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Fatal and Serious Injury Rates for Different Travel Modes in Victoria, Australia

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Abstract: While absolute injury numbers are widely used as a road safety indicator, they do not fully account for the likelihood of an injury given a certain level of exposure. Adjusting crash and injury rates for travel exposure can measure the magnitude of travel activity leading to crash outcomes and provide a more comprehensive indicator of safety. Fatal and serious injury (FSI) numbers were adjusted by three measures of travel exposure to estimate crash and injury rates across nine travel modes in the Australian state of Victoria. While car drivers accounted for the highest number of injuries across the three modes, their likelihood of being killed or seriously injured was substantially lower than that of motorcyclists across all exposure measures. Cyclists accounted for fewer injuries than car passengers and pedestrians but had a higher risk per exposure. The results varied by both injury severity and exposure measure. The results of this study will assist with high level transport planning by allowing for the investigation of the changes in travel-related FSI resulting from proposed travel mode shifts driven by safety, environmental reasons or other reasons as part of the holistic goal of transforming the transport system to full compliance with Safe System principles.

Keywords: road safety; crashes; serious injury; fatalities; vulnerable road users; modal shift; travel behaviour; exposure; Safe System

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1. Introduction

Transportation has traditionally focused on sustainable private transport. From the early part of the 20th century, the motorcar has been the preferred and most versatile mode of travel in most western countries [1,2]. With this focus on private vehicle travel, serious road accidents have blossomed to the current estimates of 1.5 million deaths annually, and between 20 and 50 million severe injuries to car occupants [3,4]. Travel modes, though, are predicted to change in the years ahead.

Seba [5] claims that, with climate change and other societal forces, the reliance on fossil fuels, coal production, natural gas and nuclear energy, conventional cars will be obsolete by 2030. However, more recent technologies, such as electric vehicles (EVs), are likely to challenge this prediction given their significant reduction in vehicle costs. Litman [5,6] further reported that transportation is changing based on consumer demand and travel costs. He noted that 20% of household budgets are currently spent annually on personal vehicle costs and that there is a shift to other cheaper forms of travel, such as motorcycles, bicycles, scooters, car-sharing and public transport. He claimed that there is an urgent need for efficient and equitable cost-effective forms of transportation. Public transport is likely to increase given it is generally more affordable and available, especially in urban areas.

Systematic efforts have been made towards eliminating fatal and serious injury crashes using the Safe System approach [7–9]. Australia was one of the first countries to formally adopt this approach, based on the Swedish Vision Zero philosophy, to improve road safety [10]. However, despite successful past achievements, crash-related deaths and serious injuries continue to be a major public health problem in Australia and throughout the world [11]. Regardless of the mode choice, safe travel relies on the effective management of multiple risk factors, including many that may be difficult to quantify and therefore address. Nevertheless, a more thorough understanding of the nature and magnitude of travel risk can lead to opportunities for more effective interventions, and can thus reduce the overall risk of travel-related deaths and serious injuries.

Previous research has highlighted opportunities for improving road safety by adjusting exposure and encouraging the use of safer travel modes [12–16]. However, individuals choose their mode of travel for a wide range of reasons, rather than just safety, including cost, time, and convenience. Moreover, safety-related judgements may be biased by personal perceptions of risk [16–19]. It is important to understand the different injury risks associated with different travel measures in order to develop an objective basis for the development of government policy aimed at achieving further safety benefits by influencing travel mode choices [20–23].

The aggregate likelihood of travel-related death or injury can be defined as the ratio of the number of deaths or injuries against a specific measure of exposure [24–28]. The most common exposure measures include: (i) number of trips, (ii) time spent travelling and (iii) distance travelled [29,30]. It is also important to note that although crash-related fatalities are typically reported consistently and accurately, they do not always involve consistent exposure measures. Savage [31] noted that fatalities alone do not accurately highlight the differences between travel modes in term of the survivability of crashes, and therefore crash-related serious injury numbers also need to be considered. Lejeune, and colleagues [32] also suggested that the number of injured persons alone does not accurately reflect the differences in risk across the travel modes without correcting for exposure.

