International Transport Forum

Cycling Safety

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The International Transport Forum

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Executive Summary

What we did

This report discusses approaches to measuring and improving the safety of cyclists. The number of cyclists killed in road traffic has risen in recent years, according to reports from several countries. This may reflect the growing popularity of this mode of travel but has increased concern over cycling safety among policy makers. Implicitly, a rise in the number of cycling fatalities also raises questions about the number and severity of injuries to cyclists, as injuries are rarely reported in official crash statistics. A total of 33 experts from national and local administrations, research and academia, consultancies as well as cycling safety advocacy groups from 16 countries explored these questions at a roundtable in January 2018 in Paris. This report summarises the discussions and insights of that meeting.

What we found

Cycling brings substantial health benefits by incorporating physical activity in daily mobility routines. From a public health perspective, these benefits outweigh the societal costs of fatal and serious cycling injuries. The net health benefits of cycling are largest for senior citizens, mostly due to the higher prevalence of chronic diseases among older people. Despite its positive impact on public health, cycling is not very popular in many countries and fear of crashes is often cited as a main deterrent.

Vast differences in safety levels for cyclists exist between countries and also between cities. The safest areas tend to be where people cycle the most and where cycling infrastructure is most developed. However, this in itself provides no clear guidance for reducing the risk of injury or increasing cycling.

E-bikes are becoming more popular in many countries. Riding a power assisted bicycle limited to a maximum speed of 25 km/h is no more dangerous than riding a classic bicycle, according to research in the Netherlands and in Switzerland. Other studies, however, found that e-bike users can have higher risks of accidents. More research in this area is therefore required.

Bike-sharing is also becoming increasingly popular in many places. Data from London and Paris suggests that users of public bike share systems are less likely to sustain serious and fatal injuries than riders of privately-owned bicycles.

What we recommend

Address safety concerns to achieve more sustainable mobility

Urban mobility policies should facilitate cycling given the benefits in terms of sustainability and health. Bike share systems have proven to be very successful in increasing the number of people cycling in many cities. To persuade more people to use bicycles, cycling must be safe and be perceived as safe. Cycling infrastructure should be provided (including protected cycling lanes) and the speed of motor vehicle traffic reduced in streets shared with cyclists.

Use appropriate indicators to measure cycling safety performance

The absolute number of road traffic fatalities and injuries are important indicators for monitoring road safety trends and setting road safety targets. However, to measure cycling safety performance, monitor progress and compare countries or cities, performance metrics that control for the underlying volume of pedal cycle traffic should also be used. Data on the number and length of bicycle trips should be systematically collected and monitored.

Set ambitious targets for reducing cycling fatalities and serious injuries

Large differences exist in cycling safety performance between countries or cities of broadly similar urban form, levels of motorisation and economic development. This suggests that significant reductions in the risk of cycling death and serious injury can be achieved in many countries or cities within a period of five to ten years. Credible operational targets should be based on known performance improvements that the implementation of safety measures have achieved elsewhere.

Collect data on serious injuries from hospitals

Fatality numbers alone are insufficient to monitor cycling safety performance; serious injuries are also an important indicator of safety. Because police reports systematically underreport crash injuries, establishing a more accurate picture of serious injuries from better sources, notably from emergency departments of hospitals, is vital. Injury severity should be coded using the Abbreviated Injury Scale (AIS), which enables international comparison of the number of seriously injured casualties (MAIS3+).

Ensure e-bike retailers provide safety advice

E-bike riders benefit from the physical activity associated with pedalling despite the assistance offered by the electric motor. Such vehicles are particularly appreciated for hilly or longer journeys and by elderly people. However, e-bikes may encourage some users to make inappropriate speed choices. Retailers should provide essential speed awareness advice to customers.

Distinguish slow and fast e-bikes and regulate their design and use

Regulation of e-bikes should make clear distinctions between slow and fast e-bikes. Slow e-bikes should be limited to a speed of 25 km/h or 30 km/h, with a pedal assistance limited to 250 or 500 watts, to be treated as bicycles. E-bikes offering more powerful assistance and higher speeds should fall under moped regulations, and require safety features associated with powered two-wheelers. Moped regulations should ensure that the design of fast e-bikes is clearly differentiated from the design of bicycles and slower e-bikes. In any case, fast e-bikes should be clearly identifiable, so that road users will not under-estimate their speeds and the police are able to enforce the applicable regulations.

Consider regulating e-bike ergonomics and power assistance configuration

E-bikes are popular among older cyclists and these are more likely than younger users to fall while mounting and dismounting. Battery position, frame design and saddle position may be improved to increase stability of e-bikes and prevent commonly observed issues older riders face. On fast e-bikes, a maximum power-assistance factor could be required in order to prevent speeds that exceed the fitness and capabilities of the rider. This is already obligatory for speed-pedelecs in the European Union.

Employ bike share systems to popularise cycling

Bike-sharing systems are a complementary part of a public transport system and should be part of any sustainable urban mobility system. They also provide a public health benefit by enabling more people to cycle more often. The launch of a bike-sharing system provides an opportunity to roll out road safety measures ranging from speed limits and enhanced enforcement of traffic regulations to construction of protected bicycle lanes and area-wide traffic management strategies. The launch of a bike-sharing system mainstreams the use of bicycles as a mode of transport for everyone, which builds support for interventions giving cyclists a greater protection from motor vehicle traffic.

Collect data on bicycle usage and crash risks from shared bicycles

Bike share operators should be requested to collect, anonymise and share data on usage, route choice and crashes to aid understanding of crash risks. Whilst the majority of crashes may not always be reported to either the police or system operators, sensors fitted on shared bicycles could detect suspected incidents, record the location and contact the user to survey crash circumstances and outcomes.

Set maintenance standards for safety equipment provided by operators of shared bike systems

All bike share operators should adhere to clear minimum standards with regard to the maintenance of safety critical equipment of the bicycles they operate. Brakes and lights in particular should be subject to strict standards of functioning.

Weigh potential benefits and drawbacks when considering whether to make helmet use obligatory

The use of a helmet is proven to reduce the severity of head injuries of cyclists in the event of some crashes. On the other hand, making the use of helmets obligatory for cyclists can have a negative impact on the popularity of cycling and the use of bike-sharing services. No consensus recommendation therefore exists on making helmet use mandatory.

Build adequate cycling infrastructure with continuous protected networks and pay particular attention to junctions

A safe and attractive cycling environment requires ambitious planning. Space should be allocated (or re-allocated) to cycling, potentially reducing private motor traffic. High-quality cycling networks require continuous inter-connected routes and particular attention in the design of intersections where crash risks are highest.

Use light segregation as a flexible solution for extending protected cycling lanes

Light segregation of cycle lanes from traffic, through the use of intermittent separators, is a relatively cheap form of protecting cyclists compared to full physical separation. It is therefore especially suited to creating a large, connected cycling network within a limited timeframe, for instance an election cycle. Light segregation is quick to install, easy to fine tune, to upgrade or remove. This makes it suited both to permanent infrastructure and for trials, which can be used to help to reduce conflicts over the re-allocation of road space.

Introduction

The primary focus of the roundtable was the safety and general health of people riding bicycles on public roads for commuting, daily travel or leisure as opposed to people engaging in competitive or off-road cycling. The safety and health of all other road users was discussed, to the extent that it can be influenced by the use of bicycles. Similarly to previous ITF research on cycling safety, a discussion on the health risks of cycling (namely crashes) would have been incomplete without a discussion on the health benefits (namely the lower prevalence of chronic diseases linked with a sedentary lifestyle).

Cycling Crash Risks

Cycling attracts strong interest from stakeholders in the transport world as one of the most sustainable mobility solutions for short and medium-distance trips. Cycling takes up relatively little space, is silent and clean, offers regular physical activity, requires relatively modest infrastructure investment, and is an affordable and rapid transport option.

Several countries report an increased number of bicycle traffic fatalities in recent years, probably reflecting the increased popularity of this mode of travel, but a cause for concern nonetheless. In addition, questions are raised about the number and severity of bicycle injuries, rarely reported in official crash data systems.

Beside the risk experienced by the rider, cycling presents some risk also to third parties. In Great Britain, out of 1792 road fatalities reported in 2016, three were pedestrians killed in collisions with a pedal cycle (DfT, 2017). This figure reflects the much lower kinetic energy carried by people cycling, in comparison with other vehicles. The concept of risk to third parties, which will be mentioned in the "Measuring performance and tracking progress" chapter, should not be neglected when assessing the safety of any particular mode of transport.

