..	..	..	Y	Y	Y	..	..	..
Speed limit	Y	Y	Y	..	..	..	..	..	Y	Y	..	..	..	..
Configuration	Y	Y	Y	Y	Y	..	Y	..	Y	Y	Y	Y	..	Y
Helmet?	Y$^{\#}$	..	Y	Y	..	..	..	..	..	Y	Y	..	..	..
Type	Y^	Y	Y	Y	..	..	..	..	Y	Y	..	..	..	..
Road-user	Y	Y	Y	Y	..	..	Y	..	Y	Y	Y	..	..	Y
Fault	Y^	..	Y	..	..	..	Y	..		Y	..	..	..	Y
Manoeuvre	Y^	Y	Y	..	..	..	..	..	Y	Y	Y	..	..	..
Most recent year														
Time	Y	Y	Y	Y	..	..	..	..	Y	Y	Y*		..	..
Day	Y	Y	Y	Y	Y	..	..	..	Y	Y		Y	Y	..
Season	Y	Y	Y	Y	Y	..	..	..	Y	Y		Y	Y	..
Weather	..	Y	Y	Y	Y	..	..	..	Y	Y	Y*	Y		..
Location	..	Y	Y	Y	Y	..	..	..	Y	Y	Y	Y	Y	..
Infrastructure	..	Y	Y	Y	..	..	..	..	Y	Y	..	..	Y	..
Speed limit	Y	Y	Y	..	..	..	..	..	Y	Y	..	..	..	..
Configuration	..	Y	Y	..	Y	..	..	..	Y	Y	..	Y	Y	..
Helmet?	..	..	Y	Y	..	..	..	..	..	Y	..	..	..	..
Type	..	Y	Y	Y	..	..	..	..	Y	Y	..	..	Y	..
Road-user	Y	Y	Y	Y	..	..	..	Y	Y	Y	..	..	..	..
Fault	..	..	Y	..	..	..	..	..	..	Y	Y	..	..	..
Manoeuvre	..	Y	Y	..	..	..	..	..	Y	Y	..	..	..	..

[a]Data at state level (Victoria); [b]Data for fatal and injury crashes combined, year-range data is for Paris City (infrastructure, road-user, and manoeuvre), and Lille metropolitan area, and national data is for 2009; [c]Data for fatal and injury crashes at city level (Warsaw);
For year range 2001-2004; ^ For year range 1996-2000; time of day and weather simply classified into day and night, and dry and wet, respectively.

More complete data were available for fatal crashes than for injury crashes, but we considered it worth reporting both (separately) in order to allow a comparison of patterns for crashes of different severity. The Polish data we received, and much of the UK data (Knowles et al., 2009), are for fatal and serious injury crashes combined, and so we report this with the injury crashes from other countries, but the inclusion of fatal crashes may produce a somewhat different pattern for these countries.

Data were police-reported data for all respondent countries. As noted in Chapter 1, bicycle crash and injury under-reporting is endemic to many countries. Further, many crashes are not recorded either in police-reported or hospitalization data. The likelihood of inclusion in official records increases with injury severity, and so the data can be considered to be most accurate for fatal crashes.

In the questionnaire responses, Denmark and Germany reported a time-frame for fatalities of 30 days. Spain reported a time-frame of 24 hours. Other countries did not report the time-frame. For data from the EU CARE database, deaths are deaths occurring within 30 days (suicides and natural deaths not included) and serious injuries concern victims injured and hospitalised at least 24 hours.

Annex B. Policy measures derived from stated preference analysis for bicycle use: Route choice factors in the Indian context

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Summary

Cyclists are spread all over the urban areas in India. These are mostly captive riders who choose to bicycle as no other viable options are available to them. This study discusses perceptions of these captive riders as compared to a group of not yet riding (potential) users (short trip makers). A stated preference survey was conducted to estimate their perception on route choice, preferred street environment and land use features.

The perception of risk among captive riders and potential riders does not show much difference as against popular beliefs. Both the captive users as well as the potential users focus on physical safety and the difficulties in crossing junctions. Differences arise in perception of comfort / attractiveness and barriers. Pedestrians / bus commuters waiting at the curb side lane are considered as predominant barriers (about 28%) by potential users while captive riders are more tolerant to them. Results indicate that perception of safety and comfort are not related to type of zone and distance travelled. The presence of informal sector on the street side is social security element and attractive for providing services for captive cyclists. However, the potential users consider informal sector as a barrier. Results show potential users perceive slope as bigger threat to bicycle compatibility as compared to captive riders. Captive riders prefer wider arterial roads against the narrow roads preferred by potential cyclists. The paper also discusses policy implication of bicycle facility planning.

B.1. INTRODUCTION

This paper presents an analysis of risk perceptions and preferences related to bicycling in Indian context. This is done employing a discreet choice modeling framework, consisting of 2 stated preference (SP) experiments and several ranking questions. The current research contributes to the literature of non motorized travel in developing south Asian countries. This also contributes to literature on commuter cyclists (mostly captive in Indian context) and potential user’s route choice related preferences through the analysis of 16 determinants of street operations and environment. This paper is based on a survey of 1400 respondents in the city of Pune, India.

The study is important for various reasons. First, it’s important for the understanding of differences in the two predominant groups viz. current cyclists and potential users. This is important especially in the many south Asian developing countries as cycling are not by choice. Therefore, this distinction among captive users and choice travelers will enrich the understanding for designing bicycle policies in short term and in long term. Second, up to 75% trips in small and medium Indian cities are short trips (less than 6 km, cycle-able); providing base of latent bicycle trips. Third, understanding route choice determinants for cycling can help its integration with urban planning and among the automobile based transport planning. Fourth, this study can provide guidelines for designing of bicycle facilities ensuring the safety and minimizing fatalities. There are various other obvious societal benefits like alleviating traffic related problems of congestion, pollution, noise etc; increased mobility, freedom and greater accessibility to students and those who cannot drive.

The bicycle planning involves primarily demand estimation and network analysis. This study shall be able to contribute majorly to the network analysis by quantifying the preferences which can be used to determine the route, facilities and framework for bicycle compatible development.

