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Mode choice and safety: How might a shift from car trips to walking, cycling, and public transport affect road safety?

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TITLE

Mode choice and safety: How might a shift from car trips to walking, cycling, and public transport affect road safety?

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ABSTRACT

Increasing walking, cycling, and use of public transport is identified in South Australia's strategic plans (*Carbon Neutral Action Plan 2016-2020* and *Operation Moving Traffic*) to reduce the state's carbon footprint and improve the operation of the transport system. The aim of this report is to investigate the road safety implications of a shift in travel modes from motor vehicles to active, yet vulnerable modes. To address this topic, a literature review was undertaken to address two key questions: What is the safest mode of travel? What happens when there are changes in travel mode? Studies of road user risk using a variety of exposure variables (e.g., number of trips, per kilometre travelled, or per time spent travelling) reveal a general hierarchy of greatest to lowest risk of motor cycle/scooter/moped > bicycle > pedestrian > passenger vehicle > bus. Factors contributing to risk among pedestrians, cyclists, and public transport passengers are examined. Further evidence regarding the reduction of passenger vehicles, the Safety in Numbers effect for pedestrians and cyclists, and the effects of mode shift is also reviewed. While an increase in injuries among vulnerable users can be expected, mode shift that favours the safer active travel modes (e.g., walking and public transport use) will likely result in a reduction in total casualties, largely driven by a reduction in car related casualties. Improving safety for vulnerable road users will be important: a traffic system made safe for vulnerable road users will be safe for all road users.

KEYWORDS

Mode choice, road safety, safety in numbers, pedestrian, cyclist, public transport, injury

Summary

Increasing walking, cycling, and public transport use is identified in South Australia's strategic plans (*Carbon Neutral Action Plan 2016-2020* and *Operation Moving Traffic*) to reduce the state's carbon footprint and improve the operation of the transport system. The South Australian road safety strategy – *Towards Zero Together* – has set the goal of a 30% reduction in fatalities and serious injuries by 2020. The aim of this report is to investigate the road safety implications of a shift in travel modes from motor vehicles to active, yet vulnerable modes. The report focuses, as much as possible, on active transport as a substitute for car trips (i.e., excluding recreational activity). To address this topic, two key questions were addressed: What is the safest mode of travel? What happens when there are changes in travel mode?

What is the safest mode of travel?

Several studies have sought to calculate the risk for different modes of transport using either the number of trips, distance travelled, or time spent travelling as exposure variables (i.e., the number of casualties per 100 million trips, per billion kilometres, or per million hours travelled). While there is some variation in the risk rates across studies there is a general trend suggesting a hierarchy such that the order of risk from greatest to least is motorcycle/moped/scooter > bicycle > walking > passenger vehicle > bus.

There is some disagreement as to the best method to calculate risk for cyclists in comparison to cars, as the characteristics of trips by each mode are different and thus lead to differential levels of exposure to risk, such that comparing one mode with the other does not accurately reflect the real-world.

While car occupants appear to have a lower risk compared to other road users, a significant proportion of road casualties can be attributed to the presence of cars. Evidence from South Australian crash casualty data indicates that passenger vehicles are involved in 77% of all casualty crashes.

In terms of risk to each mode, cars are generally the largest threat (in terms of frequency) to pedestrians and cyclists. There is also evidence that pedestrians and cyclists are also a threat to each other, while cyclists and car occupants are also injured in single-vehicle incidents. The risk to car occupants in collisions with vulnerable road users is substantially lower than that posed by cars to vulnerable road users. Passengers on public transport are rarely injured in crashes but may be injured in emergency braking situations or when boarding or alighting. Travelling unrestrained, standing, or sitting sideways increases the risk of injury for passengers of public transport.

Differences in risk have also been observed by age and sex such that young males are potentially safer as pedestrians and cyclists than as drivers. Older people have a greater risk when walking, riding, or using public transport but have less risk when driving.

What happens when there are fewer cars?

In 2003 the city of London in the UK introduced a congestion charge (the London Congestion Charge or LCC) as a measure to reduce traffic delays associated with congestion. Following the introduction of the LCC, car trips reduced while trips by bicycle, motorcycle, taxi, and public transport increased, and congestion reduced by 30%. A general reduction in crashes was reported by studies examining the effect of the LCC, but findings regarding the effect on cycling casualties are less clear, with studies reporting a reduction, no change, or an increase. Reduction in traffic congestion has also been associated with increases and greater variation in travel speeds, which, while good for travel time, can increase the likelihood of crashes and the severity of injuries in those crashes, particularly for

vulnerable road users. The reduction of crashes observed in the LCC studies are likely due to reduced vehicle volumes.

What happens when there is an increase in active modes?

A number of studies have observed a non-linear relationship between the number of pedestrians and cyclists and the number of pedestrian and cyclist injuries, such that the number of injuries to these groups does not increase at the same rate as increases in participation. That is, doubling the number of pedestrians or cyclists does not double the number of injuries for these groups. This relationship has been dubbed Safety in Numbers. The Safety in Numbers effect has been observed in several countries, including Australia, the USA, New Zealand, and several European countries including the UK and the Netherlands. Despite this, the mechanisms for the effect are poorly understood and the causal direction of the relationship is not known – is safety improved because of the numbers, or does safety produce the numbers? Several explanations for the Safety in Numbers effect have been put forward, including: increased driver awareness, improved political support for walking and cycling, and safer street design.

There is evidence that one of the factors shaping the Safety in Numbers effect is the volume of motor vehicles and pedestrians or cyclists, such that Safety in Numbers is observed when volumes of pedestrians or cyclists increase with a concurrent decrease in the volume of motor vehicles. Research investigating the substitution of car trips for walking or cycling indicate that for mode shift to benefit road safety a substantial number of car trips – at least 50% – must be replaced with active trips that favour the safer modes (i.e., walking and public transport use). Improving the safety of vulnerable road users will ensure a mode shift to any mode will benefit road safety.

Mode shift at the population level will occur incrementally and the safety of vulnerable road users will play a key role in this shift: improving safety will be necessary to both protect vulnerable road users and to encourage people to shift modes. While a substantial mode shift may be necessary to observe a positive affect on road safety, there is some evidence that the benefits of mode shift (e.g., reduced congestion and carbon emissions, and improvements in health) may be observed at lower levels with little impact on road safety provided the safety of vulnerable users is carefully managed.