Cycling casualties

Globally, the total number of cycling fatalities is likely to be higher than 50 000 per year, or 4% of the world's total number of road deaths (WHO, 2015). The lack of road user classification in casualty statistics in many countries suggests the true number could be significantly greater. Among the 29 countries providing cycling fatality data to the IRTAD database since 2000 and earlier, the median share of cycling fatalities was 8% in 2016, up from 4% in 2000. This reflects a stronger progress in reducing fatalities for vehicle occupants than vulnerable road users. Nevertheless, between 2000 and 2016, the number of cycling fatalities decreased by 34% across the 29 countries.

Injuries are another cause for concern, and an area where global statistics are lacking. This is partly due to low rates of cycling injuries being reported to the police, as a significant proportion of cycling crashes involve no other road user and/or no motor vehicle. The burden of injuries and the methods to monitor progress in relation to injury prevention will be discussed in this report along with indicators to assess cycling crash risks and measures to create safer cycling environments.

Health benefits

The health benefits[1] of cycling outweigh the cost of fatal and serious injuries (Mueller et al., 2015; ORS, 2012). Woodcock et al. (2014) found that the net health benefits are largest at older ages. This is mostly due to the higher prevalence of chronic diseases among older people, which physical activity contributes to preventing. However, there are places in the world where the crash risk of riding a bike outweighs the health benefits of physical activity. This highlights the challenge of measuring the risk of injury or death consistently in different countries and cities, and will be addressed in the first section of this report.

In light of the health benefits of cycling, some policy makers have suggested it is time to move beyond the "Vision Zero" philosophy adopted in Sweden 25 years ago (Moving Beyond Zero, 2018). Their idea is to acknowledge that participation in active travel should be a main priority because far more people die of chronic diseases due to physical inactivity and air pollution than in traffic crashes. They point to a risk that some road safety interventions, including for example obligatory helmet use, become a barrier to active healthy modes of transport like cycling and walking. This reflects some research into the effectiveness of legislation on helmet use (Robinson, 2006) contested by other researchers (Hagel et al., 2006), who nevertheless acknowledge the larger overall benefits of active mobility. Rather than modifying the principle of Vision Zero, the issue can be resolved by putting the emphasis on making the environment safe for cycling rather than requiring cyclists to protect themselves from unmanaged risks.

Participants of the roundtable supported all 18 recommendations made by the ITF in an earlier report on cycling safety (Box 1), where health was integrated as a key issue and a positive outcome of cycling (ITF, 2013). For this reason, it would be appropriate to see cycling policy integrated with public health policy and benefit from research funding and experimental methods traditionally observed in the areas of medicine and epidemiology. For instance, one could see a growing role in national governments or the European Union in the organisation of experimental research with randomised controlled trials across a number of candidate regions or cities.

Policy context

Beside the health benefits associated with physical activity, cycling is silent and clean, and shifting from motorised travel to cycling can reduce congestion and greenhouse gas emissions, whilst offering an affordable and inclusive mobility option. For these reasons, cycling is often supported at all government levels and integrated into local sustainable urban mobility plans.

Should cycling promotion therefore be given a higher priority than cycling safety? It appears the two goals cannot be separated. Indeed, the fear of crashes is often reported in surveys as the first reason why people don't cycle at all or don't cycle more often. Cycling safety is clearly an important political goal, not only for its moral value and direct impact (the number of crashes avoided), but also for its role in promoting active travel which has a potentially much greater, albeit indirect impact on public health, wellbeing and the economy.

There is concern among policymakers that getting people to cycle more carries a risk of more road traffic injuries and fatalities. In this context, it is important to identify and learn from best international practice how to reduce the risk of serious and fatal casualties and use an evidence approach to weigh decisions on promoting cycling.

With the introduction of new mobility solutions such as e-bikes and dockless bike-sharing systems, government regulations may need to adapt. With ageing of the population the number of older riders is increasing and e-bikes are particularly attractive to older riders. As a consequence, the number and severity of crashes involving this segment of users is on the rise, prompting policy makers to re-examine the responses needed.

Box 1. **ITF Recommendation on Cycling Safety**

The ITF report *Cycling, Health and Safety* (2013) contains the findings of a Working Group of experts from sixteen different countries. The Working Group made the following recommendations:

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).
2. Insufficient evidence supports causality for the “safety in numbers” phenomenon – policies increasing the number of cyclists should be accompanied by risk-reduction actions.
3. Efforts must be made to harmonise definitions of terminology so as to be able to make reliable international comparisons of cyclist safety.
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.
5. National authorities should set standards for and collect or otherwise facilitate the collection of accurate, frequent and comparable data on bicycle usage.
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.
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.
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.
9. Speed management acts as “hidden infrastructure” protecting cyclists and should be included as an integral part of cycling safety strategies.
10. Safety policy should target crashes between Heavy Goods Vehicles (HGV) and Bicycles due to the especially serious consequences of these crashes and their (relative) frequency.
11. Cyclists should not be the only target of cycling safety policies – motorists are at least as important to target.
12. Cycle safety policies should pay close attention to junction design – visibility, predictability and speed reduction should be incorporated as key design principles.
13. Authorities should match investments in cycle safety to local contexts, including levels of bicycle usage and account for cyclist heterogeneity.
14. Cycle safety plans should address safety improvement and the improvement of perceived safety.

15. The deployment of cycling infrastructure should be accompanied by adequate levels of maintenance and enforcement of access rules.
16. Where appropriate, traffic speeds should be limited to less than 30km/h where bicycles and motorised traffic mix but care should be taken so that speed control devices do not create hazards for cyclists.
17. Where speeds cannot be lowered, or where justified by traffic densities, authorities should seek to separate bicycle and motor traffic whenever feasible.
18. Authorities must critically examine bicycle facility junction design and deploy known safety-improving measures to decrease crash risks.

Measuring performance and tracking progress

Improving the safety of people riding bikes requires performance metrics, which in turn requires data collection tools and methods. This is essential not only to monitor progress, but also to compare cities/countries, identify risk factors and develop policies. In Cycling, Health and Safety (2013), the ITF made recommendations to this end (Box 1). As a result, the ITF commissioned research in this area in preparation of the roundtable.

Not only can the collection of road safety performance data be challenging, the objective to compare cycling safety performance across countries and cities adds further complexity: it requires indicators to be harmonised across the world. In this chapter the use of performance indicators that account for the actual amount of bicycle traffic is illustrated and recommended to offer solutions to current challenges for data collection and harmonisation, and an interpretation of the results is made available.

What to measure?

A consensus emerged at the roundtable meeting in support of a recommendation made earlier (ITF, 2013) that the absolute number of cycling incidents (fatalities, crashes, injuries) alone is of limited use as a performance indicator. Such absolute numbers are often normalised by population in an attempt to make them comparable over time and across locations but more relevant cycling safety indicators are those that account for the underlying pedal cycle traffic, for at least three reasons:

- Where cycling volume grows, a relatively static number of incidents indicate a falling risk of incident per unit of pedal cycle traffic. The monitoring of performance over time is more meaningful when the pedal cycle traffic is controlled for.
- When comparing cities or countries where levels of cycling differ, the use of pedal cycle incidents per unit population isn't a relevant performance metric. Some populations cycle more than others. The average distance cycled per year and per inhabitant can vary by a factor of 100 across cities in Europe.

- Controlling for pedal cycle traffic is also required to reflect the probability (per trip or per km) of an individual being injured when riding a bike. This is what ultimately matters most to cyclists and society.

Cycling risk metrics are a family of performance indicators with a numerator reflecting the number of negative outcomes (crashes, fatalities, serious injuries, etc.) and a denominator reflecting the level of cycling activity (trips, time spent cycling, cumulated distances, etc.) in comparable areas and time periods (Vanparijs et al., 2015; ITF, 2013). Cycling risk can be expressed in several different ways, each providing different insights. It can focus on fatalities alone, or include injuries of various severities, or can also include incidents where road users nearly collided (near crashes) or incidents where cyclists report intimidation from other road users. It could include as denominator cumulated cycling trip distances, the total time[2] spent cycling, the total number of trips cycled, or other metrics. For the sake of simplicity and in line with earlier research (Pucher et al., 2008; Buehler et al., 2017) this roundtable report uses distances and to express risk as a number of fatalities per unit distance cycled as the principle risk indicator for benchmarking performance.