The rest of the paper is structured as follows. The next section discusses the Indian context in detail and prepares the background of typical city in contrast to many European and American cities. Section 3 discusses the earlier studies in the area of bicycle users and bicycle route planning to identify the scope of study. Section 4 describes the sampling, questionnaire development and survey design. Section 5 describes the empirical results of survey. Section 6 describes the stated preference experiments and their results. Section 7 highlights the important findings from the research.

B.2. BICYCLE IN INDIAN CONTEXT

Bicycle is an important commuting mode for poor urban workers and students in Indian cities. It is an important means of mobility particularly for short trips in medium and large Indian cities. The medium (1-3 million) and larger (3-5 million) cities have a typical bicycle modal share of 13%-21%. Cycle trips might be as low as 7-10% in mega cities, however their absolute numbers are still large in comparison to many European cities. (1). But, contrary to most European cities the majority of them are captive riders i.e. they use bicycle because other preferred modes cannot be used for financial constraints or non-availability.

The high ownership levels of bicycles (2), its low cost and easy use make it a desirable mode of transport for students and low income workers. A large amount of utility cycling is present in Indian cities because the bicycles are the most affordable and only form of transport available to low income households. The subsidized public transport also remains cost prohibitive to them. (3, 4)

The time trend analysis in various cities shows a sharp decline in bicycle trip share during the 80’s and 90’s. During this period all these cities experienced a high growth rate of motorized vehicles and road infrastructure improvements (primarily road widening and construction of grade separated junctions). The dedicated infrastructure for bicycling is not present in any city as a network. (1)

Bicyclists face a high risk of getting involved in fatal traffic crash. It is observed that cyclists are involved in 5% to 10% of total road related fatalities in medium and large cities. About 20% to 32% cyclists are involved in crashes leading to severe injuries to bicycle users. (5) However despite the lack of safe infrastructure, high risks of fatal crashes and lack of favourable policies for cycling, bicycle trips have not disappeared completely. There is a need to provide a safe and comfortable bicycle infrastructure to these captive cyclists as well as to harness the potential user market.

B.3. LITERATURE REVIEW

Research on non-motorized transportation planning does not fully address the unique context in which developing world cities function, such as large population, low incomes, high density, low car ownership, short trips, high mix of informal housing and commerce, and poly-nucleated city structures. Data from Indian cities shows two main groups of bicycle users: the captive users and the potential users.

Captive users

Income plays a significant role in influencing transportation choices people have. Where there is extensive poverty in Indian cities, it is most important to ensure that the modes used by the poor continue to remain available as safe travel options. Although walking costs nothing, it takes a lot of time for all but very short trips. Cycling often offers four or five times greater speed and is cheaper than public transport. Irrespective of city size, the poor continue to be dependent on non-motorized transport modes for mobility in many Asian cities. (6)

Some people are forced to depend on only a specific vehicle because their choice sets are constrained, i.e. they have no other alternative to choose from or their preferred alternative is out of their acceptable financial means. The limitations on their choice set may arise from their own abilities (e.g. their ability to operate other vehicles or their ability to afford the cost of using another vehicle) or from environmental conditions (e.g. the lack of a public transportation service). Such travellers are regarded as having structural dependences on a vehicle (7) and they are called ‘‘captive riders’’ of that vehicle. (8) In Indian cities this is true for most cyclists; they are often poor people living in slums, travelling longer than walk-able distances. Hence, in the present study, captivity is defined by financial constraints especially applicable to low income workers and students (those with no vehicles or driving knowledge).

Travel patterns of low income group living in informal housing or slums are very different from residents in formal housing. Generally, cycling and walking account for 50 to 75% of the commuter trips for those in the informal sector. Their socio-economic conditions are such, that they do not own any other motorized vehicles. Even the highly subsidized public transport services remain non affordable to them (>12% of their income). They are forced to ride bicycles for long distances in high speed mix traffic. The bicycles are essential for access to their employment. They are means for survival to them and also important for poverty alleviation. This captive group takes high risk, and hence it is important to understand the needs of these captive riders. With this understanding it will be possible to create better bicycle infrastructure and facilities that cater for the direct and shortest possible routes between their major origins and destinations thus enabling safe access to employment. (9, 10)

Potential Users

There is, also a group of people who would like to cycle and could be persuaded to cycle under the right circumstances. (11). A large number of students continue to use bicycles in small and medium size cities in India. However in large cities a substantial number of students commute to school by bus or other motorized vehicles even for short distances. Potential bicycle users in the present study are young students and workers owning a bicycle, who travel short distances (less than 6 km) and are currently using motorized modes. These groups might use bicycle if safe and comfortable travelling conditions prevail. For example, many parents do not allow their children to cycle to school because safe segregated cycle paths are rare. (9, 10) Most of the available literature from western context targets student population, who could not afford a car, travels shorter distances and who do not like to rely on infrequent - uncomfortable public transport. (12) While the focus in available literature has been on possible modal shifts and benefits, little has been researched on user behaviour, perception and needs of a typical low income country city, where there is a great potential for cycling.

High ownership of bicycles and predominance of short trips in Indian cities offer supportive conditions for bicycles. In medium size cities, 35% - 65% households own one or more bicycles (2). Despite the high ownership of bicycles in urban areas in India, the typical modal share in large cities is comparatively low. The average trip length for all vehicles (excluding walk) in medium and large cities varies from 4.2- 6.9 km. It is observed from the trip length frequency distribution that 56% to 72% trips are short trips (below 6km, the typically cycle-able distance). This can be partly explained by the high residential density, mixed land use developments and poly-nucleated city structures present in Indian cities. (13). Hence, it can be argued that there should be a substantially large latent demand (of potential users) in Indian urban communities, who may use bicycles if safe circumstances prevail.

For bicycle as a means of transport, safety plays an important role and (14) safe conditions (to park and to ride) affect bicycle use. The socio-economic characteristics, income, gender, education level and car ownership levels vary with culture and country, thus affecting the bicycle use. For instance, in Chile bicycle is more used by men, low income groups, people who don't own a car and have low education level. In India, work is the main purpose for bicycle trips, although shopping is also an important motive. (15, 16, 17) The "barrier effect" reduces cycling mobility, and increases driving. These impacts tend to be inequitable because disadvantaged populations who depend on non-motorized transport bear a disproportionate share of the costs. (18) While captivity does not have an important role in American and European context, it plays a stronger and definitive role in South Asian context.