Conclusion

Determining the effect of increasing active travel modes in place of car trips is a complex problem with many facets to consider. Drawing on the available evidence it would appear that achieving a substantial level of mode shift that favours the active modes with the lowest risk (e.g., walking and public transport) has the potential for a net positive effect on road safety. While casualties among vulnerable modes will increase, a reduction in total road casualties – driven by a reduction in car-related casualties – can be expected. While a mode shift may benefit road safety, vulnerable road users will continue to face risks from cars and other motorised traffic. As such, it is imperative that strategies for encouraging mode shift work in tandem with measures to improve safety for vulnerable road users. Providing safer walking and cycling environments with infrastructure, reduced speed limits, reduced motor vehicle volumes, and other legislative and policy measures will improve safety. A transport system that is made safe for the most vulnerable users will be safe for all road users.

Note that this report was substantially completed in March 2017 and does not consider developments after that date.

Contents

1 Introduction

Active transport modes including walking, cycling, and public transport, have a number of advantages in terms of reducing congestion, assist in achieving environmental goals, and improve health (through a reduction in diseases related to inactivity). Doubling cycling and increasing public transport use by 10% by 2020 have been identified as key targets to help the state achieve goals relating to Carbon Neutral Adelaide (*Carbon Neutral Action Plan 2016-2020*) and improving the operation of the transport system (*Operation Moving Traffic*). These modes have also been recognised as important aspects of developing vibrant and connected communities. Concomitant with these strategies and initiatives is the South Australian Road Safety Strategy, *Towards Zero Together*, which sets the goal of a 30% reduction in fatalities and serious injuries by 2020. The aim of this report is to examine the road safety implications of a shift in mode choice from motor vehicles to modes that are more active but have an increased vulnerability compared to motor vehicles.

The primary focus of this review is on transport undertaken as a replacement for trips that would otherwise be made in a car (e.g., walking, cycling, or using public transport to commute to and from work). This definition excludes recreational walking and cycling as these are not replacing trips by car. One problem inherent in the existing literature in this area is that trip purpose is not generally identified in analyses of either crashes or measures of exposure, and so any evidence described below may include an aspect of recreational activity and the potential impact on the findings discussed cannot be determined.

A further aspect that needs to be considered is the quantity of evidence available. There is a substantial body of literature addressing the safety of some modes, particularly motor vehicles, walking, and cycling, while public transport modes have received little attention. It is widely recognised that public transport is the safest travel mode (see Section 2), which likely explains the limited attention this has received in the literature.

In order to address the topic three key issues need to be considered. The first is necessary to understand the safety of different travel modes. The second is to consider what happens to road safety when there is a reduction in motor vehicle use. The third issue is to consider what happens when there is an increase in active transport modes. The following sections consider each of these issues.

Note that this report was substantially completed in March 2017 and does not consider developments after that date.

2 What is the safest mode of travel?

Several studies have compared the risk of death or injury for various modes of travel. Although employing different measures of exposure, this research has generally observed that public transport has the lowest risk to users, followed by private car occupants – the risk for drivers is slightly higher than that for passengers as drivers are more often involved in crashes (e.g., single occupant crash) – then walking, cycling, and motorcycling (Albertsson & Falkmer, 2005; Beck, et al., 2007; Elvik et al., 2009; Koorey & Wong, 2013). Calculations of risk are based on the number of injuries (including fatalities) or crashes by a chosen exposure variable, such as the number of road users, number of trips (typically per 10^8 trips), distance travelled (typically per 10^8km), or time spent travelling (typically per million hours). While these variables are reasonably well recorded for motor vehicles, data regarding crashes/injury and exposure for pedestrians and, particularly, cyclists are more limited. For example, in most jurisdictions information regarding the number of cyclists and their trip characteristics are poorly recorded (if at all), while crashes involving cyclists are under-reported in official crash statistics (Boufous et al., 2013; Sikic et al., 2009), and a substantial number of cyclist injuries occur off of public road networks (e.g., De Rome et al., 2011). Similarly, injuries to pedestrians that are not the result of being struck by a motor vehicle (e.g., tripping on the footpath or while crossing the road) are also not reported in official crash statistics used to calculate risk. Finally, determinations of risk for public transport use consider only those injuries that occur while an occupant of the vehicle and do not consider injuries sustained during trips to access public transport or final destination (for example, walking from home to the train station and then train station to work). Instead, these injuries are most likely recorded against that mode (e.g., pedestrian).

Elvik Høye, Vaa, and Sørensen (2009) calculated the relative injury rates for different transport modes based on injury rates reported for Sweden, Denmark, UK, Netherlands, and Norway. A direct comparison of injury rates was not possible due to differences in crash reporting rates between countries so Elvik et al. estimated a simple mean for the five countries and set the relative injury rate for drivers to one. This enabled the risk of all modes to be easily compared to that of car occupants. The injury rates for each mode of transport are provided in Table 2.1. This shows that bus passengers have half the risk of car occupants, while the risk of injury for pedestrians and cyclists are respectively about seven and nine times that of car occupants.

Table 2.1
Relative risk of injury for different modes of transport

Transport mode	Relative risk of injury
Bus passenger	0.5
Car driver	1
Car passenger	1
Pedestrian	6.7
Cyclist	9.4
Motor cyclist	12
Moped rider	65.4

Note. Adapted from Figure 3.10, Elvik et al. (2009, p. 56).

Other studies have also identified fatal or injury risk by transport mode for the USA (Beck et al., 2007), France (Bouaoun et al., 2015), and New Zealand (Koorey & Wong, 2013). These are shown in Tables 2.2 to 2.4. While there is some variation in the rate of injury, the general trend holds such that the hierarchy of risk for different modes from greatest to least is: Motor cycle/moped/scooter > Bicycle > Walking > Passenger vehicle > Bus.

Table 2.2
Rates of fatal and non-fatal injury per 10^8 trips for different modes of transport (USA)

	Rate of injury	
Transport mode	Fatal	Non-fatal
Bus passenger	0.4	160.8
Passenger vehicle[a]	9.2	803
Other vehicle	28.4	1,020.6
Pedestrian	13.7	215.5
Cyclist	21	1,461.2
Motor cyclist	536.6	10,336.6

Note. Adapted from Beck, Dellinger, and O'Neil (2007).
[a]Includes driver and passengers.