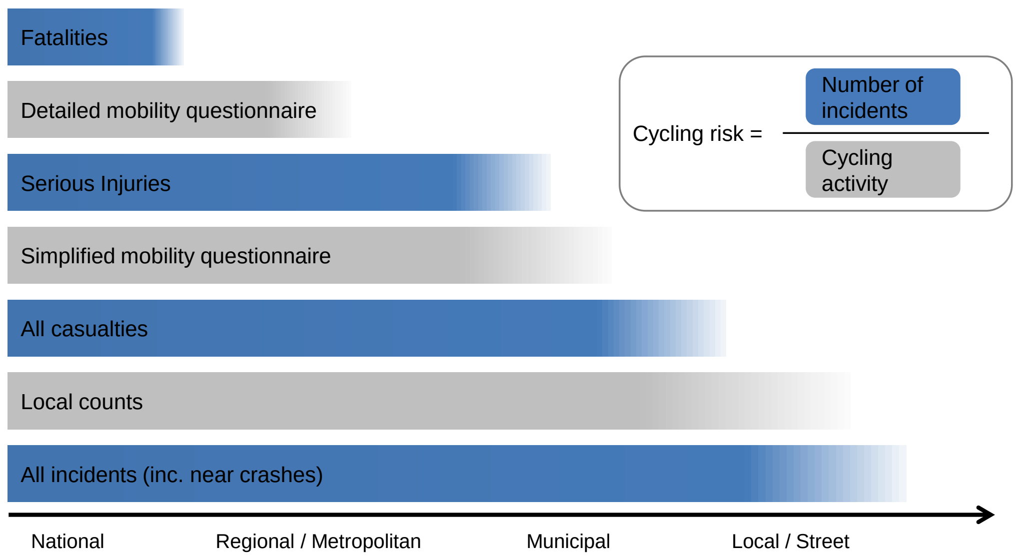
Most often, the number of fatalities is used in cycling risk metrics. The reason is the current weakness of injury data, which is discussed in a dedicated section below. Cycling *fatalities* are rare events. The frequency is of the order of 5 per year per million head of population (IRTAD database). Whilst highly significant in human terms, such numbers are rarely significant in statistical terms. Large random fluctuations can be observed and misinterpreted as trends. In other words, the number of pedal cycle fatalities in a single year is often insufficient to determine the true level of risk. For this reason, an aggregation into 3 or 5 year averages is essential for undertaking analysis of trends.

Disaggregation of crash risk indicators is required to understand exposure to risk, differentiating by year, municipality, day of the week, gender, and so on. The analysis of risk across different times of day reveals specific road safety problems and calls for specific counter-measures (Dozza, 2017). An analysis of risk by gender reveals that women can be at higher risk than men when cycling, probably due to the higher risk at the locations where they cycle despite well-known differences in risk aversion (Degraeuwe et al., 2015). Cycling on protected networks may need to be distinguished from cycling on streets where cyclists share the road with motorised vehicles. And for crashes involving motorised vehicles information on the volume of motor vehicle traffic is needed.

There can, however, be a trade-off between granularity of disaggregated risk figures and the reliability of estimates due to the small numbers of rare incidents. As a rule of thumb, at the 95% confidence level with samples close to only 10 observations, the true risk could be half as high or twice as high as the observed risk. Where observed numbers are close to 100, the true risk could be +/-20% of the observed risk.

Where reporting on rare events, such as the number of fatalities in a given city, this report aggregates figures over a 5-year period. But can policy makers be satisfied with measuring performance on a rolling 5-year average when improving cycling safety is one of their stated objectives? Can policy makers be satisfied with performance metrics at national or regional levels, when much of the cycling network development is managed at the municipal level? There is indeed value in disaggregating numbers in space and in time but this is impossible with data on fatalities alone and requires injuries to be integrated into road safety metrics (Figure 2).

Figure 1. **Indicative statistical relevance of cycling risk data sources by level of geographic disaggregation**



Serious injuries

Whilst on average road traffic injuries do not have the economic cost of fatalities, they occur more frequently. Severe injuries can also be life-changing, severely reducing quality of life. They can also entail high medical costs. Non-fatal injuries therefore make a substantial contribution to the overall road safety problem. In Norway, cycling fatalities were shown to represent only 10% of the total economic cost of cycling casualties, the majority of this total cost being associated to minor (MAIS1) and moderate (MAIS2) injuries (Veisten, 2007). Injury data helps researchers and policy makers work on a wider statistical base, making data analysis more insightful, even if injuries are also relatively rare events.

Pedal cycle injuries are notoriously under-reported in police data in most countries (Aertsens et al., 2010; Wegman et al., 2012; Watson et al., 2015). Even among serious bicycle injuries – those requiring hospital admissions – the majority are not reported in police data (Shinar et al., 2018). This may be due to the proportion of single-vehicle bicycle crashes, which in the Netherlands represents a high proportion of incidents even among serious cycling crashes (Schepers et al., 2015).

In addition to being under-reported, serious injuries are difficult to compare across countries because casualty severity definition isn't harmonised. This may change, as European countries make progress towards the estimation of their serious injury figures following guidelines that recommend MAIS3+ as the common standard (FERSI, 2016). Even while heterogeneous methods are employed and comparability across countries remains questionable, expanding data on cycling injuries is important to understanding real crash risks (ITF, 2011).

Monitoring non-injury incidents is another useful tool for understanding crash risk. Whilst single incident evaluation rarely offers enough statistical power to draw firm conclusions on potential interventions to reduce crash risk, automated analysis of video images can be used to identify a high enough number of events to reach statistically meaningful conclusions. This can be applied, for example, to assessing junction designs and the layout of cycle lanes at intersections. Near crashes can reveal risks while injury crashes remain, fortunately, rare. The analysis of near crashes is also important because it can document the type of event that might deter people from cycling (Dozza et al., 2014; Aldred, 2016).

Perception of safety

As discussed earlier, cycling is an important component of sustainable mobility and public health. Understanding how potential cyclists perceive safety is key to designing effective policies to promote cycling. Research on perceptions could include monitoring the occurrence of near crashes, close passes, and incidents of intimidation and harassment. Such events may or may not correlate with the actual risk of serious or fatal injury, which is why they deserve a dedicated monitoring strategy. Roundtable participants reported that several cities already monitor the perception of cycling safety, including Copenhagen and Mexico City. Research suggests that those who cycle perceive a lower cycling risk than those who do not cycle (Papon, 2018). Therefore, further data on the perception of cycling safety should be collected both for cyclists and non-cyclists.

Monitoring of demographic diversities of the cycling population can also be insightful. The participation of women, for example, has been used not only as an indicator of inclusiveness, but also as a proxy indicator for the perception of cycling safety. The proportion of women cyclists in the total bicycle traffic varies between countries and seems to be lower where risk is higher and where people cycle less (Pucher et al., 2008; Aldred et al., 2015).

Exposure data

In the context of cycling safety analysis, exposure data refers to the cycling activity in a given area, which can be expressed as the total number of trips cycled, the cumulated distance cycled, the total time spent cycling, the total number of cycle commuters, and so on.

Information on bicycle trips and traffic can be collected through household travel surveys, or through other methods (see Box 2). Within the IRTAD group and the Safer City Streets programmes, the ITF has developed a better understanding of why this information is rarely used by road safety professionals in the calculation of risk indicators. Reasons include the silo effect between the traffic/mobility teams and the road safety teams, but also some limitations of the exposure data. Indeed, traffic/mobility data isn’t always collected annually. Data collection campaigns could be 10 years apart with no extrapolation made between survey rounds. Another limitation is the partial scope of traffic/mobility surveys. For example if the survey is carried out on winter school-term weekdays, this is clearly insufficient to estimate the total annual traffic or mobility. Survey samples are often insufficient for extrapolation to produce reliable national average figures (Blaizot et al., 2012).

Some mobility and traffic surveys have focussed on the design of peak-hour weekday vehicle traffic models and neglected active travel modes. The limited scope of such surveys doesn’t facilitate the estimation of total walking and cycling activity or total exposure to crash risk. In response to this problem, in the area of walking, International Walking Data Standards have been developed by Walk21 (Sauter et al., 2016).

Box 2. **On-street cycle counts**

To monitor the growth in cycling, many cities chose to count bicycle traffic at a panel of locations, either manually or automatically. Count data can be used to compute cycling risk figures but care must be taken in the extrapolation of such data. One limitation of this approach is that the selection of count locations is rarely randomized, which could artificially increase the rate of growth. This may explain why in one study, in all 7 US cities where on-street counts were conducted, the risk of cycling death or injury per unit cycling traffic fell between 2007 and 2013 (NACTO, 2016). Such issues, along with the quality of automatic data collection, are discussed in Dozza, 2017.

Panel count data is also very difficult to extrapolate to provide an indication of the total volume of pedal cycle traffic, which often makes it impossible to compare the risk of injury from one city to another on the basis of indicators derived from panel counts. With a dense and randomized sample of 1 250 monitoring locations, Transport for London has overcome these limitations (TfL, 2017). More than 3.7 million kilometres are cycled in London on any given weekday, a figure updated with monitoring each year. In Central London, where counts are more frequent, cycle traffic is estimated every three months.

Innovative solutions are bringing down the cost of mobility surveys. Shorter questionnaires, online questionnaires and dedicated survey apps on smartphones are options to reduce the cost of surveys and address the fall in survey response rates. For every innovative solution however, a more traditional survey in parallel is important so as to measure any loss in quality and calibrate a correction model.