Route Choice Factors

The link level and route level factors along with this many social variables seems to play a definitive role that affect route choice. (19). The link-level factors influencing route choice may include bicycle facility presence and motor vehicle traffic characteristics (20,21,22,23), parking characteristics (24,25,26), riding surface quality (23,26,27) and hilliness (28). A substantial amount of previous research on bicycle facilities has focused on examining the impact of link-level factors on route choice and related decisions. (19) The factors considered in these studies have included geometric configuration measured by automobile lane width and the number of driveways/side streets providing access to the link and motor vehicle factors like speed, volume, and percentage of heavy vehicles etc. Few studies consider bicycle facility factors like width of bicycle lane or separate path and pavement factors.

Most Bicycle Level of Service (BLOS), including Bicycle compatibility models, stress-level index, hazard score and junction level-of-service models, measure the suitability of roadways for bicycle travel. (24-30) Many RP based route choice studies have indicated commuter bicyclists prefer directness en route to their work place, willingness to detour to use bicycle facilities, and commuter bicyclists non-preference for turns, hills, major roads, and off-road routes, signalized traffic control and sensitivity to route travel time. (31, 32)

Most of the measures in these studies rely on the analyst's judgment regarding the importance of each link-level factor. Thus, though the measures provide quantitative indices of facility rating and performance, they are developed through qualitative weightings of the various link-level attributes. However to get rid of this drawback, study by Bovy and Bradley (27) used SP survey and found that travel time is the most important consideration in route evaluation, followed by surface quality, traffic level, and facility type. Abraham et al. (33) also used SP survey to find that commuter bicyclists were willing to incur additional travel time to use routes with bicycle facilities. A very few handful studies also focus on parking controls, and adjacent land-use attributes.

Summary and Scope of Current Study

Most of these studies did not look into the street environment from the bicyclist's perspective. The measures related to land use like type of built environment, density, land use intensity and mix, presence of informal sector etc. also may influence the safety and comfort (especially in South Asian cities). An appropriate measure of safety, comfort and social security in the context of Indian cities also require people's preference evaluation of street environment.

B.4. SURVEY DESIGN

Pune city (previously known as bicycle city of India, in western state Maharashtra, India) has been selected for this study. Pune city has a history of high bicycling modal share (currently 13%), Bicycle Master Plans exists since 1982 and dedicated bicycle tracks since late 1980's. Considering this and other logistics, the Pune city is taken as the representative city for small (population size 1-3million) and medium (population size 3-5million) cities in India. The city has an area of 250 square kilometers with an estimated population of over 3.15 million (2010).

Objectives of the study were -

- To understand the socio-economic and travel profile of predominant groups among short trip makers.
- To compare the route preferences of current bicycle users and potential bicycle users.

Sampling, target groups and zoning

In our case stratified random sampling was done to capture those who are making a short trip (< 6km) in the city of Pune. To reduce sampling errors, zones are stratified by land use and proportionate sample size within each zone is worked out. Pre-questionnaire judgment was made based on distance between predominant origin and destination (should be less than 6 kms). Age had to be more then 10 (for understanding the questionnaire and responding).

Questionnaire development and survey

A testing of designed questionnaire was conducted on a focus group; in the pilot survey of 300 households, (34) it was observed that despite simplification, filling out the questions appeared to be a complex task requiring a lot of explanation. Some people in the pilot survey could not suggest improvements as they appeared to be happy with the environment where they are bicycling. They had no idea what could be better in terms of type of infrastructure or segregated facilities, simply because they have never experienced it. Ranking / choice based pairs of different options seemed to be better in the situation where all the questions were asked by the interviewer orally, showing relevant pictures when necessary. In Indian context, bicyclists are mostly literate with at least secondary education but are unwilling to fill questionnaire themselves. Hence pictorial presentations were adopted for ease and the number of levels is kept to a minimum of 2 with only 4 attributes at a time.

A stratified sample of 1400 (99% confidence level and 5% error), bicyclists and potential users (short trip makers) were captured for representing typical socio-economic strata. These are the people who are likely to govern and be affected by the improvements in bicycle infrastructure and facilities. The target groups were broadly divided as captive users and potential users, using the first section of interview.

B.5. RESULTS

Of all the respondents, 19.40% are cyclists who take the bicycle to workplace, school, grocery, social places and other destinations (captive riders mostly). 80.60% are potential cyclists who presently do not cycle but they own/can afford a bicycle and travel short distances. About 59% are male respondents and 25% of total interviewed were students below age of 19 years, about 57% are adults (20-49 years) mostly workers or home makers, and about 18% in their late adulthood (50+ years). Cyclists are mostly students and workers while potential users are other short trip makers like home makers, students and workers.

Social Profile

Current cyclists are mostly primary or secondary level educated while potential users are mostly sr. secondary or graduate. The cycling use in urban context decreases with increasing education and income. Similarly current captive cyclists belong to the category of the poor (12%) and / low income group (41%). While the potential bicyclists are observed to be in categories of middle income groups (42%) and higher income groups (5%).

Bicycle is used by 20% of the people surveyed. It was found that these are all captive cyclists. Captive riders are defined here as those who use bicycle for commuting, cannot afford other modes of transport and whose work place is beyond walk able distance. And the remaining 80% people surveyed are the potential users. Potential bicycle users are defined here as those whose (one side) trip length is less than 6 km, own a bicycle but are commuting using either bus or motorized vehicle (car/scooter/motorbike/auto).

Travel Profile

26.3% of regular bicycle users are school/college students. Also 30% of cycle destinations are work related like office, job, and factory etc. and 18% trips are for shops / banks / accessing amenities etc. (for work as well as other purposes). The average trip distance is about 3.9 km for cyclists (ranging between 1.8km to 6.0 km) taking about on an average 22 minutes (ranging 10-40 minutes) at the speed of 10-12 km /hr. The travel costs are mentioned to be negligible but sometimes in the range of Indian Rupees 2-6 per day referring mainly to maintenance and in rare cases parking. Potential cycle trips are identified to be mostly of the short work related trips to offices, factories and shops and some other short trips are to school and college. These trips are mostly on motorized two wheelers (20%) or walk (22%), and on public transport (36%). The average trip distance being 4.6km consuming about 26 minutes on an average, costing about Indian Rupees 10-40 per day. (Approximately 45 INR = 1 USD)

Risks

Out of every three cyclists, two have experienced some kind of accident / crash. The biggest deterrents to cyclists are the fear of accidents (30%) from other vehicles. It is closely followed by concerns like crossing junctions and no space on roads (18% and 22% respectively). Potential cyclists too are deterred from using bicycle as mode for the fear of accidents from other vehicles. The issue of less space on roads along with the bad roads is most important dissuading factors for choosing bicycle as mode. Contrary to belief, few (7%) cited the reasons of socially unacceptable / poor man’s vehicle status as a reason for not using bicycle.