Table 2.3
Rates of fatal injury to French residents per number of trips and kilometres and hours travelled (France)

	Rate of injury		
Transport mode	100 mill trips	billion km travelled	million hours travelling
Car occupant[a]	5.1	3.6	0.15
Pedestrian	3.6	41.6	0.15
Cyclist	7.5	22.9	0.23
Motor cyclist	100	114.8	3.59

Note. Adapted from Bouaoun et al. (2015).
[a]Includes driver and passengers

Table 2.4
Rate of injury based on kilometres and hours travelled (New Zealand)

	Rate of injury	
Transport mode	100 mill km travelled	million hours travelled
Bus passenger	3	-
Car driver	27	10
Car passenger	18	7
Pedestrian	120	5
Cyclist	245	29
Motor cyclist	540	205

Note. Adapted from Koorey and Wong (2013)

While the hierarchy of risk is generally consistent across these studies there is also evidence that the measure of exposure influence these rates. For example, estimations based on the number of trips or distance generally show that the rate of injury (fatal and non-fatal) for cyclists and pedestrians is substantially higher than that for car occupants. However, comparisons based on travel time suggest the rate of injury is much closer to that of car occupants for cyclists while the rate for pedestrians is equal or lower than that for car occupants. It has been suggested that distance- and trip-based measures are distorted because these include motor vehicle trips made on highways, which are relatively safer than trips made in urban environments (Wegman et al., 2012). The result of this is a comparison of cycling or walking undertaken in environments where crashes are more likely to driving in environments where crashes are less likely. Such comparisons understate the risk to vehicle occupants and overstate that to pedestrians and cyclists. Comparisons based on time can reduce this distortion (Mindell et al., 2012). Dutch research comparing cycling trips with car trips (excluding car trips on motorways) suggests that the risk is similar for car drivers (20.8 per million km) and cyclists (21 per million km) (Dekoster & Schollaert, 1999 cited in Wegman et al., 2012).

Other research undertaken in North Carolina in the US examined the injury and fatality rates related to travel to school (McDonald et al., 2014). While other studies have generally focussed on adult road users, this study focussed on children aged 5-18 years and considered travel by car, motorcycle, bicycle, walking, and school bus; pedestrians killed or injured by a school bus were classified as a bus injury on the assumption that they had been a passenger on the bus. Analysis of police-reported crash data showed that 90% of injuries and fatalities were the occupants of passenger vehicles. Six per cent of injuries and two per cent of fatalities involved a school bus, while walking and cycling accounted for less than two per cent of annual injuries and six per cent of annual fatalities. Buses were considered to provide the safest mode of travel to school. Teen drivers were found to have substantially higher injury and fatality rates per trip than all other ages and modes, while non-motorised modes were found to have the highest proportion of serious injuries (McDonald et al., 2014).

While the issue of risk is complex, the general indication is that travel by car is one of the safest modes. As such, these findings suggest that increasing active travel modes may place more road users at risk of injury. The number of road users put at risk may be greater than anticipated because the shift to active travel is not necessarily a straight 1:1 swap: replacing one car trip may result in multiple active trips as all vehicle occupants must also use an alternate mode. To understand the impact of an increase in active travel on road safety it is necessary to consider the risks faced by active modes, the risk they pose to other vulnerable road users, and how changes in the volume of different road users influence these risks.

3 Risks to other road users

In an effort to better understand how increasing active transport might impact safety, it is necessary to determine what the risks are for each mode and also the risks that a particular mode poses to other road users. Table 3.1 offers a starting point for this section. It shows the number of hospital separations for land transport injuries in Australia for the period 2009-2010, showing for each mode the counterpart involved in the incident leading to injury. These figures exclude fatalities. Focussing on those modes most relevant to this review, it is clear that (excluding non-collisions) cars and similar vehicles are most often involved in injuries to other car occupants, pedestrians, cyclists, and bus occupants. For pedestrians, heavy vehicles or buses are the second greatest threat, followed by cyclists and other pedestrians (or animals). For cyclists, other cyclists are the second greatest threat followed by pedestrians and heavy vehicles or buses. Bus occupants are most at risk from cars and heavy vehicles or buses. Table 3.1 also demonstrates a significant number of injuries from non-collision incidents, particularly for cyclists; non-collision incidents are also the most common cause of injury for bus occupants.

Table 3.1
Mechanisms of injury for land transport injury cases (excludes cases identified as “other land transport accidents”)

Injured person’s travel mode	Counterpart in collision									
	A	B	C	D	E	F	G	H	I	J
Car	143	n.p.	29	7470	589	11	29	4406	3691	1077
Motorcycle	212	13	388	1749	64	n.p.	15	1562	7772	2323
Bicycle	72	498	12	1267	68	n.p.	15	502	5664	1523
Pedestrian	100	112	104	3183	201	37	43	n.p.	n.p.	245
Animal rider or animal drawn vehicle	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	8	13	2762	369
Heavy transport vehicle	n.p.	n.p.	n.p.	45	82	n.p.	n.p.	66	437	47
Pick-up truck or van	n.p.	n.p.	n.p.	78	22	n.p.	n.p.	70	197	34
Bus	n.p.	n.p.	n.p.	45	34	n.p.	n.p.	25	359	62
Three-wheeled motor vehicle	n.p.	n.p.	n.p.	8	n.p.	n.p.	n.p.	6	35	n.p.
Total	537	627	540	13845	1060	57	112	6650	20921	5680

Note. Adapted from Tovell, McKenna, Bradley, and Pointer (2012).
n.p. = not published. Small cell counts were suppressed to prevent patient identification.
A = Pedestrian or animal; B = Pedal cyclist; C = Two- or three-wheeled motor vehicle; D = Car, pick-up truck or van; E = Heavy transport vehicle or bus; F = Railway train or railway vehicle; G = Other non-motor vehicle; H = Fixed or stationary object; I = Non-collision transport accident; J = Other and unspecified transport.

In section 2 car occupants were identified as having one of the lowest risks of injury of all road users. However, while travelling by car may have a lower risk for the occupants, a significant proportion of road casualties can be attributed to the presence of cars. Examination of the vehicles involved in all casualty crashes in South Australian for 2015 reveals that slightly over three quarters of all casualty crashes involved at least one passenger vehicle (DPTI, 2016). To provide further context, Figure 3.1 shows the proportion of vehicles involved in casualty crashes. Note that pedestrians have been excluded; “other” includes Light Truck (> 4.5 Tonnes), animal drawn vehicles, ridden animals, railway vehicles, and trams.