Economies of scale can be achieved between national and metropolitan transport authorities, through the elaboration of a national survey framework, where local funding can increase the national survey sample and produce local statistics, an approached called local sample boost. Surveys conducted for other purposes: population census, physical activity surveys, activity-based time use surveys, etc. can also be a useful source of information on cycling.

Harmonisation of travel surveys across the world is recommended to make results comparable. This is challenging as national governments are likely to want to retain their traditional survey methods to preserve longitudinal comparability, rather than adopt new solutions (Armoogum, 2014). For this reason, the most realistic short term objective would be to promote the release of standard survey meta-data so as to better understand scope and methods used. A medium term objective could be to promote the release of post-harmonised, standardised results. Post-harmonisation involves the calibration of correction factors so as to adjust for any misalignment in scope or method between a survey and international standards.

New technologies and crowd-sourcing techniques can help to collect mobility data, for example through smartphone location services, cycling apps or through mobile telephone companies (COWI, 2017). However, the technical limitations, the severe biases and cost limit the potential of such sources. Surveys and counts remain essential.

Numbers and safety

A positive correlation pattern can be observed between the level of cycling activity in the population and the safety of cycling (Aldred et al., 2017; Castro and Götschi, 2018). Whilst the correlation is evident, its interpretation is less so. Several hypotheses can be made:

- The pattern could indicate a reduction in risk caused by higher cycling activity. This hypothesis called “Safety-in-Numbers” could be explained by the higher awareness among motorists of pedal cycle movements where interactions are more frequent and/or where motorists are also cyclists. Some counter-examples were mentioned in the roundtable discussion in rare places where cycling numbers have grown but no cycling safety policy has been implemented, crash numbers have also grown.
- The pattern could indicate growth in cycling activity resulting from a safer cycling environment. One could indeed imagine that lower speed limits, traffic calming features and speed enforcement together might encourage people to cycle more.
- The pattern could be the result of confounding factors, such as policies which aim to increase both cycling numbers and cycling safety, for example the development of protected cycling networks.
- Some consider that the apparent correlation could be an artefact, as randomly generated data can produce the same pattern (Elvik, 2013). Whilst measurement errors in exposure data inevitably exist and probably contribute to the pattern observed, their contribution shouldn’t be overstated. Differences in cycling level between countries and cities are real and well documented. These differences can be captured by surveys, at least through the analysis of the method of travel to work, a figure collected in many countries. Where cycling level varies by a factor of 100 between cities, the influence of measurement errors is limited.

It is possible that all hypotheses listed above contribute to the pattern observed, in various proportions. To clarify this, causality pathways could be investigated in future research. However, more important than the apparent linkage between two variables, the key research questions remain to measure the effect of specific policies, regulations and actions on both cycling safety and the number of people cycling.

Benchmarking

ITF (2013) concluded that the risk of death per unit time spent cycling was 4 times higher in the UK than in the Netherlands. Such significant differences between countries are confirmed by further analysis from Castro and Götschi (2018) from which Table 1 is adapted. The limited number of countries in Table 1 is explained by the requirement of high quality exposure data sources. At city and metropolitan levels, in research conducted at the ITF (2018) as part of the Safer City Streets programme, similarly large differences in risk are observed.

Large differences in risk observed between countries (Table 1 and Figure 2).

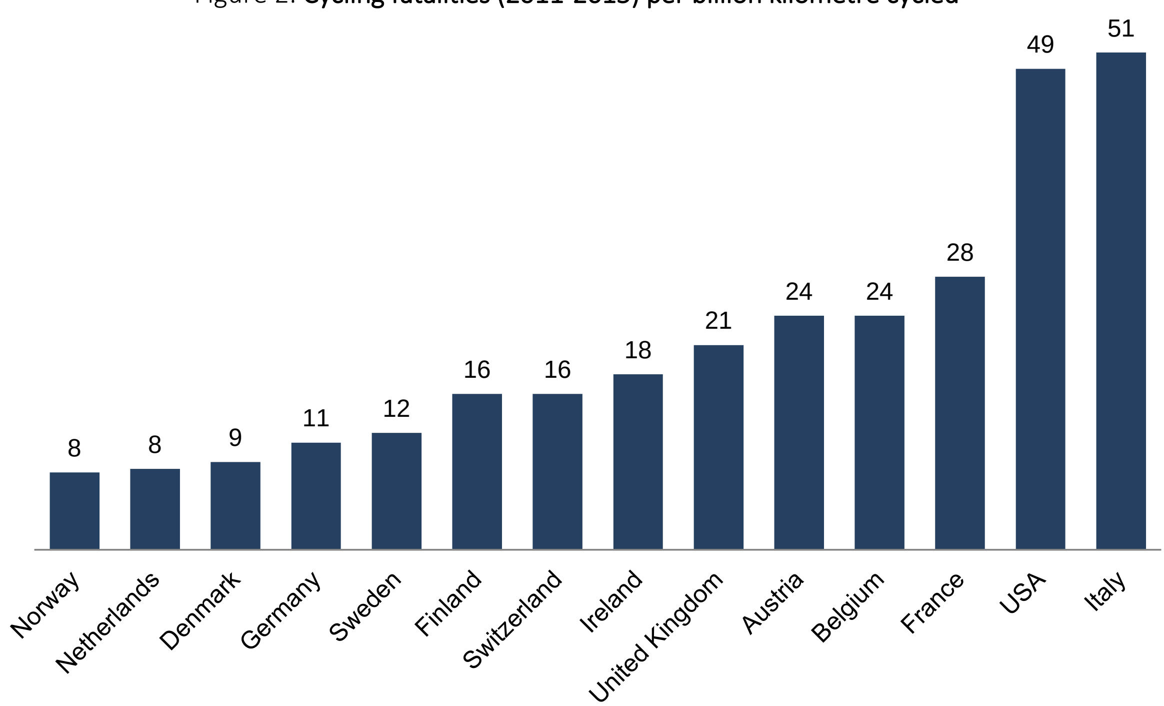
Figure 2) can be interpreted as room for progress and for setting risk reduction targets. Rapid reduction in risk is indeed possible, and has been documented in a number of places. New York City Department of Transportation (2017) reports a rapid fall in cycling risk between two consecutive 5-year periods. The risk of being killed or seriously injured per cycle trip fell by 73%.

Table 1. **Cycling exposure and risk by country**

Country	Distance cycled per year per inhabitant (km)		Cycling fatalities per year per million inhabitant		Cycling fatalities per billion km cycled
Austria	223	(2014)	5.4	(2011-2015)	24
Belgium	279	(2009)	6.5	(2011-2015)	24
Denmark	547	(2013)	5.0	(2011-2015)	9
Finland	267	(2011)	4.2	(2011-2015)	16
France	88	(2008)	2.4	(2011-2015)	28
Germany	439	(2011-2014)	4.8	(2011-2015)	11
Ireland	103	(2012-2014)	1.9	(2011-2015)	18
Italy	89	(2011-2015)	4.5	(2011-2015)	51
Netherlands	891	(2011-2015)	7.4	(2011-2015)	8
Norway	255	(2014)	2.0	(2011-2015)	8
Sweden	199	(2014)	2.3	(2011-2015)	12
Switzerland	262	(2011-2015)	4.1	(2011-2015)	16
United Kingdom	83	(2011-2015)	1.8	(2011-2015)	21
USA	48	(2009)	2.4	(2011-2015)	49

Source: adapted from Castro and Götschi (2018), ITF (2013) and ITF IRTAD database

Figure 2. **Cycling fatalities (2011-2015) per billion kilometre cycled**



Exposure data: Austria (2014), Belgium (2009), Denmark (2013), Finland (2011), France (2008), Germany (2011-2014), Ireland (2012-2014), Italy (2011-2015), Netherlands (2011-2015), Norway (2014), Sweden (2014), Switzerland (2011-2015), United Kingdom (2011-2015), USA (2009)

Is cycling dangerous compared to other modes?

Considering the wide-spread fear of riding a bike in traffic, it is interesting to collect figures to compare the risk of a passenger being hurt when travelling the same distance using different modes. All available evidence indicates that riding a pedal cycle is significantly safer than riding a powered-2-wheeler (Blaizot, 2012; ITF, 2013; DfT, 2017). Results from the Safer City Streets programme confirm at city-level what was already known at national level: merging figures from five cities, it appears that riding a motorcycle is 4 times more likely to result in a fatality than riding the same distance on a pedal cycle (ITF, 2018). Cycling also appears to be safer than walking, in terms of fatalities per unit distance travelled. However, caveats must be introduced at this stage due to a number of confounding factors.