Preferences to Surroundings

Current cyclists (captive riders) preferred residential areas (76%) as routes; followed by the mix of commercial activities in the residential areas (13%). Few preferred purely commercial (3%) areas as well as extremely low density areas for the regular bicycle routes. The low density areas and residential areas (9% and 80%) are perceived as the ones most attractive by potential users. By all kinds of captive cyclists and potential users, purely commercial areas and increasing mix of commercial and manufacturing activities are seen as non attractive for cycling. The most common reasons for not taking the shortest possible routes are designated one ways (50% of cases) by the traffic police. Other common reasons being poor pavement quality (25%) and large traffic volume of motorized traffic (5%).

Key Variables

It is observed from previous studies (9,10) that following key variables /factors appear to be most important in the context of Indian cities. The survey was focused to collect the weightages for different parameters like physical safety, social safety, barrier etc. which affect the route choice of bicycle and consequently affects choice of bicycle as travel mode. (TABLE 1)

The parameters physical safety and junctions are assigned approximately 30% and 22% weights respectively both by captive riders and potential users. A further detailed disaggregated analysis of the physical non-safety perception reveals various aspects which affect it. This is not in any particular order or hierarchy with almost the same weight age attached to each attribute. Slightly higher importance is attached with buses in curb lane and speed of motorized vehicles (~29%). It is considered a threat more by current captive cyclists. Probably, experience with ill designed and ill maintained existing bicycle tracks prompted low response to dedicated bicycle infrastructure Potential users are more concerned with volume of motorized vehicles and to them, segregation with bicycle tracks (about 25.5%) seems to be a better solution to deal with dangerous aspects of cycling on road.

The predominant differences were evident (Table B.1) among the captive riders and potential users with respect to social security aspects. Detailed ranking results showed that captive riders attach high positive value to informal sectors on road side (30% weight) and to the fellow bicyclists and pedestrians (25%). The informal sector presence makes streets relatively crime free and safer for women, children and the elderly. (4, 5) On the other hand, potential users attach high value to street lighting (27.2%) and to other bicyclists and pedestrians (25.6%).

While, a detailed understanding of the type and frequency of barriers on the curb side lane revealed that pedestrians / bus commuters waiting (about 27.4%) at the curb side lane are considered as predominant barriers by potential riders. But it seems current captive cyclists are more tolerant to them. Poor pavement quality on curb side is the biggest barrier to captive riders. One of the other factors which act as major deterrents for bicycle travel is street side parked vehicles on the curb side lanes (25%). Gradients / undulating topography are also considered to be barriers especially f captive riders.

The junctions have been disaggregated to roundabouts, uncontrolled MV entry/exit, crossings and type of junctions (signalized / un-signalized). The perception of risk among captive riders and potential users does not show much difference. Un-signalized crossings are ranked much higher (27% weight) on risk and are still considered more difficult to cross (especially while turning right in left side driving Indian context). Surprisingly, this is closely followed by the signalized crossings (26%) mostly without any markings, signage, priority boxes in front for cyclists etc. Roundabouts rank just higher than the uncontrolled motorized vehicles entry /exit (from properties / land use). (Table 1) The rankings are limited to the linear weights given by analyst for the various aspects. In the next section of the study pictorial sets were used to determine respondent’s preferences to physical and environmental attributes of routes / streets in a SP choice experiment.

B.6. CHOICE BASED SP EXPERIMENT

All alternatives in a SP experiment need to be identified based on the global utility maximizing rule. In case where large number of alternatives tends to exist, the analyst can use experiments that that do not name the alternatives (i.e. analyst defines generic or unlabelled alternatives). Unlabelled experiments are only appropriate for the exploratory research. The paper includes both the experiments as unlabelled for the simple reason of presence of too many / numerous alternatives among the street type and designs and operations.

It is more appropriate in this case to estimate utility function generic to the general class of good or service. (Unlabelled experiments) (Table B.2) The list and definition of 8 attributes and their levels which together explain the alternatives is prepared. This is done in our case out of a comprehensive list of about 40 attributes (from literature) from the focus group and pilot of 300 respondents. The concept of inter- attribute correlation while identifying the attributes to be used in the experiment must be considered. (35) Since, the influence of land use and street characters on non motorized transport has not been explored in Indian context; this is a unique research in the context.

The first experiment is designed (full factorial and unlabelled) keeping most effective and common attributes (from literature) that influence the route choice like conditions on curb side lane and other street operations. South Asian cities function in a unique context of large population, low incomes, high density, low car ownership, short trips, high mix of informal housing and commerce, and poly-nucleated city structures. For non motorized modes, these land use and street environment elements along with street operations play an important role. Hence the second experiment (full factorial and unlabelled) has been designed to understand the impact of these upon the current bicycle users and potential users.

The estimation results of random coefficients, and individual's specific coefficients have been obtained using computer software BIOGEME version 1.5 for these unlabelled full factorial SP experiments. The results of the discrete choice estimation provide four main outputs: (1) Coefficient estimates (2) T-statistics and standard errors, (3) Log-Likelihood measures, and (4) Rho Squared goodness of fit. The captive group data and potential user data are modeled separately for the main effects only. Utility function generic to the general class of good or services has been estimated to understand the weights attached by total short trip makers (combined data) and captive users (-c) vs. potential users (-pu). (Table B.3)

As the terrain is flat, the utility is high; also when the pavement quality is better, the utility is high. When the parked vehicles are less, the utility is high. Captive cyclists give high weight-age to pavement quality and parked vehicles. While, the potential users see the pedestrians on the curb side lane as the biggest barriers followed by slope. The coefficient for pedestrians as barriers for captive cyclists is positive and significant. It is evident that cyclists are more tolerant to pedestrians on the curb side lane. This may be inferred as having direct implication to safety. Also it is comparatively easier to negotiate pedestrians while cycling then motorized vehicles (moving / parked) in the curb side lane. Parked vehicles pose a greater threat to physical safety of cyclists while moving in and out of parking or when a motorized four wheeler door suddenly opens. For both the captive and potential user model in the SP experiment 1 has excellent goodness of fit.