The International Transport Forum [33] collected mobility and road safety data from 31 various cities to evaluate, monitor and benchmark road safety outcomes. Analysis reveals considerable differences in the road safety performance between modes within the same city and between cities. Pedestrians, cyclists, and motorcyclists, together called vulnerable road users, make up approximately eight out of ten road users killed in city traffic [33].

The United Nations 2030 Agenda for Sustainable Development [34], adopted by all Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. The Agenda is based on 17 Sustainable Development Goals (SDGs). Transportation issues have been part of the sustainability discussion for at least 30 years, initially with a focus on reducing congestion and improving energy efficiency. However, road safety was not explicitly included among the development goals and targets until the adoption of the 2030 Agenda for Sustainable Development in 2015. The specific inclusion of road safety targets in Agenda 2030 reflects universal recognition that death and injury from road crashes are now among the most serious threats to the future of our people and planet. This means that road safety is no longer a need that can be compromised or traded-off in order to achieve other social needs. It implies, for example, that the safety risks inherent in raising speed limits should not be tolerated in order to realise economic benefits of faster traffic, and that investments necessary to improve road safety should not be diverted for other needs [35].

This study set out to estimate injury rates (including fatal, serious injury and combined fatal and serious injury (FSI) rates) across nine travel modes by three exposure measures in the Australian state of Victoria between 2012 and 2016. Based on the authors' knowledge, this is the first and most recent work to estimate risk rates for the nine travel modes on the state of Victoria in Australia. The goal of this study is to develop an understanding of road safety performance across different modes to investigate the effects on road safety outcomes of a shift towards sustainable modes of public and active travel.

2. Materials and Methods

The analyses in the current study estimated the annual average FSI rates based on travel exposure data from government sources over a four-year period in the state of

Victoria (Australia). Descriptive and relative risk analyses were conducted after the filtering, matching, and processing.

2.1. Data

The main source of travel data was the Victorian Integrated Survey of Travel and Activity (VISTA), a survey-based sample of Victorian households who complete travel diaries on a single specified day. The data received from the VISTA team within the Department of Transport in Victoria were based on a survey they administrated to provide further details. More details of the survey they conducted can be found on their website [36]. Three measures of exposure were available for each travel mode: (i) the number of stops, (ii) the distance travelled (in kilometres) and (iii) travel time (in minutes). A "stop" was recorded whenever a road user changed travel mode (e.g., walking to the station and "stopping" to take the train) or changed their purpose of travel, such as dropping a passenger off while travelling to work [36]. The exposure measures are adjusted in VISTA using total population numbers to provide the population estimates available for analysis [36].

Our data and analysis approach are similar to previous studies carried out in France [27], the USA [31,37,38], Canada [39] and Australia [22]. However, the exposure data used in this study were obtained from the STOPS database within VISTA and provide the amount of travel by each mode within a full journey, overcoming the limitations of having the overall trip exposure calculated from the main mode of transport only (as was reported in a previous study [27]). A wider range of travel modes were included for comparison.

Road injury data were obtained from the VicRoads crash statistics system CrashStats for the period between 2012 and 2016 [40] and public transport injury data from Transport Safety Victoria (TSV), a state authority responsible for documenting all public transport incidents [41]. For a crash to be recorded as road-related, it must be reported to the police or other relevant authority as being caused by the movement of a vehicle on a road [42]. Public transport injuries, unless relating to a crash involving a motor vehicle, are not collected by VicRoads CrashStats. These include incidents such as passengers falling inside trams and at tram stops. Thus, injuries related to train, tram and bus passengers were obtained from TSV. In Victoria, any person who dies within 30 days as the result of a road crash is recorded as a crash-related fatality, whereas a serious injury is recorded for any person who is injured in a road crash and admitted to hospital, irrespective of the length of stay [42]. This approach of defining crash-related serious injuries based on hospital admission status is consistent with the approach used in most jurisdictions across Australia and internationally [42].