One must bear in mind that different modes are used by different people, with different age profiles, different attitudes, travelling in different areas, at different times for different purposes. Controlling for such factors would add value to the analysis. Age is an important factor since the risk of fatal and serious injuries goes up sharply with age, a phenomenon observed across all modes of transport (TfL, 2013; Feleke et al., 2017). In countries where older people are over-represented in pedestrian traffic, a comparison of risk across modes is likely to over-estimate the relative risk of walking.

Controlling for age and gender can reveal interesting findings. For instance, cycling can be safer than driving in the case of young people (Wegman et al., 2012; Feleke et al., 2017). Confounding factors, such as the age distribution of the cycling population, can also interfere with the monitoring of road safety performance indicators. Areas where cycling risk is reported to go up have found some explanation in the rising share of older people in the pedal cycle traffic.

Beside young drivers, travelling by car is generally safer than walking and cycling. However, that is only accounting for the risk of injury within one mode. The risk imposed by each vehicle type on more vulnerable road users is rarely taken into account and explicitly calculated. The idea isn’t to attribute responsibilities or blame a particular user group, but to give an indication of the road safety benefits in the event of mode shift. In dense urban areas, such calculations of third party risk could reveal the high impact of motor vehicles on the overall number of casualties, and strengthen the case for mode shift towards walking and cycling (Stipdonk et al., 2012).

In conclusion, in terms of fatality risk, cycling is far safer than riding a powered-2-wheeler, safer than travelling as a young driver and relatively close to walking. Much work remains to be done to include serious injuries and third party casualties in the analysis.

Recommendations

The absolute number of casualties per unit population is the most commonly used road safety indicator. The absolute number of pedal cycle fatalities and serious injuries is an important metric, particularly for setting targets. However, it provides a very narrow perspective and can be misleading if used alone. Cycling safety indicators that control for the underlying volume of pedal cycle traffic are also required to monitor and compare performance. It is recommended that national and local governments measure such indicators and report pedal cycle casualties per kilometre cycled.

In order to measure cycling safety performance, information on bicycle trips and traffic should be collected frequently and comprehensively: covering all days of the week, all seasons, all street types and all user groups. Efforts should be made to reduce the cost of surveys with the trial of new methods, with joint-working across layers of government, and with global platforms for sharing experience in this area. Precise international guidance would improve survey quality and comparability. Comparability could be improved by the definition of a standard set of survey meta-data, and a methodology to estimate post-harmonisation factors. Techniques such as data fusion should be used to compute post-harmonisation factors and to extrapolate exposure figures beyond survey years.

The true number of serious injuries should be estimated and monitored using health data as well as data from the police. Data from insurance companies and direct population surveys can also be useful. Where possible, injury severity should be coded with the Abbreviated Injury Scale (AIS), which enables international comparison of the number of seriously injured casualties (MAIS3+). Beyond the estimation of serious injury totals, linking data sources so as to attach contextual information to each casualty is recommended to better diagnose problems, and ultimately reduce the occurrence of crashes.

Whilst the disaggregation of cycling safety performance indicators in time, in space and by user group is recommended, some statistical limitations when using small numbers should be considered. Statistical tests should be conducted to separate significant conclusions from random noise.

Future research should focus on the evaluation of policies and actions aimed at increasing cycling safety and increasing the number of people cycling. Cycling research should seek to control for the large number of confounding factors, such as age and gender, affecting the comparison of risk across vehicle types. Research is also needed to measure the impact of each vehicle type on more vulnerable road users, something which could be particularly high in urban areas. The perception of safety should be investigated: we recommend the survey of attitudes towards cycling, the analysis of near-crashes and the monitoring of the demographic diversity in the cycling population.

New vehicles, new services

Several countries report a sharp rise in the sales of electrically assisted bicycles of various types, together called e-bikes. With crashes involving e-bikes becoming more frequent, it has become essential for policy makers to understand how e-bikes are used, if they are safe, and whether cycling safety policy should be reviewed as a response. As bike sharing systems are rapidly being developed and are likely to expand further with dockless solutions, their effect on road safety was also examined. As with e-bikes, the ambition is to bring together the latest findings from a range of countries. Countless innovations are observed in the transport world, which are enabled by new technologies. From ITS to autonomous vehicles, the question is whether innovation can deliver a safer cycling environment, and which regulations could help this happen.

E-bike definition and sales

In this report, the term e-bike refers to electrically power-assisted bicycles with functioning pedals. The terms **pedelec** or **slow e-bike** will be used where the electric power output is limited to 250 watts, (available only when the rider places pressure on the pedals) and when the speed is below 25 km/h. Other e-bikes will be called **speed-pedelecs** or **fast e-bikes**.

Benefits created by e-bikes are evident: similarly to classic bicycles, they are silent, clean, affordable transport options. Their strength is to support a greater mode shift towards cycling by removing some of its physical difficulty, especially in hilly or hot areas and in the case of longer distances. In a German survey, e-bike riders most often stated the car as their alternative means of transport, whereas other bicycle users most often identified public transport as the alternative (GDV, 2017). In Switzerland, more than half of the distances travelled by fast e-bike would otherwise be travelled by car (SVI, 2017). In the Netherlands, two thirds of speed-pedelec users would otherwise use a car (SWOV, 2017). E-bikes are not only a substitute for car use but also for mopeds and motorcycles.

The health benefits of e-bikes are currently being investigated. According to research not yet published, e-bike users do benefit from the physical activity associated with the required pedalling, especially considering that most of them would otherwise drive and be absolutely inactive.

In the European Union, the most popular and highest selling e-bike is the pedelec, a bicycle with electric pedal-assistance up to 250 watt; up to 25 km/h (Table 2). This low power vehicle does not have to be type approved like motorised vehicles and is regulated through CEN standards, with work ongoing to establish a global ISO standard. It is seen essentially as a bicycle by all public authorities (ECF, 2018).

In Europe, close to 1.7 million pedelecs were sold in 2016, which represent more than 8% of the bicycle market (CONEBI, 2017). Pedelecs represent 15% of bicycles sold in Germany (GDV, 2017) and more than 1 in 4 in the Netherlands (SWOV, 2017).

The share of **speed-pedelecs** in the overall e-bike market is below 3% in Germany, but is remarkably higher in Switzerland at 20%, possibly because the Swiss legislation allows speed-pedelecs to use cycling infrastructure. In the Netherlands, despite representing a small fraction (less than 0.1%) of the e-bike fleet, speed-pedelecs attract significant attention from the media and from policy makers. They can be found using bike paths despite being forbidden to do so.[3]

Experts acknowledge that regulation can easily be bypassed. People can purchase a speed-pedelec and remove the registration plate, so as to ride on bicycle infrastructure and avoid helmet regulations. Alternatively, people can transform a classic bike into a speed-pedelec, or tamper with the speed limiting mechanism on pedelecs. In all these instances, there is very little the police can do, since these vehicles look very much the same as pedelecs.

Table 2. **Comparison of the technical characteristics and legal classification of pedelecs and speed-pedelecs in most EU countries**

	Max Power output	Assistance up to	Regulatory vehicle type	Driving license	Use of cycling infrastructure	Helmet	Insurance
Pedelec	250 watts	25 km/h	Bicycle	No	Yes	Recommended	No
Speed-pedelec	4 000 watts	45 km/h	Moped	Yes	No	Mandatory	Yes

Sources: adapted from GDV 2017, and Directive 168/2013/EG

E-bike users and behaviours

E-bikes users are often new to the use of bicycles (SVI, 2017) and pedelecs are particularly popular among older people. Users of pedelecs in Switzerland, the Netherlands and Germany are found to be significantly older than users of classic bicycles (BfU, 2017; Schepers et al., 2018; GDV, 2017). SWOV

(2017) considers that elderly people with a strong decline in muscle strength are more likely to opt for a pedelec than a classic bike, while at the same time their sense of balance or their reaction speed also decreases. Such factors will make the comparison of safety performance across bike types rather complex. Therefore, Schepers et al (2018) included control variables describing health such as Body Mass Index and morbidity conditions. Yet other confounding factors exist, such as travel distance and road type.

GDV (2017) measured the average distance travelled per trip on pedelecs, which appears to be longer than on classic bikes, but the difference did not reach statistical significance. Average trip distance on speed-pedelecs was however significantly higher. Schepers et al (2018) found a higher annual distance cycled among pedelec users than among classic bike users. It is possible that e-bike users cycle more often on roads outside built-up area. In Germany, the percentage of crashes occurring outside built-up areas was almost twice as high for pedelecs as for classic bicycles (GDV, 2017).

The speed difference between pedelecs and classic bikes is most noticeable on inclines, but in all other situations, the difference in cruising speed is of the order of 2 km/h. As documented in Switzerland, Germany and in the Netherlands, pedelec riders appear to use motor assistance primarily to attain similar speeds to cyclists, only with less effort (SVI, 2017; GDV, 2017; SWOV, 2017; Schepers et al., 2018).