In the overall model density is insignificant. But for captive cyclists the Density is significant at 95% confidence level and the utility value increases with increase in density. All the other values for captive and potential users attributes are significant at 95% confidence level or higher. Table 3 shows similar coefficients attached by the captive riders and the potential riders to different attributes; except for the coefficient value attached to slope. This can be partially explained by the non-existent bicycle infrastructure /facilities which led captive cyclists to choose shortest distance and on at least one side of the trip, the slope is in favour. While potential cyclists who have a choice of other motorized vehicle see it as bigger threat to bicycle compatibility.

While comparing the road related factors (the SP experiment 2 for comfort and attractiveness), there is a difference in captive riders preferring wider roads (despite high speeds, high volumes of motorized vehicles) against the narrower / lower hierarchy roads preferred by potential cyclists. Since captive cyclists have no other affordable option available, they are used to higher risks in mix / fast traffic and prefer shorter direct routes for quick commutation (which are often served by arterials and sub arterials).

Potential users attach high weight-age to comfort and less conflicting road situations. And also for both captive and potential users, land use mix seems to be not a major concern (low coefficient) while the negative sign indicates that higher commercial / public semi-public land use mix decreases the utility. The positive sign of density indicates that high density has high utility for captive cyclists i.e. preferred environment. Also the informal sector presence and absence is significantly different for both groups. Captive users seem to like the presence of informal sector as social security and service providers. On the contrary, potential users find informal sector presence as major barrier to cycling. For both the captive and potential user model, the SP experiment 2 has excellent goodness of fit.

B.7. SUMMARY AND CONCLUSIONS

This paper attempts to evaluate the perceptions of captive and potential users of bicycles regarding different aspects of traffic characteristics (speed of motorized vehicles, presence of buses) and land use (intensity of mixed land use, density of development, presence of street vendors).

1. Key issues like familiarity with new scenarios (situations) (e.g. bicycle tracks and bicycle prioritized junction) and safety / security improvement (e.g. lighting, informal sector integration) must be well designed to present to respondents.
2. The parameters physical safety and junctions are assigned high weights respectively both by captive and potential users. Social security on the roads is considered an important issue by captive cyclists and potential users alike.
3. The perception of risk at type of junctions among captive cyclists and potential users does not show much difference. Signalized/un-signalized crossings are ranked high on risk by both groups, closely followed by the roundabouts
4. However, the presence of informal sector on the street side is social security element and comfortable and attractive for providing services for captive cyclists. But for potential users informal sector is like a barrier, although, lighting seems to be important for social security concerns.
5. As expected when the terrain is flat, and when the pavement quality is better, or when the Parked vehicles are less; the utility is high in all these cases.
6. The results indicate negative sign and low coefficient values for pedestrians as barriers. It is evident that captive cyclists are more tolerant to pedestrians owing to easier negotiation and their presence makes streets relatively crime free and safer.
7. Potential users who have a choice of other motorized vehicle see slope as bigger threat to bicycle compatibility as compared to captive riders.
8. Captive cyclists prefer wider roads (despite high speeds, high volumes of motorized vehicles) against the narrower / lower hierarchy roads. Since captive cyclists have no other affordable option available, they are used to higher risks in mix and fast traffic and prefer shorter direct routes for commute.

9. Also for captive users, land use mix seems to affect route choice while the sign indicates that higher activity mix decreases the utility. The negative sign of density (and low coefficient) indicates that low density are preferred environment; but does not play a very important role in route choice.
10. Interestingly, the presence of informal sector on the street side is seen as social security element and is considered comfortable / attractive for providing services to captive cyclists.

Policy implications

This study can also help in indicating and prioritizing the road improvement projects and integration of formal - informal land use aspects in transportation/city planning. This understanding shall provide priorities and inputs for designing safe bicycle infrastructure for current users and attracting potential users. The insights from this study can be useful in planning for bicycles and develop guidelines for bicycle compatible neighbourhood design strategies for safer and more comfortable commute of bicycle trips.

The interaction effects of socio-economic and travel profile can be estimated to understand taste heterogeneity among the various groups of users. Ultimately the use of bicycle has to be by choice. The insights then can be useful in planning and designing strategies to attract the large potential of short trips and convert them in regular bicycle trips. Up to 75% trips in small and medium Indian cities are short trips (less than 6 km, cycle-able); providing base of latent bicycle trips.

This can be further used for evaluating Area Bicycle Compatibility (ABC) or for estimating relationship between land use aspects and bicycle use. This can also help generate bicycle compatibility benchmarking among different roads / zones based upon people's perception and the current road infrastructure conditions. The survey information can be used for traffic assignment and designing land use for bicycles.

Further Work

This study presents results of a survey including 1400 respondents. The results for experimental designs of street operations and street environment are indicative and statistically significant. But, further work is required to increase the sample size for better estimation of differences in choice of the captive and potential bicycle users. The more number of levels will improve the research from merely exploratory and the linear relationships can be tested to more defined relationship. This can be further utilized in developing mode choice model for bicycle trips. Also the cross-elasticity in parameters and other aspects like willingness to pay can be developed further for the system change in bicycle compatibility; reflecting more accurate traveller's decision and thus could yield more accurate demand prediction. The weights calculated from this research can be used for the calculation of bicycle compatibility index / grades for the routes/ links for network analysis or route assignment. (36)

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Annex C. A stated preference analysis on bicycle user's perception on cycling safety and its policy implications in Korean contexts

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Abstract

This paper reviews previous quantitative researches on cycling route choice and quantitatively evaluates representative policy measures effectiveness by employing stated preference methodology.