2.2. Analysis

CrashStats uses two types of attributes to report injured persons in a crash: (i) vehicle type (e.g., car) and (ii) road user type (e.g., driver). VISTA includes three main attributes to record the person's trip: (i) vehicle type mode info (e.g., hire car), (ii) main mode (e.g., vehicle driver) and (iii) full mode (e.g., car driver). Transport Safety Victoria (TSV) provided data for public transport passengers only (road user type), and specifies the vehicle type as either train, tram, or bus.

Exposure data were divided into three classifications: journey time, journey distance and the number of stops per trip. Descriptive and relative risk analyses were conducted after filtering, matching, and processing. Travel and injury data were recorded by different classifications: vehicle type and road user type. Each record includes vehicle type as car and road user type as passenger. On the other hand, VISTA data include three main classifications: full mode information, main mode and full mode; an example of one record includes running, walking and jogging.

Public transport injury data were only for passengers. An example of introducing the car driver category from CrashStats data is to combine driver as road user with car and station wagon from vehicle type. From VISTA data, private car was combined with full mode info with vehicle driver from main mode and driver of car and 4WD from full mode. It should be noted that VISTA records personal travel only, so injury data from CrashStats were filtered and professional drivers were not included (i.e., those employed to move goods or people including heavy vehicle, bus, and taxi drivers).

Injury data from the road crash data source did not include on-road-related public transport incidents (e.g., slips, trips and falls) that were available from the TSV dataset. These injury data were then re-classified for train, tram, and bus accordingly to match the data from CrashStats. Differences between public transport injuries recorded by the TSV and VicRoads were quantified between 2012 and 2016; TSV recorded 340 serious injuries on public transport (i.e., train, tram, and bus) compared to 56 police-reported injuries recorded by VicRoads in CrashStats. The filtered and matched data were then processed to produce a unified list of nine travel modes that were created from the three data sources, including car driver, car passenger, taxi passenger, motorcycle rider, pedestrian, cyclist, bus passenger and train passenger.

To allow for comparisons of risk between different modes of travel, injury and fatality numbers were divided by each of the three measures of travel exposure to estimate injury risk rates for the four-year period and were then converted to an average annual rate. FSI are relatively rare events in a large population, and therefore a Poisson distribution was assumed with 95% confidence intervals. More details on these procedures can be found in references [43–46] for those interested.

3. Results

3.1. Injury Frequency

There was an annual average of 224 fatalities and 4597 serious injuries (4821 FSI) between 2012 and 2016 across the nine travel modes (see Table 1). Most FSI were associated with car occupants (drivers and passengers), followed by motorcyclists, pedestrians, and cyclists.

Table 1. Annual average FSI by mode, Victoria, Australia 2012–2016.

Travel Mode	Fatalities per Annum	% of Total Fatalities	Serious Injuries per Annum	% of Total Serious Injuries	FSI per Annum	% of Total FSI
Car driver	99	44.2%	1935	42.1%	2034	42.2%
Car passenger	40	17.9%	720	15.7%	760	15.8%
Taxi passenger	0	0.0%	11	0.2%	11	0.2%
Motorcycle rider	39	17.4%	914	19.9%	953	19.8%
Pedestrian	36	16.1%	529	11.5%	565	11.7%
Cyclist	8	3.6%	419	9.1%	427	8.9%
Bus passenger	1	0.4%	34	0.7%	35	0.7%
Tram passenger	0	0.0%	25	0.5%	25	0.5%
Train passenger	1	0.4%	10	0.2%	11	0.2%
Total	224	100.0%	4597	100.0%	4821	100.0%

3.2. Travel Frequency

Table 2 shows the travel exposure distribution by travel mode. Overall, Victorians spent 109 billion minutes travelling per annum, covered 47.2 billion kilometres and made 5.9 billion stops (across all modes under study). By distance, most travel occurred by car, followed by public transport and as a pedestrian. By time, most travel again occurred by car, followed by as a pedestrian and then by public transport. It should be noted that slower travel modes may be subject to higher exposure in terms of time and the number of stops, whereas faster modes may be subject to higher exposure by travel distance.