Considering the wide range of cruising speeds observed among riders of classic bikes, one could wonder if the modest difference in speed observed between the two fleets has a significant road safety impact. Some experts suggest that the problem is elsewhere. With the assistance they provide, e-bikes enable some riders to ride faster than they otherwise could. Further, the propulsion design of some e-bikes pushes cyclists to keep a constant speed of 25 km/h independently from the traffic situation (Huertas et al., 2018). Whilst higher speed can be positive in some circumstances (e.g. providing stability uphill) this remains a cause of concern in other circumstances. In other words, e-bike riders may adopt a speed which is inappropriate for their physical condition, cognitive abilities, cycling experience, and for the state of the cycling infrastructure.

E-bike safety

Road casualty statistics in Switzerland show that the proportion of serious injury among riders of e-bikes is higher than among riders of classic cycles. However, the two populations aren't comparable since e-bike riders are older and therefore more vulnerable in the event of a crash (BfU 2017). Controlling for age, Schepers et al (2018) report that no difference between pedelec and classic bike crash severity can be found in the Netherlands, Germany and Switzerland. Some roundtable participants called for more research before conclusions can be drawn. In China, e-bike crashes are found to be more severe than classic bike crashes, which is likely due to generally much higher speeds than in Europe (Hu et al. 2014).

In the Netherlands and Switzerland, once age and travel distance are controlled for, the risk of injury isn't higher on a pedelec than on a classic bike (Schepers et al., 2018; BfU, 2017). This risk is however significantly higher on a speed-pedelec (BfU, 2017), probably again due to their higher speeds.

An international literature review conducted by BfU (2017) reveals that the proportion of single-vehicle crashes is significantly higher for e-bike riders. In Switzerland and in the Netherlands, the higher age of e-bike riders was found to be the main cause, older people being more likely to fall while getting on or off for instance (BfU, 2017; Schepers et al., 2018). A report from SVI (2017) identifies a certain lack of cycling experience among e-bike users as contributing to the frequent loss of control observed in reported crash data.

Whilst some characteristics of e-bikes can be suspected of making single-vehicle crashes more likely, such as the vehicle's weight distribution (SWOV, 2017), Swiss research suggests that only a small proportion of such crashes are due to the electrically assisted nature of the vehicle (BfU, 2017). Similarly, Schepers et al. (2018) did not find e-bike riders to be more likely to fall while (dis)mounting after age and gender were controlled for.

Evidence from research consistently indicates that e-bike riders are more at risk of having their right-of-way disregarded by motor vehicles (BfU, 2017; SVI, 2017). Since electric bicycles enable a more relaxed cycling, with lower pedal frequency and more upright position, compared to classic bikes at similar speeds, it might be that other road users underestimate their speed (GDV, 2017; Dozza et al., 2016).

The safety of third party road users and of pedestrians in particular, should not be overlooked. German crash data compiled by ECF (2017) show that e-bikes are not increasing crash risk for pedestrians. In 2016 in Germany, 11 pedestrians were seriously injured in collisions with pedelecs, whilst more than 7 000 were seriously injured in collisions with cars. Adjusting for fleet size, a car is nearly 50 times more likely to be linked with a serious pedestrian injury.

Bike share

In most parts of the world, local authorities have invested in dock-based bike share systems as a means to help more people cycle, or help people cycle on more occasions. By the end of 2012, the global bike share fleet comprised about 400 000 bicycles (ITF, 2103). By the end of 2017, the fleet was several million bikes, of which the vast majority are part of dockless bike share systems. These are located by GPS using smartphone apps and can be left almost anywhere at the end of a ride. The app-based dockless bike share solution developed first in 2015 in Asia, before expanding to the rest of the world.

In China, the development of dockless bike share systems has had both negative and positive significant consequences. On the negative side, the bikes have obstructed pavements. Being launched independently from local government intervention, the number of bicycles grew faster than the number of on-street bicycle parking spaces. On the positive side, reports from China suggest that dockless bike share has contributed to a remarkable drop in car use and congestion (ITDP, 2018).

To a large extent, bike share use is spontaneous, which may explain why bike share users are 4 times less likely to wear a helmet than users of private bikes (Fischer et al., 2012). This was observed in Boston, Washington DC, and London. In Vancouver where helmet use is mandatory and enforced, its prevalence is 15 percentage points lower among bike share users than among personal bicycle riders (Zanotto et al., 2017). A number of cities, such as Mexico City, Tel Aviv, and Dallas, repealed their helmet laws in preparation for launching bike share systems (NACTO, 2016). Malta, the only European Union member state with full helmet compulsion for adults and children, has acknowledged that obligatory helmets can be of hindrance to such initiatives. The country is working to repeal the obligation (for users of classic bikes and pedelecs) in the hope to get more people cycling (Malta Today 2018).

On one hand, bike share users are reluctant to wear helmets; on the other hand, they tend to ride at lower speeds. The safety record of bike share systems is reviewed in the next section.

Bike share safety

In North America, research suggests that the total number of bicycle injuries declined by 28% in cities introducing bike share systems, whereas bicycle injuries remained virtually unchanged in control cities

(Salomon et al., 2014). Assuming that bicycle traffic grew faster in bike share cities, this indicates an even greater reduction in the risk of injury per unit distance cycled, where bike share systems are introduced.

Where a bike share system is introduced, evidence from North-America[4] is that cycling becomes safer overall, regardless of the type of bike used. Beside the possible influence of some safety-in-numbers effects, Fishman et al (2018) suggests this is likely explained by the rapid improvements in the cycling networks by local authorities in anticipation of the increased bike traffic.

At the individual level, a bike share user appears to be less likely to be killed or seriously injured, per unit distance cycled, than all other bicycle users (Fishman et al., 2018). This was observed in Paris and London where dock-based public bike share systems are in operation. To a large extent, this may be due to the geographical distribution of bike share trips, mostly in inner city streets, which are thought to be significantly safer than suburban road networks. The comparison in Fishman et al. (2018) was based on the entire metropolitan areas, and therefore didn't control for the spatial distribution of trips. Other factors are likely to contribute to the relative safety of bike share users, especially their full time working front and back lights, and the lower speeds they can reach, due to their weight and upright riding position.

Dockless bike share hasn't been the focus of similar research efforts. As a new, rapidly changing, highly fragmented and mostly unregulated service, very little data is available. Several initiatives aim at collecting dockless bike share traffic data. The recording of dockless bike crashes is challenging but the app-based technology offers new opportunities for data and survey collection. Fishman et al (2018) recommend that a standard crash data collection protocol is consistently applied across dock-based and dockless bike share industries.

With very little data on the actual risk of using dockless bike share systems, one can however be concerned by the general quality of the fleet (Schmitt, 2018). In a survey conducted by Bicycle Transit Systems (2017) in Seattle and Washington D.C., a significant share of the bikes had defects such as damaged brakes or missing lights, causing safety hazards.

Safety and innovation

New technologies can improve the safety of people cycling. Roundtable participants underlined the importance of the introduction of two new safety features on cars that can reduce crashes involving third parties in particular, Autonomous Emergency Braking (AEB)[5] and Intelligent Speed Assistance (ISA)[6]. AEB and ISA could soon be mandatory on all new cars sold in the European Union, as part of the next round of vehicle safety requirements. Autonomous Vehicles (AVs) also have the potential to deliver a safer cycling environment, although AVs need time to be tested and gain market share. Research on their effect on cycling safety will be important.

Speed management is central to achieving a Safe System (ITF, 2016). In its most common configuration, ISA currently only offers guidance to drivers, leaving them the option to drive above the speed limit. Speed enforcement therefore remains an absolute necessity and a cornerstone of road safety policies. Infrastructure layout visual keys and physical infrastructure design are also effective in reducing the speed of motor vehicles. Whilst ISA in the form to be mandated in Europe doesn't change the basic speed management and enforcement principles, it is expected to make implementation of such measures better accepted by the public as it provides valuable assistance in sticking to limits and avoiding penalties.

Trucks and buses are over-represented in crashes involving cycle fatalities (TfL, 2018c). This is due to their mass in part, but also to their close proximity to people cycling (in the case of buses) and to blind spots and off-road design features (in the case of trucks, especially construction vehicles). Interventions to prevent these crashes include better speed enforcement, bike-awareness training for drivers, and cab design for better direct vision, side sensors and a comprehensive set of mirrors.

The detection, autonomous braking and control systems undergoing rapid development for use in Autonomous Vehicles (AVs) can reduce crash risks for cyclists. The use of such systems on conventional vehicles will bring benefits in the short term even if autonomous vehicles only become a significant part of the vehicle fleet in the much longer term. AVs could be designed to be technically safe yet fairly aggressive in relation to vulnerable road users. The regulation of courtesy towards other road users will most likely remain a challenge even with AVs. The keys to improving safety and the perception of cycling safety are likely to remain unchanged: reduction of the volume and speed of motor vehicle traffic and the design of protected infrastructure.

