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.

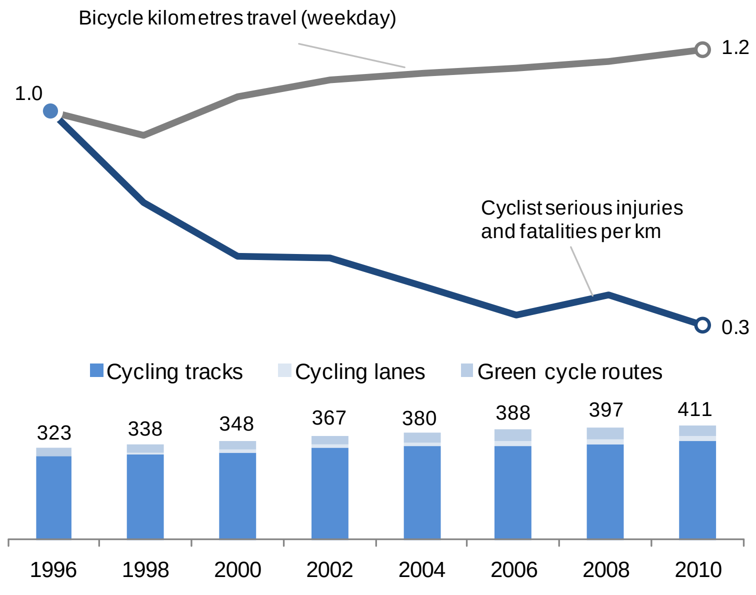
Do policies that increase the number of cyclists contribute to more crashes?

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

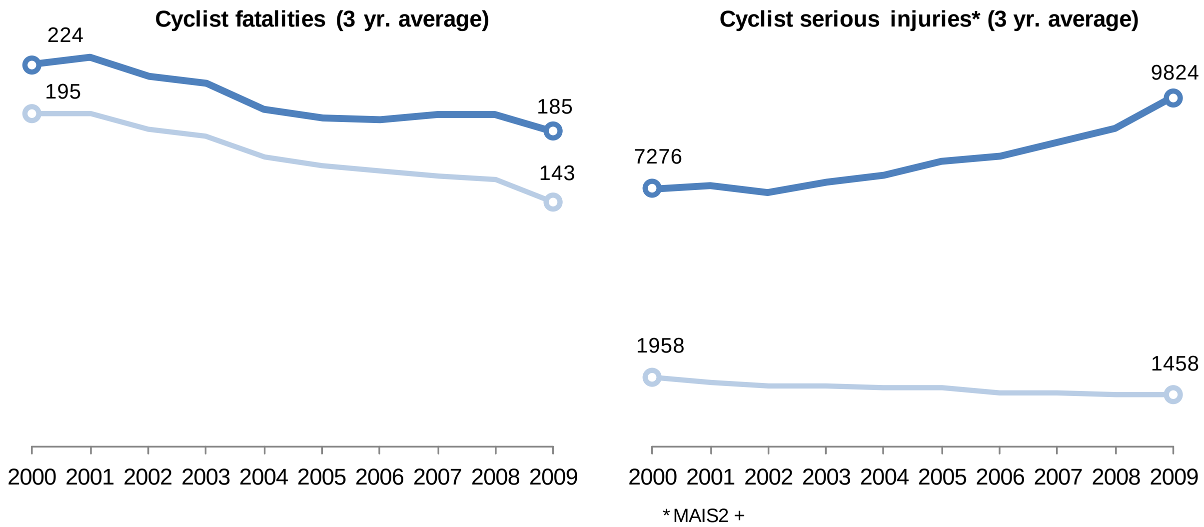
Under-recording of cycling accidents is an essential problem for bicycle safety analysis. The underlying reason of under-recording is that personal injury accidents are not systematically registered. It should be kept in mind that the analysis that follows in this report is based largely on data of recorded 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.