3.3. Injury Risk Rates

The number of injuries were divided by the corresponding travel times, travel distances and number of stops to calculate injury rates per travel measure.

Table 2. Average annual travel exposure by mode, Victoria, Australia 2012–2016. Source: VISTA.

Travel Mode	Travel Time per Annum		Distance per Annum		Stops per Annum	
	Minutes × 100 Million	% of Total	Km × 100 Million	% of Total	Stops × 100 Million	% of Total
Car driver	517.6	47.6%	265.7	56.3%	24.5	41.6%
Car passenger	255.4	23.5%	134.0	28.4%	13.3	22.6%
Taxi passenger	4.1	0.4%	1.7	0.4%	0.2	0.3%
Motorcycle rider	3.0	0.3%	1.6	0.3%	0.1	0.2%
Pedestrian	177.0	16.3%	12.7	2.7%	15.1	25.7%
Cyclist	23.5	2.2%	4.4	0.9%	1.0	1.6%
Bus passenger	24.0	2.2%	9.2	1.9%	1.2	2.1%
Tram passenger	16.6	1.5%	3.4	0.7%	1.0	1.8%
Train passenger	65.7	6.0%	39.2	8.3%	2.4	4.1%
Total	1086.9	100.0%	472.0	100.0%	58.8	100.0%

3.3.1. Fatal Injury Rates

Table 3 quantifies fatality rates based on the three measures of exposure. For "car occupants", three groups were included: car driver, car passenger and taxi passenger. Although the three groups use "car" as the mode of travel, their fatal injury risks were different. By all of the measures, travel as a taxi passenger was less likely to result in fatal injury compared to travel as a car driver and/or passenger, and also travel as a bus or train passenger (no fatalities were recorded for taxi passengers over the time period under consideration).

Table 3. Annual average fatality rates (F) across nine travel modes, Victoria, Australia 2012–2016.

Travel Mode	Fatalities per 100 Million Minutes		Fatalities per 100 Million Km		Fatalities per 100 Million Stops	
	Fatality Rate	95% CI	Fatality Rate	95% CI	Fatality Rate	95% CI
Car driver	0.19	0.16–0.23	0.37	0.30–0.45	4.05	3.31–4.90
Car passenger	0.16	0.11–0.21	0.30	0.22–0.40	3.01	2.18–4.06
Taxi passenger	0.00	0.00–0.60	0.00	0.00–1.4	0.00	0.00–13.42
Motorcycle rider	13.08	9.44–17.69	24.64	17.78–32.32	334.62	241.54–452.50
Pedestrian	0.20	0.14–0.28	2.83	2.01–3.87	2.38	1.69–3.26
Cyclist	0.34	0.16–0.64	1.83	0.86–3.46	8.42	3.97–15.88
Bus passenger	0.04	0.00–0.19	0.11	0.00–0.51	0.83	0.08–3.86
Tram passenger	0.00	0.00–0.15	0.00	0.00–0.72	0.00	0.00–2.40
Train passenger	0.02	0.00–0.07	0.03	0.00–0.12	0.42	0.04–1.96
Average	0.21	0.18–0.23	0.47	0.42–0.54	3.81	3.34–4.34

Motorcycle riders and cyclists had the highest fatal injury risk across the three measures of exposure. The travel risk for pedestrians varied significantly by the exposure measure; relative to car drivers, pedestrians had a 7.6 times higher fatal injury risk when measured per distance (2.4 versus 0.4), but practically the same as the car driver risk when measured by travel time (0.20 versus 0.19). In contrast, public transport users had the lowest fatal injury risk across all three exposure measures (except for taxi passengers).