Recommendations

Early research suggests that e-bike riders do benefit from the physical activity associated with pedalling, despite the assistance offered by the electric motor. E-bikes offer a clean, cheap and rapid transport solution which is particularly appreciated for hilly or long journeys and by elderly people, providing a sustainable transport alternative to the car. From the public health and the sustainable mobility perspectives, e-bikes are a precious addition to the mobility landscape.

We recommend measures to raise awareness of the dangers associated with speed. Even low speeds in absolute terms may be too high for the capabilities of the rider. The licensing of retailers to ensure that they provide essential speed awareness instruction to customers could be part of this policy. The design of all e-bikes could be improved, and potentially regulated, so as to prevent the most commonly observed problems. Battery position, frame design and saddle position may be improved to increase stability and prevent crashes while mounting and dismounting. Pedal power sensors should prevent the bike from reaching speeds which are excessive in comparison with the detected fitness and capabilities of the rider: a maximum power assistance factor could be imposed.

Regulation of e-bikes should make a clear distinction between slow and fast e-bikes. Slow e-bikes should be limited to a speed of 25 or 30 km/h with a pedal assistance limited to 250 or 500 watts, so as to be treated as bicycles. Vehicles offering more powerful assistance designed to achieve higher speeds should fall under moped regulations, and be regulated to benefit from the safety features associated with powered-2-wheelers. Moped regulations should be updated to ensure that speed pedelec design is clearly different from bicycle and slow pedelec design. That is to prevent similarity in appearance, which causes confusion not only to road users, potentially under-estimating vehicle speeds, but also to the police, unable to know which vehicle regulations to enforce.

The development of e-bikes and electrically assisted cargo bikes is an opportunity to revise infrastructure design guidelines, essentially to allow for safe overtaking manoeuvres on wider bike paths and tracks. Minimum width should be brought in line with international best practice[7] observed in countries where a cycling infrastructure was designed to accommodate high volumes of bicycle traffic and high shares of cargo-bikes. Cycle routes shared with pedestrians aren’t recommended in countries where speed-pedelecs are found using cycling routes.

Development of a bike share system is seen as beneficial, not only as part of a public transport system, but also from a public health perspective. The launch of a bike share system is an opportunity to roll out road safety measures ranging from “soft infrastructure”, such as speed limits and enforcement, to more visible infrastructure such as protected lanes/tracks or area-wide traffic reduction strategies. The launch of a bike share system also normalises the use of bicycles as a mode of transport for everyone, which builds support for road safety policies.

Bike share operators should be regulated so as to ensure maintenance standards on safety critical components of their bicycles, brakes and lights in particular. Bike share operators should also be requested to collect, anonymise and share data on usage, route choice and on crashes. Whilst the majority of crashes may well never be reported to either the police or the operator, the sensors fitted on bicycles could be used to detect suspected incidents, record the location and help contact the user to survey crash circumstances and outcomes. Ensuring consistency of data collection across bike share operators is a challenge that should be addressed now.

We must acknowledge the limits of the evidence gathered so far on the relative safety of e-bikes, shared bikes and classic bikes, due to the small amount of research so far available and the lack of reliable data on both casualties and exposure. In most countries, bike type is neither recorded in the casualty data from the police, nor in the exposure data from counts or surveys. Therefore, disaggregation is recommended to separate out various types of e-bikes and bike share systems. In Switzerland and Germany, e-bikes have been a separate vehicle category in national road casualty statistics since 2011 and 2014 respectively (BfU, 2017; GDV, 2017).

Similarly to research comparing risk across countries and cities, the risk comparison across bicycle types is further complicated by various confounding factors. Factors such as experience level, fitness level, attitude to risk, use of protective personal equipment, age, sex, journey purpose, street type, time of day, day of the week, could all be suspected to influence the results. Controlling for such factors will be a true challenge for researchers in the years ahead. It is therefore recommended to support academic research in this field.

The use of a helmet is proven to reduce the severity of head injuries in the event of some crashes. However, no consensus recommendation could be reached on mandatory helmet legislation due to its possible negative side-effects, namely the reduced attractiveness of cycling and bike-share services, which may cause more harm than good from a public health perspective.

Bicycle parking, especially on-street parking, should be developed in response to the rapid growth in cycling, so as to keep pavements free of clutter and avoid putting pedestrians at risk. This issue becomes critical where dockless bike share systems are in operation.

In the context of rapid innovation, despite speculations on the safety benefits of autonomous vehicles, policy makers should focus efforts on proven road safety policies. If and when 50% of motor vehicle traffic is automated, an unprotected road will remain unattractive and unsafe to cyclists. Technologies such as Intelligent Speed Assistance (ISA) and Automated Emergency Braking (AEB) could be rolled out more quickly and should be mandated on all new cars. All heavy vehicles should be designed with direct vision to the front and sides of the driver, with a complete set of mirrors to eliminate blind spots.

The regulation of semi- and fully-automated vehicles, as well as research on their interaction with vulnerable road users, will be critical to ensure the potential road safety benefit of automation isn't undermined by the creation of new road safety problems. Lastly, as automation could induce greater traffic volumes and create a higher demand for road space, road pricing could help transport authorities allocate space to developing a safe and dense cycling network.

A safe cycling environment

When people are asked why they don't cycle, a fear of crashing is often mentioned as the main barrier. Customer research reveals that the lack of visible cycling infrastructure is the main reason for not using bike-share schemes, despite such schemes being designed to increase the number of people cycling. Solutions to create a safer cycling environment are examined in this section.

The conditions for a safe cycling environment were thoroughly discussed in *Cycling Health and Safety* (ITF, 2013) whose main recommendations are listed in Box 1. In this section, a range of solutions are discussed, with no pretention of making an exhaustive inventory of measures. Due to time constraints, the roundtable discussion didn't cover education, training, behaviour, goods vehicles and buses. Instead, much of the discussion focussed on the physical environment: the management of speed, traffic and the separation of people on bikes from fast moving motorised traffic.

Governments planning for rapid growth in cycling usually seek to improve safety rapidly over large parts of the road network, often to tight budget constraints. Light segregation, defined as the discontinuous use of physical objects to give protection to a cycle lane, is attracting much interest in certain countries – especially as a way of "jump-starting" coherent and extensive bicycle networks where there were none before. The strengths and weaknesses of a network based approach, hidden infrastructure and light segregation were thoroughly reviewed during the roundtable and findings are explored further below.

A network-based approach

The highest value of a cycling network is found in its continuity, consistency, and the careful treatment of junctions. A cycling route is only as good as its weakest link or weakest junction. Some cities indeed make junction improvement a priority, on the basis that most serious crashes take place at junctions. Junction treatment is complex, especially where cycling traffic is protected but loses some of this protection at a junction. There are two solutions to mitigate the threat a poorly planned junction poses: either stop the protection far enough from the junction to alert all road users to the increased crash risk, or preferably design the junction to provide enhanced protection right through the intersection.

The design and maintenance of the street network can play a role in preventing single-vehicle crashes. A large proportion of serious cycling injuries occur in single-vehicle crashes (Shinar et al., 2018). Under-reporting in official police statistics is even more of a problem for this type of crash than for crashes involving a third party. In the Netherlands, single-vehicle crashes account for almost three-quarters of all serious injuries among hospitalised cyclists (Schepers et al., 2015). In terms of street design, the training of planners and engineers is inadequate in most parts of the world. With regards to on-street maintenance, new tools have recently emerged for cyclists themselves to report problems, providing a new avenue for authorities to monitor and address issues.[8]

Countries and cities where a connected network has been developed saw cycling numbers grow and risk fall. In places, the absolute number of crashes also fell. The New York City Department of Transportation (2014) reports a fall in the number of injuries over 7 miles of protected bike lanes. Interestingly, pedestrians have also benefited from the new street design: pedestrian injuries fell by 22%. This sets a clear objective for others to follow, but raises the question of cost. Governments are looking for solutions to develop a large and connected network. Hidden infrastructure solutions, as well as light segregation, can be appropriate fast responses and are discussed in sections below.

Hidden infrastructure

Before discussing investment in protected infrastructure, it is useful to review options that don't necessarily require major changes to the physical environment. Most important is the choice of speed limits and their enforcement. There is clear evidence that 30 km/h speed limits in urban areas improve safety, on the condition that all road users adhere to the limit. This could be achieved with police or automated enforcement or with the use of traffic calming solutions (e.g. physical features such as humps and chicanes) or both. The introduction of 30km/h limits and zones not only improves the safety of people cycling but also that of all other road users (Leblud, 2017; Quigley, 2017; ITF, 2018b).