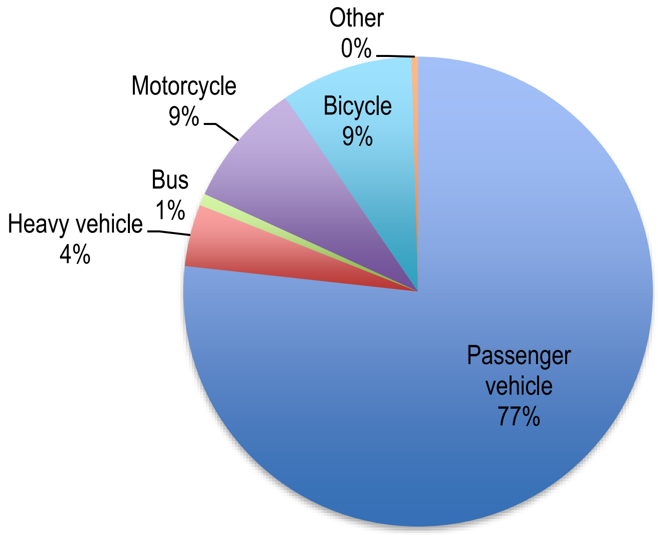

Figure 3.1
Proportion of vehicles involved in South Australian casualty crashes, 2015

3.1 Risks when travelling on public transport

As is evident from Table 3.1, crash-related injuries for public transport are relatively rare compared to the other modes of travel. In a review identifying the patterns of injury and crashes for buses, Albertsson and Falkmer (2005) found that a substantial proportion of injuries arose from non-crash incidents associated with boarding and alighting the vehicle, and emergency braking. In a crash, bus passengers were found to have an increased risk of injury when unrestrained, standing, or sitting sideways. This review also found females were more likely to take the bus and, therefore, exhibit a higher frequency (compared to males) of being injured as a bus passenger. Passengers over the age of 60 were also found to account for a significant proportion of injuries. Albertsson and Falkmer (2005) also identified that most crashes occurred on low-speed urban roads with other four-wheeled motor vehicles as the most common counterpart in a bus crash. Fatal bus crashes were found to be more common on high-speed roads.

Trams are another public transport mode that share public roads and thus have the potential for interactions with other road users. As with bus safety, very little literature addressing tram passenger safety or the impact of trams on other road users was identified. A Swedish study from the mid 1990s (Hedelin et al., 1996) investigated the mechanisms of injury for pedestrians killed or injured by trams in the city of Gothenburg. The majority of incidents were found to occur at or near tram stops and included falling under a tram, being hit by a tram, getting stuck between two trams, and suicide. Pedestrians are also at risk of injury from trams and buses while crossing the road or waiting at bus or tram stops (Hedelin et al., 2002). While it was not identified in this research (injuries to passengers on a tram were not investigated) it is possible that some injuries associated with falling under a tram occurred when boarding or alighting.

Annual reporting of tram incidents occurring in Victoria, Australia show that in 2015 there were no tram-related fatalities (suicides were excluded from analysis), while there were 47 serious injuries with an estimated rate of around 2 per million kilometres travelled (TSV, 2016). Of the 47 injuries, the majority (64%) were to other road users and the remainder to tram passengers. While the report does not engage in a detailed investigation of injury cause by type of incident it does report on the occurrence of incidents, all of which have the potential to result in injury. These include: collisions between trams and other trams, pedestrians, infrastructure, track obstruction or road vehicle, derailment, and fire. In 2015 there were 203 slips, trips, or falls on a tram (injury severity not reported) which amounts to around eight per million kilometres travelled. Other incidents include slips, trips, and falls on a platform, which appear to be related to boarding or alighting (TSV, 2016). Entrapment in tram doors, although rare, does occur and has the potential to result in injury.

A study from the US also found that increased mass transit use (i.e., use of public transport) was associated with fewer fatalities due to motor vehicle crashes (Stimpson et al., 2014). Together this body of research indicates that increasing the use of public transport in place of private car trips can be expected to have benefits for road safety.

3.2 Risks to vulnerable road users

Compared to public transport, the safety of pedestrians and cyclists has received a great deal of interest and research. With regard to these modes road safety has traditionally focussed on only those injuries that occur on the road network *and* are the result of a collision with another road user, particularly a motor vehicle. However, as is apparent in Table 3.1, pedestrians and cyclists are also injured in collisions that involve non-motorised road users and the majority of cyclist injuries are the result of non-collision transport incidents (e.g., a single-bicycle crash). Factors that contribute to the risk of injury to pedestrians and cyclists are outlined below.

Whereas vehicle occupants are afforded a degree of safety from the vehicles in which they travel, vulnerable users lack this external shielding and are thus exposed to a greater risk of injury when involved in collisions with other road users. All motorised traffic poses a threat to the safety of vulnerable users as vehicle designs are not very forgiving. A number of recent advances have seen improvements to vehicle design in order to reduce the risk of injury to pedestrians and cyclists. These include increased clearance between the bonnet and hard structures beneath (i.e., engine) (Hutchinson et al., 2011), external airbags (Fredriksson & Rosén, 2012; Fredriksson et al., 2011), and bonnets that “eject” and soften the impact when pedestrians are struck (Lawrence et al., 2006). Other technologies such as autonomous emergency braking may also benefit vulnerable road users (Anderson et al., 2011; Edwards et al., 2014; Searson et al., 2014).

3.2.1 Pedestrians

Evidence from transport injuries in Australia show that the greatest risk to pedestrians is posed by cars (see Table 3.1) and they are at greatest risk when crossing the road. Categories of pedestrians that may have higher risk than others include the elderly, children, and those with a disability (e.g., vision impaired). Children can behave unpredictably and can be difficult to see in the presence of parked cars and other visual obstructions, and may also lack the cognitive development and experience to interact safely with motorised traffic (Oxley et al., 2012a). Due to declines in physical, cognitive, and perceptual abilities, older pedestrians walk more slowly, have difficulty climbing up or down the kerb, and can also experience difficulties selecting appropriate or safe gaps in traffic when crossing (Dommes et al., 2013; Tournier et al., 2016). Depending on the nature of their impairment, disabled pedestrians may face a number of challenges in the traffic environment, including footpath obstructions, uneven surfaces, inadequate infrastructure (e.g., lack of kerb ramps for wheel chairs), and difficulties crossing. Quiet vehicles such as electric cars and bicycles also pose a challenge for vision impaired pedestrians as they are difficult to detect and can have a negative impact on the ability to select safe gaps in which to cross (e.g., Oxley et al., 2012b).