3.3.2. Serious Injury Rates and Combined Fatal and Severe Injury Rates

Annual serious injuries (SI) were 20 times higher than fatalities, and there were differences in the relative risks between modes for serious injuries compared with fatalities. However, the SI rates FSI rates shown in Table 4 were quite similar due to the predominance of serious injuries.

The differences between car users changed compared with fatalities, with the taxi passenger risk higher than that of car passengers based on distance and stop-based metrics. Motorcycle riders and cyclists also had the highest SI and FSI rates across the three travel measures. Injury rates for pedestrians were high when measured per distance but were lower than car drivers when measured based on time and the number of stops. Travel by public transport was safer than all other travel modes, with train passengers being the safest followed by bus passengers; however, when measured by distance, the tram passenger risk (7.34 per 100 million kilometres) was almost the same as that of car drivers (7.65 per 100 million kilometres).

Table 4. Annual FSI risk rates across nine travel modes, Victoria, Australia 2012–2016.

Travel Mode	FSI Rate per 100 Million Minutes		FSI Rate per 100 Million Km		FSI rRate per 100 Million Stops	
	FSI Rate	95% CI	FSI Rate	95% CI	FSI Rate	95% CI
Car driver	3.93	3.76–4.10	7.65	7.33–7.99	83.13	79.58–86.81
Car passenger	2.98	2.77–3.19	5.67	5.28–6.09	57.19	53.23–61.36
Taxi passenger	2.67	1.42–4.63	6.42	3.41–11.11	59.93	31.80–103.73
Motorcycle rider	319.62	299.81–340.40	602.09	564.77–641.24	8176.83	7670.01–8708.50
Pedestrian	3.19	2.94–3.46	44.39	40.84–48.16	37.35	34.36–40.52
Cyclist	18.20	16.53–19.99	97.77	88.82–107.38	449.28	408.17–493.43
Bus passenger	1.46	1.03–2.00	3.82	2.70–5.25	28.94	20.50–39.77
Tram passenger	1.50	1.00–2.19	7.34	4.87–10.66	24.29	16.10–35.28
Train passenger	0.17	0.09–0.29	0.28	0.15–0.49	4.62	2.45–7.99
Total	4.44	4.31–4.56	10.21	9.93–1051	82.05	79.76–84.39

3.3.3. Risk Incidence Matrix

This section compares the dual influence of the number of injuries and the injury rates by travel mode by constructing a risk matrix plotting the FSI rate against absolute FSI for each mode [47,48].

The matrix for time-based FSI rates is shown in Figure 1 for four categories, namely, (i) low risk, low injuries, (ii) low risk, high injuries, (iii) high risk, low injuries and (iv) high risk, high injuries. Logarithmic scales were adopted given the high discrepancy across vehicle modes. Across the nine travel modes under study, motorcyclists have the highest FSI risk and injuries, with the second highest number of FSI after car drivers. While car drivers account for the majority of injuries, their risk per time was substantially lower than that of motorcyclists. A similar interpretation can be made for cyclists compared to car passengers and pedestrians. Cyclists were consistently at higher risk but account for fewer FSI than car passengers and pedestrians. Conversely, public transport users were consistently classified as low risk, low injuries.