Reducing the volume of motorised traffic is another approach to making cycling safer. In congested traffic, there is a risk that motorists use every minor residential road as a through route. The spread of navigation apps increased this risk although many follow protocols to avoid residential streets. Some transport authorities design area-wide traffic management plans, which typically include modal filters. Modal filtering is the concept of stopping the traffic of motor vehicles, whilst offering full permeability to people walking and cycling, and to public service vehicles where applicable. Modal filtering diverts through-traffic onto the main roads, something that is sometimes accused of worsening congestion. Instead, it has the potential to reduce overall traffic volume through a rebound effect known as traffic evaporation (Cairns et al., 2002). In the Netherlands, area-wide traffic management plans have created large "traffic-calmed areas" and "bicycle streets", where motorised traffic volumes are low, and which together carry half of the pedal cycle traffic in towns where they have been deployed. The main safety element provided on bicycle streets is simply the low volume of motor vehicle traffic (GDV, 2016).

Reducing the speed and volume of motor vehicle traffic can be challenging in political terms. Some countries therefore chose to invest their efforts more in the regulation, promotion and enforcement of minimum passing distances. In Australia where this has been implemented and evaluated, drivers are indeed giving more room as they overtake people cycling. However, this didn't result in a dramatic change in the level of hazard perceived by cyclists (Heesch, 2017).

Vehicle design and vehicle technology can also contribute to a safer cycling environment. Auto Emergency Braking (AEB), discussed in the previous section, has tremendous potential. The safety of heavy vehicles was not discussed in details, but there is rapid progress in this area. London has adopted policies to impose side guards and Class VI mirrors or full direct vision on heavy vehicles (TfL, 2018; TfL, 2018b). Public sector procurement is an area where authorities can most rapidly include such requirements, not only on vehicles but also on driver qualifications and training.

Severe crashes are also caused by the opening of car doors in the path of cyclists (known as "dooring"; GDV, 2017b). In line with the safe system principles, whilst education in this area is important, further solutions must be found. One solution deployed extensively in Copenhagen is orientating on-street parking spaces at a 45 degree angle to the roadway, so that no door opens into the traffic flow. Another solution is the creation of buffer zones between parked vehicles and roadways and cycle-ways. A longer-term solution could be to require a technology which prevents the full or rapid opening of doors when an approaching road user is detected. Mandating such technology on taxis and ride-hailing vehicles could be a priority, considering their rising share in urban traffic and their frequent on-street passenger pick-up and drop-off.

Most improvements to vehicle design would however take years to reach a significant level of market penetration, and wouldn't fundamentally change the perception of danger associated with close proximity to fast and heavy traffic. Separating bikes from motor vehicles on main roads is therefore essential, and can be done relatively quickly thanks to light segregation solutions.

Light segregation

The separation of bikes from motorised traffic not only provides significant protection but visible cycling infrastructure is also what many people require in order to consider cycling a safe and viable option. Indeed, the intimidation experienced in shared traffic conditions is enough, in many countries, to deter the majority of people from cycling. Engineering solutions such as barriers, often seen in Asia[9]; stepped tracks often seen in Denmark, and kerb separated tracks offer a variety of forms of separation. Adding to this engineering toolbox, light segregation creates a discontinuous use of physical objects that gives protection to a cycle lane. It is used in a range of countries, including Mexico, the USA, Canada, Spain, Italy, UK, Japan, Australia and New Zealand (Deegan, 2018; TfL, 2013; NACTO, 2011). The city of Seville, Spain, developed more than 100 km of protected bike network in the space of only 4 years with the help of light segregation (Marqués et al., 2015). The objects used as separators can take various forms, from small plastic or concrete humps sometimes called 'armadillos', to large removable concrete blocks or boxes planted with flowers.

Light segregation has several advantages, over alternative infrastructure solutions:

- It brings the cost of developing a network down to EUR100-250k per kilometre, which is several times lower than other forms of segregation where, notably, drainage reconfiguration is required (Deegan 2018, Marqués et al., 2015).
- It is adaptable in the sense that its modular components can be moved or removed, if, when and where a cycle lane is upgraded, widened, suspended or diverted.
- It offers a better level of perceived safety than painted lanes, but still gives its users the freedom to move in and out of the lane, to overtake and to avoid obstructions.

Some hesitancy exists but no evidence was found to document possible negative impacts of light segregation on pedestrians (tripping over separators) and riders of powered-2-wheelers (hitting separators), possibly because this risk is usually taken into account and addressed from the design stage. Further research should go into the impact of treatment types vis-a-vis these two road users.

The choice of light segregation should consider:

- Regular sweeping and winter maintenance, since the physical components could be damaged by maintenance vehicles.
- Enforcement against parking and loading offences, as few forms of segregation are absolutely immune from this sort of issue.
- Maintenance costs, by choosing components which can resist the repeated impact of motor vehicles.
- The risk of powered-two-wheelers mounting low profile separators and losing balance (best practice is to include some vertical elements to ensure maximum visibility of separators).
- The risk of pedestrians tripping (best practice is to avoid low-profile modules in areas with the highest pedestrian traffic).
- The spacing of physical components so cycles can easily come in and out of the track.
- The aesthetic sensitivity of the location.

Recommendations

We recommend ambitious plans to create a safe and attractive cycling environment. Space should be reallocated to this effect in urban design, potentially locking-in reduction of private motor traffic observed in places where sustainable travel is prioritised. High quality networks should be created, without gaps or inconsistencies, where links are connected and junction design focuses strongly on safety aspects.

Local governments should identify and address any gap in cycling design expertise, with training and reference to international best practice. Local governments should take ownership of the maintenance of cycling networks, considering the vulnerability of people using it. Tools should be available to report, map, monitor and address network issues.

In urban areas, speed limits by street type should be implemented. Speed limits at 30 km/h should be deployed more widely and be the default option. Speed limits should come with appropriate enforcement, monitoring and traffic calming features. Also recommended is the design of area-wide traffic management plans to reduce the volume of motorised traffic and create truly quiet cycle routes.

The risk of “dooring” should be given attention as a matter of priority and technical solutions implemented in line with the Safe System approach, where human mistakes are acknowledged and solutions are sought beyond the realm of education. In the short term, local design guidelines should be revised to include a suitable safety buffer zone between parked vehicles and roadways and cycle ways.

Where motorised traffic speed or volume cannot be reduced, protected routes should be designed. Light segregation being cheaper than other forms of physical separation, it can be used to create a large connected network within the timeframe of a municipal government mandate. Being quick to install, fine tune, remove or upgrade, it could be presented as a trial, which helps make the re-allocation of road space less conflictual.

Cycling routes should be planned within a wider policy framework to make public space safer, healthier and more liveable.

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Notes

[1] The World Health Organisation created a tool called HEAT which enables non-experts to quickly estimate the order of magnitude of the health benefits of a walking or cycling interventions

[2] Time spent cycling is arguably the most relevant denominator for the comparison of risk across different modes of transport and different activities more generally.

[3] In the Netherlands, bicycle infrastructure is also used by slow mopeds, whose recorded average free flow speed is 33km/h, despite their limitation to 25km/h in law. Discussions are taking place to forbid the use of bicycle infrastructure by such slow mopeds

[4] From media sources, by end 2017, it is known that two bike share riders have been killed in the United States, ever. One was in Chicago, and the other was in New York. Both involved large vehicles, in crashes that may have been addressed by the new European standards.

[5] Autonomous Emergency Braking (AEB), also called Advanced Emergency Braking, is a system which should be able to detect cyclists on front and side of a vehicle, even in case of a truck turning. Some AEB implementations may not be designed to detect pedestrians and cyclists and could therefore be regarded as sub-standard.

[6] Intelligent Speed Assistance includes different systems from voluntary open (which warns the driver) to mandatory closed (which limits the speed automatically).

[7] Many cycling infrastructure design standards exist over the world: CROW manual, NACTO Global Street Design Guide, London Cycling Design Standards, etc. Neither the inventory nor the evaluation of such standards was undertaken during the roundtable discussion.

[8] The “FixMyStreet” platform allows individuals to report maintenance issues, attach photos and GPS coordinates, track the resolution of issues and view reports made by other contributors. In the UK, this platform handles almost 1000 reports each day.

[9] Research conducted by Transport for London (TfL 2017b) suggests the use of pedestrian guardrails can lead to more crashes due to “tunnel vision” among drivers. There is therefore a risk this phenomenon occurs where barriers of a certain height are used to protect cycle tracks.

Cycling Safety

This report summarises the findings of an ITF Roundtable on Cycling Safety held in April 2018 with 33 researchers and practitioners from 16 countries. Cycling has a net positive effect on public health, despite the risk of injury it is often associated with. Policymakers are nonetheless concerned that increasing numbers of cyclists carries a risk of more traffic injuries and fatalities. Uncertainties also exist regarding the safety record of e-bikes and bike share systems.

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