Recently, with the introduction of new laws allowing cyclists of all ages to ride on the footpath, there has been some public concern about the potential risk to pedestrians. Table 3.1 indicates that pedestrians are injured in collisions with cyclists (and vice versa), although the number of pedestrian injuries sustained in crashes with cyclists were similar to the number sustained in collisions with other pedestrians. Motor vehicles were the largest threat to pedestrian safety. However, at the time when that series of data was collected (2009-2010) cycling on footpaths for adults and children was illegal in most states. The recent changes introduced in South Australia and other states have the potential to increase the number of interactions and conflicts between pedestrians and cyclists. Research has found that collisions between pedestrians and cyclists can result in serious injuries to both pedestrians and cyclists but not necessarily in the same collision (i.e., a cyclist may not be injured in the same collision in which a pedestrian is injured and vice versa) (Chong et al., 2010).

Other road users aside, pedestrians also face the risk of injury from other sources such as falls due to slippery or uneven surfaces.

3.2.2 Cyclists

Table 3.1 demonstrates that non-collision transport accidents are the most frequent mechanism for cyclist injuries requiring hospital admission, while collisions with other motorised road users and pedestrians are also identified. While single bike crashes are generally found to be one of the most common crash types for cyclists, road safety is traditionally concerned with collisions with other road users and which occur on the road network.

Passenger cars are the most common counterpart in multi-vehicle collisions, including cars, SUVs, vans, utes, and taxis (Biegler et al., 2012; Knowles et al., 2009). Collisions with larger vehicles, including trucks (light and heavy) and buses are less frequent but these vehicles, particularly trucks, are over-represented in fatal cyclist crashes (Knowles et al., 2009; Raftery & Grigo, unpublished bicycle crash statistics). European research has found trams to be a larger threat to cyclists than buses, although the incidence of injuries for both are low (Hedelin et al., 2002). Other research also indicates cyclists are injured in crashes with pedestrians, which can also result in serious injury (Chong et al., 2010). Children carried as passengers on bicycles are also at risk of injury (Raftery et al., 2016).

The majority of cycling-related injuries are sustained in single bike only crashes (e.g., Biegler et al., 2012; Schepers, 2012; Weijermars et al., 2016; also, see Table 3.1), so increases in cycling can also be expected to increase bike only crashes. As single bike crashes are generally under-reported in official crash databases derived from police records, data regarding single bike crashes tend to come from either hospital admissions records or cyclist surveys. A limitation of these data sources, particularly the former, is the potential that many single bike crashes occur off-road during risky recreational riding (e.g., downhill mountain biking), which may both inflate the number and severity of such cases. It should also be noted that off-road recreational injuries are outside the scope of this report. Studies investigating the causes of single bike crashes in road or traffic environments have identified a number of factors including: cyclist inexperience, loss of control due to surface conditions (pot holes, debris, wet/slippery surface, tram tracks), collisions with infrastructure (e.g., kerbs, bollards), the low visibility of infrastructure (e.g., edge of road/path), mechanical failure of the bicycle (e.g., brake failure), and manoeuvres to evade other road users (Biegler et al., 2012; Boufous et al., 2014; Schepers & den Brinker, 2011). While single bike crashes may result in serious injuries, collisions between cyclists and motor vehicles can have more severe outcomes (Chong et al., 2010; De Geus et al., 2012; Knowles et al., 2009).

3.3 Age and risk

Studies that examine the association between risk and age have generally found that young people (excluding children), and particularly young males, are potentially safer walking or riding than driving (they are physically more robust while as drivers are over-represented in crashes), thus swapping modes for this group could yield a net benefit to road safety. Conversely, older drivers are generally less of a risk when driving but have been found to have increased risk when walking, riding, or using pubic transport (Bouaoun et al., 2015; Schepers & Heinen, 2013; Stipdonk & Reurings, 2012).

4 What happens when there are changes in travel mode?

This section seeks to answer questions about the effects of changes in the travel mode share. It begins with an examination of a reduction in car use, followed by an examination of increases in walking and cycling. The section concludes with an examination of mode shift where car trips are replaced by walking or cycling.

4.1 What happens when there are fewer cars?

A comprehensive search for relevant literature regarding the potential effect of fewer cars/motor vehicles identified two main papers of interest, both of which investigated the effect of congestion charging on traffic casualties.

In 2003 a congestion charge was introduced in Central London (the London Congestion Charge, LCC) in order to improve trip quality by reducing delays associated with congestion (Green et al., 2016; Li et al., 2012). Following the introduction of the LCC distance travelled by cars in the charge zone reduced by 34%, yielding a 30% reduction in congestion (Green et al., 2016; Li et al., 2012). An increase in bicycle, motorcycle, taxi, and public transport use was also observed (Green et al., 2016; Noland, 2008). Two studies employed a difference-in-difference methodology where differences in traffic casualties observed in the congestion charge area (the treatment condition) were compared to differences in traffic casualties observed in control groups (Green et al.; Li et al.), while the third (Noland et al., 2008) used an intervention analysis to account for seasonality and trends in the time-series trend for traffic casualties. A summary of the key characteristics of each study and relevant findings are provided in Table 4.1.

Table 4.1
Comparison of findings of studies examining LCC

	Green et al. (2016)	Li et al. (2012)	Noland et al. (2008)
Study period	2000-2009 (3 years pre-LCC, 7 years post-LCC)	2002 (pre-LCC) - 2003 (post-LCC)	1991-2004 (12 years pre-LCC, 2 years post-LCC)
Method	Difference-in-difference using 20 largest cities in Britain as control sites	Difference-in-difference using the following control sites: Leeds (car casualties), Manchester (cycling casualties), Birmingham (motorcycle casualties)	Intervention analysis of time-series trends in traffic casualties.
Findings	1. The congestion charge was associated with 30 fewer crashes per month; a 38-40% reduction 2. Bicycle casualties increased to 2005 but declined to 2010	1. 5.2% reduction in car casualties 2. 5.7% increase in motorcycle casualties 3. 13.3% increase in cyclist casualties[a]	1. No statistically significant effect on KSI[b] or slight injuries in the LCC zone. 2. A reduction in car occupant casualties. 3. No effect on cyclist or motor cyclist casualties.

Note. [a]Transport for London report a reduction in cycle (both motor cycle and bicycle) crashes from 1,353 in 2002 to 1,254 in 2003 (Li et al., 2012). [b]Killed or seriously injured.