The dedicated bicycle only road and bicycle lanes are estimated to enhance cyclists' safety perception. It is also estimated that lowering vehicle travel speed is very effective in increasing cyclists' safety perception. From the elasticity estimation it is shown that in Korean context lowering vehicle travel speed is estimated to be most effective policy measure in increasing safety perception and thus for increasing bicycle modal share. Providing dedicated infrastructures such as bicycle only roads and lanes are also estimated to be highly effective.

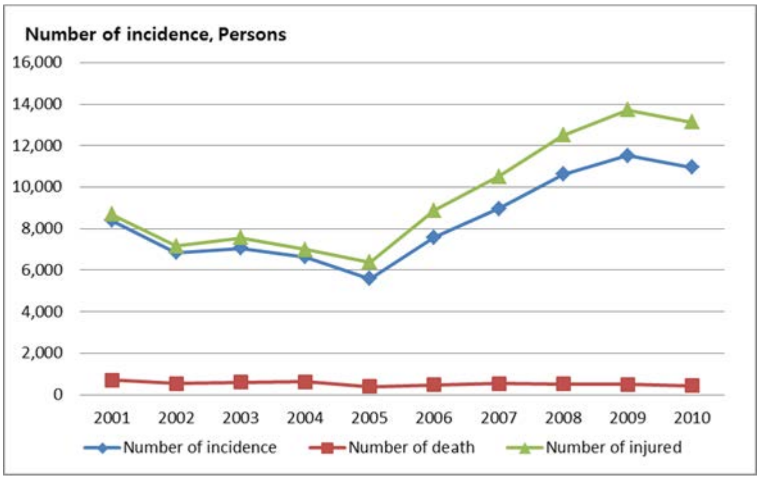
C.1. Introduction

The purposes of this paper are to quantitatively evaluate effectiveness of policy measures aimed at increasing cycling modal share by increasing safety perception of cyclists in a Korean context and to draw policy implications from the analysis. While bicycling has long been a significant mode of transport in a relatively small number of Organisation for Economic Cooperation and Development (OECD) member countries and many developing countries, bicycling is now rapidly gaining popularity in many other countries as an alternative low carbon transport means for short distance urban trips. However, a major impediment to large-scale bicycle use is the serious concern over bicycle safety in an urban context. Improving cycling safety would contribute greatly to the popularization of bicycling as a means of routine urban travel.

Most countries include increasing the share of urban trips made by bicycle in their national transport plan objectives as part of their policies to develop more sustainable transport systems. If these policies are to be successful, public perceptions of the safety of using bicycles in cities will need to improve. More fundamentally, any risks in terms of increased deaths and serious injuries to cyclists and to pedestrians as a consequence of increased bicycle use need to be identified, and where these are significant, cost-effective countermeasures need to be developed.

This paper reviews previous quantitative researches on cycling route choice and quantitatively evaluates representative policy measures effectiveness by employing stated preference methodology. As people's perception toward safety and transportation infrastructure development levels differ across countries, country specific quantitative studies should be required in order to explore the possibility of country specific policy recommendations for cycling safety improvement.

Figure C1 **Trend of bicycle crashes in Korea**



C.2. Previous Quantitative Researches on Cycling Route Choice

There have been several international collaborations on bicycle safety and promotion of bicycle use in general. The European Conference of Ministers of Transport's (ECMT) work on national policies to promote cycling (2004) dealt with current international statistics related to bicycle use and national promotion policies. Safety concerns were also dealt with but with limited scope. Another ECMT study, Safety in Road Traffic for Vulnerable Users (2000), and the OECD report on safety of vulnerable road users (1998), recognized the vulnerability of cyclists in the context of having direct interfaces with vehicle users in most country cases. These studies provide bicycle user characteristics and accident pattern analysis in member countries and also provide policy recommendations in the areas of vehicle construction, regulations related to visibility, vehicle speed, user behaviour and rider protection and infrastructure provision and improvements.

Other international organizations such as the European Commission and European Transport Safety Council (ETSC) have been involved with cycling safety-related projects. They have focused mainly on maintaining international traffic safety data and professional and NGO networks. Their policy recommendations also include speed regulations, safer vehicle designs, helmet requirements and road safety campaigns.

For quantitative studies on cycling safety policies, there is substantial literature which tries to analyse bicycle users' route choice: Recent ones on developed country cases include M. Stinson et al (2005) and I. Sener et al (2005). Stinson et al (2005) divided cyclists into two groups, i.e., experienced and inexperienced and analysed cyclist route choice behaviour and compared the results. They found that the most important route choice factor for experienced commuter cyclists is the travel time. And they also found that safety related bicycle facilities are also important. For inexperienced cyclists, they found that separation from vehicle traffic is the most important. Travel time is also found to be very important for inexperienced cyclists as well. The main policy implication from their study is that to retain cyclists, design alignment to minimize travel time and direct connection between home and work are preferable. And to minimize potential conflicts with motor vehicles is also very important to induce inexperienced cyclists to more frequent use of bicycles.

Sener et al (2005) explored how bicycle riders' route choice is affected by various attributes related to bicycling. They examined quantitatively the impacts of attributes that influence bicycle route choice. They found that travel time and motorized traffic volume are the most important attributes in bicycle route choice implying reducing bicycle travel time and motorized traffic on the route could increase bicycle use significantly for daily commuting. Other important attributes with a high impact include number of stop signs or red lights, speed limit, and on street parking characteristics.

Jain et al (2010) is a most recent SP study on cycling safety conducted in a developing country. They evaluated the subjective cyclists' perception by SP methodology in India. As a developing country case, they divided the cyclist into two groups, i.e., captive riders and potential riders. They found that the subjective perceptions on cycling barriers are different among the two groups. Potential riders tend to regard hilly terrain as a significant barrier. While potential riders seem to be more concerned with possible safety threat, captive cyclists prefer wide road with the possibility of faster travel. Their findings are similar to Stinson et al's in terms of policy implications.

C.3. A Stated Preference (SP) Analysis on Bicycle User's Perception on Cycling Safety and its Policy Implications in Korean Contexts

Stated preference methodology can be regarded as a social experimentation as it is usually employed to analyse quantitative impact of a policy measure which is currently not in place or even hypothetical. The most common application of stated preference methodology has been therefore estimation of demand for new transport infrastructures such as high speed rail or light rail transit which could increase traveller's welfare by reducing travel time or increasing amenity level of trip.