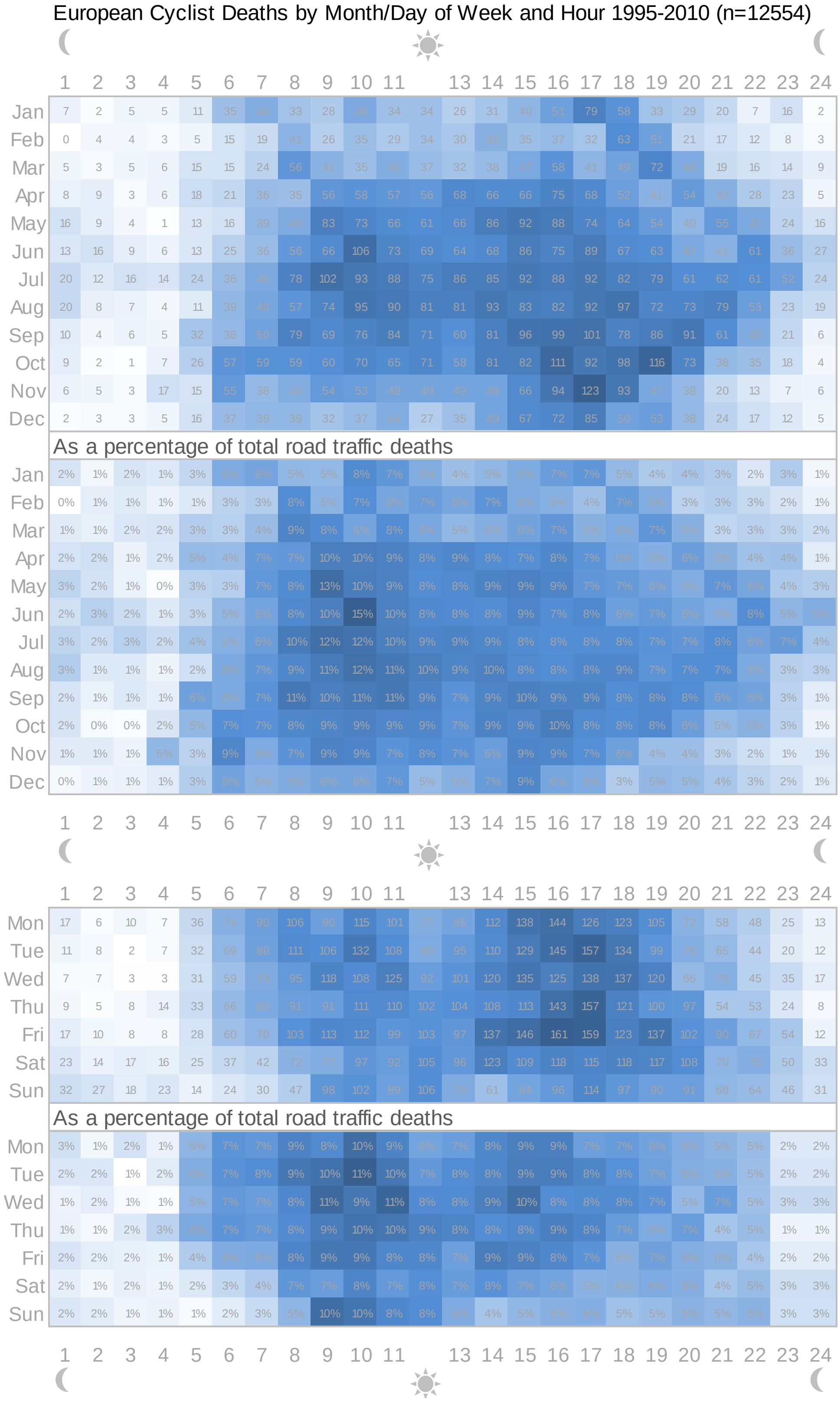
Most countries report decreasing bicycle crash numbers though cycling safety improvements lag behind other modes.

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.

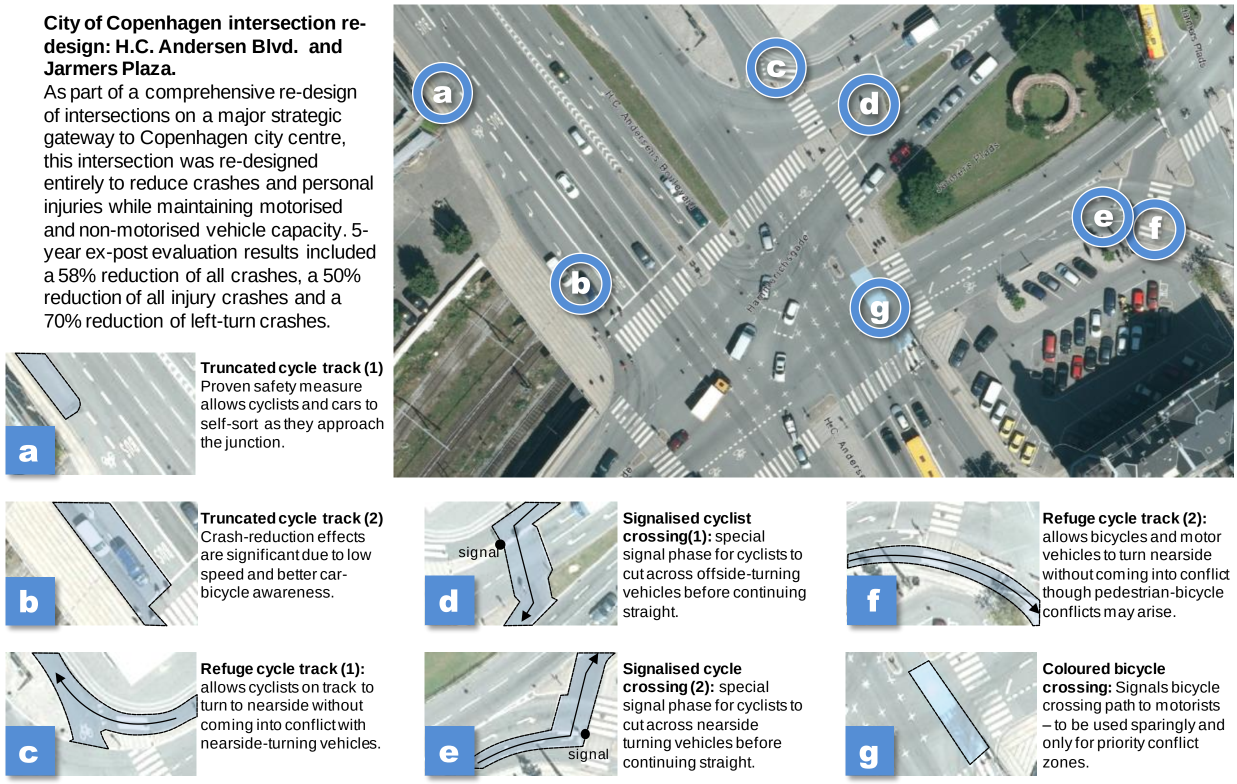
Recommendation 18:

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