A point of interest from Table 4.1 is that the statistical analysis undertaken by Li et al. (2012) found an increase in bicycle casualties of 13.3% whereas official statistics show a reduction of around 7%. By way of explanation the authors state that based on the observed trend in casualties for the control group the predicted number of casualties in the LCC area was fewer than the 1,254 observed, suggesting that the implementation of the LCC contributed to a higher number of casualties than would otherwise have been expected (H. Li, Personal communication, 18th August, 2015). A problem with this analysis that may explain this is that comparisons were based on the trend in casualties, which can be influenced by trends in cycling participation such that the frequency of casualties does not rise in proportion to the number of cyclists (Elvik & Bjørnskau, 2017; Jacobsen, 2003 – see discussion of Safety in Numbers in section 4.2). Noland et al (2008) also found an increase in cyclist casualties although the effect of the congestion charge was not statistically significant. While an increase in cycling can be expected to be associated with an increase in cycling casualties (Jacobson, 2003), Transport for London casualty statistics for the period show a decline in casualties despite increased participation (Li et al., 2012). Similarly, differences in cycling safety may be observed between sites with some providing safer environments for cycling than others. Green et al. also considered a much longer follow-up period and also observed an increase in cycling casualties in the three years following the introduction of the LCC, which was followed by a decline in the four years after that. They hypothesised that the increase in casualties following the introduction of the LCC may have been due to an influx of inexperienced cyclists, with casualties declining as experience is gained. It should also be noted that some of the revenue raised by the LCC was spent on safety initiatives for cycling and walking, and road safety in general (Green et al., 2016).

Another aspect associated with the reduction in the number of motor vehicles that has been observed in several studies examining the effects of congestion charging is an increase in the average speed of vehicles but also a greater variation in the travelling speed of vehicles (Green et al., 2016; Li et al., 2012; Stempfel et al., 2016). While increases in travel speed may be good for travel times, it also increases the likelihood of crashes and the severity of injuries in those crashes, particularly for vulnerable road users (Anderson, 2001; Elvik, 2013; McLean et al., 1994; Nilsson, 2004; Stempfel et al., 2016).

4.2 What happens when there are more pedestrians and cyclists?

The term “Safety in Numbers” has been used to describe the observed statistical relationship between the numbers of people cycling and walking and the frequency of crashes with motorists (Jacobson, 2003). Essentially the association is non-linear such that injury frequency is proportionally less than the increase in the number of pedestrians or cyclists: rather than doubling the number of crashes early estimates suggested that doubling cycling or walking will increase crashes by 32% (Jacobson, 2003). A more recent meta-analysis of 34 studies suggests that increasing walking or cycling by 100% (i.e., doubling the number of pedestrians or cyclists) can be expected to increase the number of crashes by 41% (Elvik & Bjørnskau, 2017). There is also evidence of a Safety in Numbers effect for single bike crashes (Schepers, 2012). The Safety in Numbers effect has been examined in some detail with evidence of reduced risk with increased numbers observed in Australia (Bonham et al., 2006; Robinson, 2005), New Zealand (Tin Tin et al., 2011), Canada (Leden, 2002), and the USA and several European countries including the UK and Netherlands (Elvik & Bjørnskau, 2017; Jacobsen, 2003).

While the Safety in Numbers effect is robust and has been observed in many studies, the mechanisms that produce this effect are poorly understood (Bhatia & Wier, 2011; Elvik, 2009). In his original exposition of Safety in Numbers, Jacobsen (2003) suggested the effect may be due to an increase in driver awareness. Recent research from Norway (Fyhri et al., 2017) found that cyclists reported fewer incidents of being overlooked by a driver at times when there were more cyclists (based on cyclist counts), which they argue offers some support for this hypothesis. Other evidence from self-reported surveys undertaken in Australia (Johnson et al., 2014) also suggests drivers who also cycle are more likely to drive more safely around cyclists and have a more positive attitude to cyclists than drivers who do not cycle. It should be noted, however, that while significantly more likely to adopt behaviours like leaving a gap of one metre when passing or performing a head-check before turning left, not all driver-cyclists reported doing so. While the hypothesis of increased driver awareness is plausible, it would appear that other factors are also at play. Wegman et al. (2012) have suggested that while driver awareness and expectancy are important for pedestrian and cyclist safety, the creation of safer conditions for walking and cycling through well-designed infrastructure also plays an important role.

Revisiting the Safety in Numbers effect Jacobsen et al. (2015) identified a number of other factors that may also explain it. These include: safer street regulation, design, and operation in societies with higher numbers of pedestrians and cyclists; changes in the behaviour of pedestrians and cyclists such that they may cluster in bigger groups, making them more visible to other road users; and changes in driver behaviour brought about by the higher frequency of pedestrians and cyclists, increasing the likelihood of drivers expecting to encounter them when driving. Bhatia and Wier (2011) also consider socio-political issues as contributing to the Safety in Numbers effect, suggesting that increased participation in walking and cycling leads to stronger political constituency for improving the safety of these modes and also for better enforcement of dangerous motorist behaviours.

The central tenet of Safety in Numbers is that increasing the number of pedestrians or cyclists will also increase safety for these vulnerable road users. However, one of the main criticisms of this is that there is a lack of evidence regarding a causal direction (Bhatia & Wier, 2011). Do more pedestrians or cyclists increase safety, or do safer walking and riding environments attract more pedestrians and cyclists? One of the key shortcomings of Safety in Numbers research is comparing locations with high levels of walking or cycling to locations with lower levels of cycling and walking. In most cases it would appear that locations with higher numbers of cyclists and pedestrians are better walking and cycling environments compared to locations with lower levels of cycling or walking, even in studies comparing locations within the same city, state, or country (e.g., Bonham, et al., 2006, Jacobsen, 2003; Leden, 2002; Robinson, 2005; Tin Tin et al., 2011). As such it is difficult to determine whether the safety associated with Safety in Numbers is due to the increased numbers or whether the increased numbers are the result of safer environments – "safety could be producing the numbers" (Bhatia & Wier, 2011, p. 237).

There is evidence that one of the key determinants of the Safety in Numbers effect is the volume of motor vehicles, pedestrians, and cyclists. Elvik (2013) demonstrated a Safety in Numbers effect where pedestrian and cyclist volumes increase concurrently with a decrease in motor vehicles. Where pedestrian and cyclist numbers increased concurrently with an increase in motor vehicles a hazard in numbers effect was observed. Further, a partial Safety in Numbers effect was observed when motor vehicle volumes remained constant while pedestrian and cyclist volumes increased. This evidence suggests that Safety in Numbers is only possible where motor vehicle use is replaced by other modes, or by reducing the presence of motor vehicles in areas of high pedestrian or cycling behaviour. While increasing volumes of pedestrians and cyclists concomitant with a reduction in motor vehicle volumes has been found to improve safety for pedestrians and cyclists, Wei and Lovegrove (2010) have suggested that there is a critical level at which cycling becomes safer. The question remains as to how much walking and cycling need to increase and motor vehicle use decrease in order to achieve this effect.