SP methodology thus presupposes a hypothetical transport market and estimates traveller's utility function based on the respondents' mode or route choice data. The quantitative impacts of each attribute variables are thus inferred from the estimation of the parameters of the utility function. The SP analysis usually follows the steps described below:

1) Identification of attributes of the utility function
2) Specification of attribute measurement and variation levels
3) Experimental design of SP
4) Survey design
5) Model estimation (Utility function)
6) Quantitative impact analysis based on parameter estimates

7) Policy implications

In the SP survey, individuals are usually required to answer a choice between two alternatives. In the transportation mode choice, the usual supply-side variables are travel time, travel expense, service levels of the transport mode or route. Demand side variables are generally composed of income, sex, and education. In cases where these variables are too numerous, and the levels of variables too widely varied in order to be able to identify trade-off of modal choices, it is practically impossible to create a full factorial design which includes all the possible sets of SP questionnaires. Therefore, a fractional factorial plan, which analyses only the main, most important effects and guarantees the orthogonality of variables, is generally applied in the SP technique (Hensher, 1994).

In our cycling safety study, the main empirical questions that need to be addressed are as follows:

1) Is dedicated bicycle infrastructure going to be effective in increasing bicycle use by altering the safety perception of potential cyclists?
2) Reducing speed limit of vehicles would make the cyclists safer?
3) How do cyclists evaluate the perceived barriers to cycling?
4) Are there differences between experienced versus potential cyclists in their perceived safety regarding cycling infrastructures and soft measures?

In estimating of mode or route choice behaviour, individuals are first asked to make a choice among the alternatives that is most preferred. A sample binary choice experiment would look like the following:

Route 1

- Dedicated cycling route
- Four lane wide road
- Vehicle speed limit of 50 km/h
- 20 minutes

Route 2

- Shared cycling lane
- Four lane wide road
- Vehicle speed limit of 30 km/h
- 15 minutes

Based on the SP design, the utility functions of the route or mode choice model are constructed as follows;

$$U_{C1} = \beta_1 \cdot LNUM + \beta_2 \cdot ONLY + \beta_3 \cdot LANE + \beta_4 \cdot SPEED + \beta_5 \cdot TIME$$

$$U_{C2} = \beta_1 \cdot LNUM + \beta_2 \cdot ONLY + \beta_3 \cdot LANE + \beta_4 \cdot SPEED + \beta_5 \cdot TIME$$

where LNUM= Number of lanes, a priori expectation is that LNUM could be regarded as an impediment to cycling

ONLY= A dummy variable for dedicated cycling road, dedicated cycling road is preferred in countries with car oriented transport culture

LANE= A dummy variable for cycling lane, cycling lane provides separation from vehicles and thus could improve safety perception for bicyclists although the level of separation is lower compared with ONLY

SPEED= Speed limit of a road, lower speed limit could increase safety perception by lowering the probability of serious injuries or death when bicycle accident happens

TIME= Travel time required by route choice, TIME allows a trade-off between safety perception related variables and time

The relative impact of policy variables can be quantified by estimating the policy related parameters in the model and comparing the relative magnitudes.

In order to test the difference in the explanatory power of variables, we can employ the Asymptotic t-Test. For testing the null hypothesis that the estimates of the coefficients of the policy parameters are the same, we need the test statistic of the following.

$$\frac{\hat{\beta}_i - \hat{\beta}_j}{\sqrt{\mathrm{var}\left(\hat{\beta}_i - \hat{\beta}_j\right)}}$$

And we would be able to test the hypothesis of identical impacts by constructing and testing the above test statistic.

Discrete choice model, which analyzes effectiveness of each explanatory variable and uses socioeconomic characteristics and transportation decision-making data of individuals on mode or route choice, is divided into RP (Revealed Preference) model and SP model depending on the data. While RP model is the methodology of estimating demand behaviour based on the data of individuals who have automobiles currently, SP model is the estimation methodology based on survey data about individuals' choice behaviour in imaginative plot. If RP data are available we could conduct RP study and verify the accuracy and applicability of the SP study.

However in cases where reliable RP data are very difficult to obtain SP technique is more widely used. The SP has improved despite of its methodological limitations, as it is perceived to be useful for analyzing the effectiveness of newly developed policies.

For the SP analysis we surveyed bicycle users in Seoul metropolitan area. As we can see in Figure 2 below, bicycle use in Korea are mainly for leisure and social activities. Commute and work related are not very prevalent considering the fact that the survey was focused only on current bicycle users. Accordingly health benefits were reported as the primary reason for bicycle use in Korea.