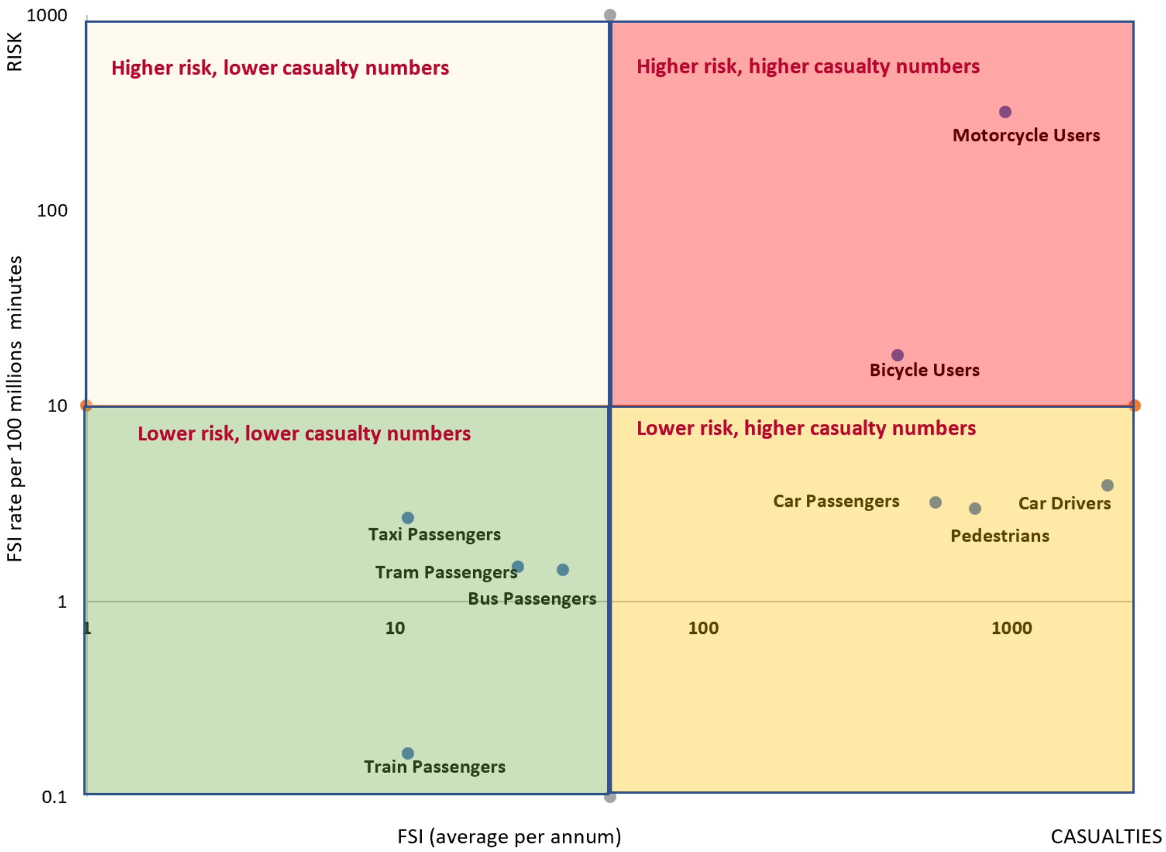


Figure 1. Risk–injury plot for road user groups between injuries and injury rate per 100 million minutes on a base-10 log scale.

4. Discussion

In this study, the risk of fatal and severe injuries (FSI) was quantified for nine travel modes (including both private and public modes) across three measures of exposure (per time, distance and frequency or stops). The injury rates provide an indication of the relative risk associated with each travel mode and identify groups with the highest risk of FSI.

4.1. Overview of Findings

Travel data showed the car to be both the predominant mode of travel in Victoria and the mode with the highest absolute injury numbers across all exposure modes, as would be expected given the fact that three-quarters of all private journeys are by cars in Victoria. However, when corrected for exposure, motorcyclists, cyclists, and pedestrians were at a higher risk of injury than car occupants, with the exception of pedestrian travel per time exposure.

While the proportion of motorcycle travel was very low, the number of annual FSI was second highest after travel by car (~20% of total FSI), and, when adjusted for exposure, regardless of the exposure unit, motorcycle riders were at the highest risk of FSI. Results from other published authors [27,31,38] have shown similar findings.