4.3 What is the effect of mode shift?

Elvik (2009) modelled the safety effects of swapping car trips for walking and cycling. Motor vehicle volumes (based on Annual Average Daily Traffic (AADT) ranging from 2,000 to 30,000) were reduced with motor vehicle trips redistributed as two thirds to walking and one third to cycling. At baseline pedestrian and cyclist volumes were 200 and 100 respectively. Reducing motor vehicle volumes by 25% was found to reduce crashes at all volumes although the effect was small at high traffic volumes (estimated reduction in crashes ranged from 16% at 1,500 AADT to 2% at 22,500 AADT). A 50% reduction in motor vehicles produced a reduction in crashes at all volumes (estimated reduction in crashes ranged from 38% at 1,000 AADT to 24% reduction at 15,000 AADT). It would appear that significant mode shift is required – enough to reduce motor vehicle volumes by 50% – before safety is improved.

Schepers and Heinen (2013) also modelled the effect of mode shift, this time focussing on replacing short car trips (≤ 7.5 km) with cycling at levels of 10%, 30%, and 50% shift, on fatalities and serious injuries. The findings are presented in Table 4.2. With the exception of cyclist fatalities resulting from a collision with a car, which remain relatively stable, cyclist crashes resulting in death or serious injury were found to increase at all volumes. The increase in serious injuries to cyclists are largely due to the increase in single bike crashes. Deaths and serious injuries to car occupants and "All other road users" show a decline. What is interesting about this study is that while cyclist injuries and deaths increase, the rate is in keeping with the Safety in Numbers effect and is lower than the increase in cycling. Also of interest is that the reduction in injuries to car occupants and other road users are also smaller than the decrease in motor vehicles: 50% fewer motor vehicles does not translate in to a 50% reduction in deaths and injuries for these road users.

Table 4.2
Effect on deaths and serious injuries for different road users based on per cent of car trips replaced by cycling

Road user injured	Death					Serious Injury[a]				
	BL	10%	30%	50%	Effect	BL	10%	30%	50%	Effect
Cyclist vs. car	77	77	78	77	↔	1092	1114	1148	1170	↑
Cyclist vs. other motor vehicle	72	78	89	100	↑	463	495	558	620	↑
Carr occupant	252	247	237	227	↓	2574	2518	2405	2291	↓
All other road users	101	99	94	89	↓	2820	2742	2586	2430	↓
Cyclist vs. non-motor vehicle[b]	40	42	45	49	↑	7400	7906	8887	9832	↑
Total	542	543	543	542	↔	14349	14775	15584	16343	↑

Note: BL = base line: annual injury rates for the period 2004-2007. ↔ [illegible]; ↑ [illegible] ↓ [illegible]. Adapted from Schepers and Heinen (2013).

[a]Serious injury is classified as an injury requiring a minimum one night admission to hospital and a MAIS2+. [b]Includes single bike crashes.

In addition to modelling the effects of mode shift, Schepers and Heinen (2013) also modelled the effect of mode shift if the average risk for cyclists is reduced or increased by 20% on both deaths and serious injuries. Unsurprisingly, they found that a mode shift of any level results in an increase in total death and serious injury if the risk of cyclist injury increases by 20%, while a reduction in injury risk of 20% led to a reduction in total deaths and serious injury at all levels of mode shift. This demonstrates that improving cyclist safety can be expected to reduce cyclist casualties. Interestingly Elvik et al. (2009) estimate that bicycle lanes are effective for reducing 19% of cyclist crashes that occur along the road, 25% that occur at intersections, 9% that occur at signalised intersections, and a total effect of 9% reduction in all cyclist crashes. Cycle lanes also reduced crashes for other road users including pedestrians and motor vehicles (Elvik et al., 2009). Separated bicycle paths were found to reduce crashes along the road by 11% but increase crashes at intersections by 24% (Elvik et al., 2009). The protective effect of separated infrastructure is lost at intersections, which may be due to a reduction in attention paid to other road users by drivers and cyclists (Elvik et al., 2009).

Another effect evident in Table 4.2 is the increase in cyclist crashes with non-motor vehicles observed with increases in cycling. Schepers and Heinen (2013) suggest this type of crash predominantly involve a single cyclist. Given the majority of cycling-related injuries are sustained in this type of crash (e.g., Biegler et al., 2012; Schepers, 2012; Weijermars et al., 2016) increases in this mode can also be expected to increase bike only crashes. Drawing on Dutch data, Schepers (2012) examined the relationship between the amount of cycling (based on km travelled) and single bike crashes and found a Safety in Numbers-like effect, such that bike only crashes increased at a rate lower than that of the increase in cycling. Analysis of travel survey data found that more experienced cyclists were less likely to be injured in single bike crashes while older cyclists were more likely to sustain serious injuries (Schepers, 2012).

The evidence presented above is, at first, somewhat contradictory but there are important differences between the studies that need to be considered. First, Elvik (2009) modelled mode shift to walking and cycling with the increase in active travel weighted towards walking while Schepers and Heinen (2013) considered a shift towards only cycling. Of all active travel modes cycling carries the greatest risk of injury (see section 2), which, in conjunction with the inclusion of single bike crashes, likely explains the increase in casualties observed by Schepers and Heinen. Together these findings imply that for mode shift to benefit road safety a significant number of car trips must be replaced with active trips that favour the safer modes (i.e., walking and public transport use). Furthermore, a transport system that is made safer for vulnerable road users will ensure a mode shift to any mode will benefit road safety.

5 Discussion

5.1 Summary

To determine the effect of increased walking, cycling, and public transport use in place of car trips, a literature review was conducted addressing three issues: what are the risks for each mode, what happens when there are fewer cars, and what happens when there are more pedestrians and cyclists?