Figure C.2 **Main purposes of bicycle use in Korea**

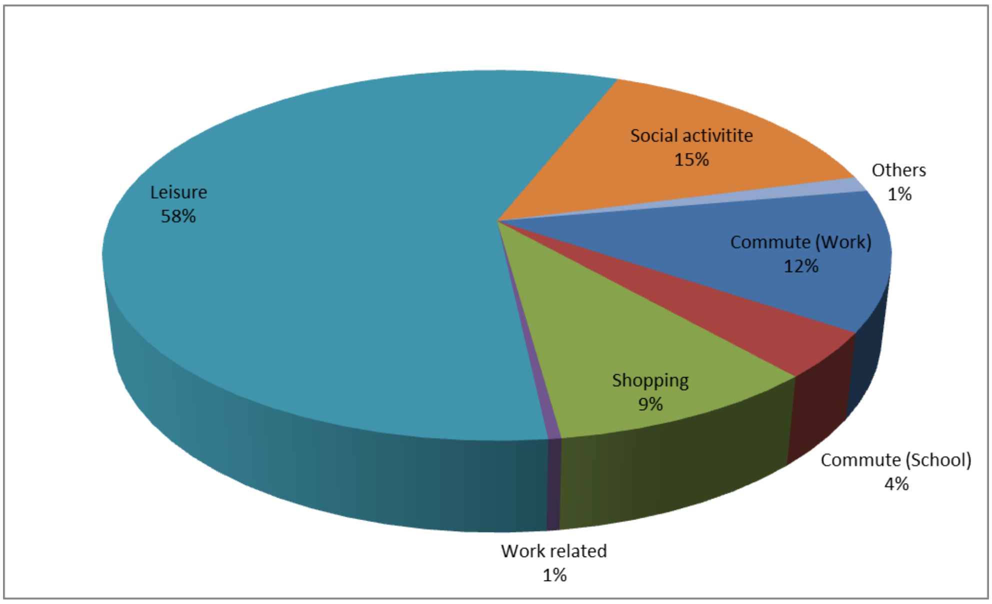
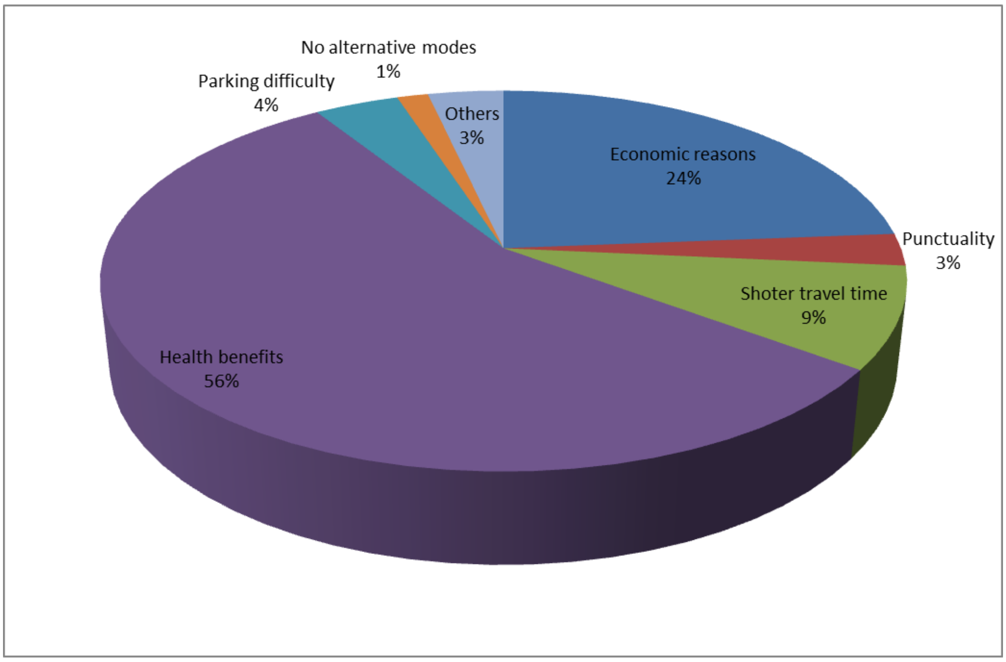


Figure C.3 **Main reasons for bicycle use as a transport mode in Korea**



Estimation results and policy implications

From the SP survey the coefficients of bicycle users' utility function was estimated as shown in Table 1. All of the coefficient estimates are turned out to be significant at 95% level. The most unexpected finding is the positive significant estimate of LNUM coefficient which was conjectured to be inversely correlated with bicycle travel conditions. This could be explained by the fact that in Korea, unlike other countries wider roads could provide friendlier condition for bicycle. Narrower two lane roads are frequently blocked by illegal parking and etc.

The dedicated bicycle only road and bicycle lanes are estimated to enhance cyclists' safety perception. It is also estimated that lowering vehicle travel speed is very effective in increasing cyclists' safety perception as shown by negative significant coefficient for SPEED variable.

From the elasticity analysis it is shown that in Korean context lowering vehicle travel speed is estimated to be most effective policy measure in increasing safety perception and thus for increasing bicycle modal share. Providing dedicated infrastructures such as bicycle only roads and lanes are also estimated to be highly effective.

Table C.1 **Estimation result for total bicycle travel**

Variable	Coefficient estimate	Standard Error	b/St.Er.	p[|Z|>z]
LNUM	0.0552	0.0179	3.087	0.0020
ONLY	3.1844	0.0965	33.005	0.0000
LANE	2.2054	0.0814	27.100	0.0000
SPEED	-0.0215	0.0023	-9.536	0.0000
TIME	-0.0657	0.0078	-8.472	0.0000

Table C.2 **Elasticity of bicycle travel demand with respect to the attributes**

Attribute	C1	C2	Mean
LNUM	0.1222	0.0851	0.1037
ONLY	0.3152	0.3542	0.3347
LANE	0.4459	0.1776	0.3118
SPEED	-0.7030	-0.4189	-0.5610
TIME	-0.5870	-0.3663	-0.4767

Subgroup analysis

In order to find whether the subgroups defined by travel purpose or cycling experience have similar or different characteristics we divided the respondents into several subgroups. The estimation results are shown in Table C.3 and C.4.

Unlike the all bicycle user case, the LNUM variable is estimated to be insignificant. However other coefficients show similar pattern to the all user case. In this subgroup, providing dedicated bicycle facility is estimated to be the most effective policy measure.

Table C.3 **Estimation result for bicycle work commuters**

Variable	Coefficient	Standard Error	b/St.Er.	p[|Z|>z]
LNUM	0.0670	0.0388	1.729	0.8370
ONLY	2.0517	0.1711	11.994	0.0000
LANE	1.5017	0.1451	10.351	0.0000
SPEED	-0.0130	0.0044	-2.972	0.0030
TIME	-0.0465	0.0158	-2.947	0.0032

Table C.4 **Elasticity of bicycle travel demand for work commute with respect to the attributes**

Attribute	C1	C2	Mean
LNUM	0.1424	0.1112	0.1268
ONLY	0.2151	0.2978	0.2565
LANE	0.2955	0.1346	0.2151
SPEED	-0.4068	-0.2721	-0.3395
TIME	-0.3976	-0.2806	-0.3391

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International Transport Forum

Cycling, Health and Safety

Many jurisdictions around the world are trying to retain or increase the share of cycling in urban traffic in order to benefit from the many health and transport efficiency benefits. Safety is a key concern and should be accounted for in these policies.

This report of the International Transport Forum's Cycling Safety Working Group monitors international trends in cycling, safety and policy, and explores options that may help decision makers design safe environments for cycling. Key messages relate to strategic goal-setting for cycling policy and managing crash risks while increasing health benefits. The report also discusses how to better capture crash and bicycle usage statistics. The safety impacts of a wide range of pro-cycling measures are examined in detail.

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