While public transport is consistently found to be the safest travel mode, walking and cycling carry a greater risk of injury compared to travelling in a car. There is good indication that the main reason for this risk is due to collisions with motor vehicles, particularly passenger cars. As such, a reduction in motor vehicles may serve to ameliorate the risks to vulnerable road users. However, the effects of reducing the number of motor vehicles is complicated: fewer cars would potentially reduce the number of conflicts but there is also evidence of an increase in vehicle speeds, which could potentially increase the severity of collisions when they occur. A further aspect of this issue is the impact of increases in active modes with a concomitant reduction in motor vehicles. The available evidence addressing this indicates that for mode shift to benefit road safety a significant number of car trips – at least 50% – must be replaced with active trips that favour the safer modes (i.e., walking and public transport use). Additionally, improving the safety of vulnerable road users will ensure a mode shift to any mode will benefit road safety.

Mode shift at the population level will occur incrementally and the safety of vulnerable road users will play a key role in this shift. First, concerns about safety are one of the primary barriers preventing people from cycling, particularly females (Bauman et al., 2008; Garrard et al., 2006; National Heart Foundation and Cycling Promotion Fund, 2011, 2013; Rose et al,. 2008). Second, as mode shift will be incremental, the full benefits of a 50% reduction in car trips will not be immediately realised. Improving safety will be necessary to both protect vulnerable road users and to encourage people to shift modes. Although the findings of Elvik (2009) suggest a 50% reduction in car trips replaced with walking and cycling is necessary to observe tangible improvements in road safety, small improvements were also observed when doubling the number of pedestrians and cyclists and with a 25% reduction in car trips. Schepers and Heinen (2013) have also shown that improving safety can be expected to reduce casualties. While a substantial mode shift may be necessary to observe a positive affect on road safety, there is some evidence that the benefits of mode shift (e.g., reduced congestion and carbon emissions, and improvements in health) may be observed at lower levels with little impact on road safety provided the safety of vulnerable users is carefully managed.

The other side of replacing car trips with more active modes is the risk those other modes pose to each other. Increased public transport use will likely result in increases in the number of buses and potentially trams. While bus crashes with pedestrians or cyclists are relatively rare, they are large vehicles, the design and mass of which have the potential to be more harmful to vulnerable road users. Broadening the tram network, which has been proposed in South Australia, will also increase the prevalence of tram tracks along road corridors, which may also increase single bike crashes due to bicycle wheels becoming trapped in the track. The incidence of trams colliding with pedestrians are relatively infrequent events and can be managed by well-designed tram stops and pedestrian crossings. While the potential for tram collisions with cyclists also exists no evidence of such were identified in the literature. This is perhaps an area requiring further investigation.

The Safety in Numbers effect is often cited as a strategy for improving the safety of vulnerable users, particularly cyclists. The net evidence of studies investigating the Safety in Numbers effect indicate an increase in casualties albeit to an extent somewhat lower than the proportion of the increase. This is generally interpreted as a reduction of risk at the individual level but the effect at the population level is an increase in road casualties. This issue is itself also complicated as there is evidence that an increase in cyclist casualties is due to an increase in the number of single bike crashes. While this may be true, there is also evidence of a Safety in Numbers effect for single bike crashes such that the increase in casualties due to these crashes is not proportional to the increase in cycling. Where increases in walking and cycling are accompanied by reductions in motor vehicle trips, evidence suggests that overall road casualties decline despite the increase in injuries among vulnerable users. This in itself poses an interesting dilemma. Injuries to vulnerable users will increase with increased participation but there is evidence that severe injuries will be less common and that injuries sustained in single vehicle (i.e., single bike or single pedestrian) incidents, collisions between pedestrians and cyclists, or cyclist vs. cyclist crashes may be less severe than those incurred in collisions with motor vehicles. It will be necessary for authorities to resolve whether they are willing to accept an increase in less severe injuries to achieve a reduction in higher severity injuries and fewer road casualties in general.

A further note on the Safety in Numbers effect: while evidence suggests the effect is robust and has been observed in a number of different jurisdictions, the evidence regarding the mechanisms that underpin it are poorly understood. A number of plausible explanations have been offered but it is still unclear as to whether numbers lead to safety or whether increased safety brings about the change in numbers. Regardless of the causal direction, creating safer conditions for walking and cycling through well-designed infrastructure and political support will also improve the safety of these road users. Evidence linking the incidence of single bike crashes with cyclist experience suggest that there is the potential that the risk of single bike crashes will reduce as new cyclists gain experience. Strategies that accelerate this process (e.g., rider training and educational programs) may also help to limit the risks to novice riders.

One of the interesting findings to emerge from research into the risks of different travel modes is the impact of age and sex on safety. Young drivers, particularly males, are over-represented in road casualties but have a lower risk as pedestrians and cyclists, as they are physically robust and better able to cope with the forces of injury, particularly those arising from falls. Conversely, older drivers have a lower risk as drivers but, due to their physical frailty, an increased risk as pedestrian, cyclists, and passengers on public transport. As such, the characteristics of people who make the mode shift will also influence the effect on road safety.

Another issue that has not been considered as yet are the health benefits of active modes. The preceding sections have considered the impact on risk of injury arising from collisions with other road users or single vehicle crashes. This shows the risk to the users but what has not been addressed are the potential health benefits of active travel. Research in this area has found that active transport can have benefits for both mental health and cognitive functioning, help achieve recommended activity levels, and reduces the risks of Type 2 diabetes, cardiovascular disease, coronary heart disease, and some cancers (Garrard et al., 2012; Oja et al., 2011; Pucher et al., 2010). Some have found evidence suggesting that the health benefits of cycling outweigh the risks of illness (due to exposure to pollutants from vehicles) or fatal injury (de Hartog et al., 2010; Rabl & de Nazelle, 2012). There are also broader social benefits arising from reduced car use, including reductions in air and noise pollution (Rabl & de Nazelle, 2012; Xia et al., 2015).

5.2 Conclusion

Determining the effect of increasing active travel modes in place of car trips is a complex problem with many facets to consider. Drawing on the available evidence it would appear that achieving a substantial level of mode shift that favours the active modes with the lowest risk (e.g., walking and public transport) has the potential for a net positive effect on road safety. While casualties among vulnerable modes will increase, a reduction in total road casualties – driven by a reduction in car-related casualties – can be expected. While a mode shift may benefit road safety, vulnerable road users will continue to face risks from cars and other motorised traffic. As such, it is imperative that strategies for encouraging mode shift work in tandem with measures to improve safety for vulnerable road users. Providing safer walking and cycling environments with infrastructure, reduced speed limits, reduced motor vehicle volumes, and other legislative and policy measures will improve safety. A transport system that is made safe for the most vulnerable users will be safe for all road users.

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