Cyclists were the next highest risk group after motorcycle riders across the three measures of exposure. Although the health benefits of cycling are well established [49,50], there is the potential for this mode to produce other additional benefits in reducing traffic congestion and air pollution [49,51]. Exposure to crash risk, however, is a safety concern, as cyclists often have to use the same road infrastructure as cars, buses and trucks (for at least some part of their journeys), and are far more vulnerable than vehicle occupants [52].

Safety is likely a major deterrent to cycling due to both perceived and actual levels of risk [53]. The higher rates of injuries per exposure for cyclists compared to travel by car suggest that a shift from travel by car to cycling may lead to a potential increase in the numbers of injuries [54]. However, a common counter argument is ‘safety in numbers’, which has been used to explain the non-linear statistical relationships between the number of cyclists and the number of injuries [53,55,56]. ‘Safety in numbers’ suggests that the more cyclists there are, the safer cycling becomes, but there is likely to be a transition period, with the boost in relative safety lagging slightly behind the increase in the number of cyclists. In Victoria, for instance, cycling increased at a faster rate than any other part of Australia, but injury rates have also spiked. Using the theory of “safety in numbers”, one might expect the injury rate per kilometre travelled to reduce in the coming years as cycling skills and road infrastructure improves and driver behaviour adapts to the needs of cyclists [53].

Pedestrian safety risk has a different interpretation when corrected for the various exposure measures. Due to the fact that people have a limited ability to walk for general transportation, the percentage of distance travelled by walking was only 2.7% of the total distance travelled. However, when adjusted for the distance and time exposure measures, pedestrian risk resulted in the third highest FSI rate. The larger amount of exposure based on time and stops reduced the FSI rate of walking and showed it to be safer than travel as a car driver by time and safer than the three modes of motorised car travel by the number of stops. This is valuable in showing that the choice of an exposure measure can have a significant impact on assessing the risk by travel mode.

Regarding public transport, the results showed that travel by train was the safest travel mode regardless of the exposure unit considered. However, this is somewhat restricted by the extent of rail lines available. The risk of travel by bus and tram was almost similar based on the number of stops and time, although travel by bus was safer when measured by the distance travelled. This warrants further investigation.

4.2. Fatal versus Serious Injuries

The risks also differed markedly when considering fatalities only compared with serious injuries only or combined fatal and serious injuries. For example, cyclists with a fatality rate of only 1.8 per travel distance increased up to 97.8 per travel distance when compared with FSI. This suggests that most of their risk is in sustaining a severe injury, yet the reason behind this is unclear. The analysis also illustrates how different exposure measures tell different stories. Setting targets for fatalities alone may underestimate the risks, such as with the results of the taxi passenger group, and it is also important to account for the serious injury dimension of the road trauma problem.

Estimating the relative risk based on fatalities only can overcome some of the difficulties in accessing accurate and timely serious injury records, but it might be disadvantaged by not revealing survivable crashes [31]. It also provides more opportunities for comparison with other jurisdictions due to a generally better consistency and completeness of fatality data across jurisdictions, highlighted by studies such as the one by the International Transport Forum [33] in determining fatality rates among cities in Europe, the Americas and Oceania.

4.3. Selection of Exposure Measures

This study showed how the relative risk between travel modes can change depending on the exposure measure used, as reported previously [37]. The choice of exposure measure might not be crucial when considering the absolute injury risks for a single mode because the travel characteristics are usually constant; however, when considering multiple modes, the varied travel characteristics can significantly alter the magnitudes of one or more of the exposure metrics, and it is important to highlight these differences when comparing the travel injury risk across different modes [44].

Previous studies have not always agreed on the best matrix to use. The choice of explanatory variables could be restricted by the data availability [44]. The International Transport Forum [33] findings suggested to work primarily with distance, as it is the most commonly used metric. However, the findings by Guler and Grembek [44] suggested that using a time-based exposure metric might provide a better interpretation because of: (i) a better capture of the different travel risk characteristics of different modes, (ii) a better capture of the difference in speeds between the modes and (iii) because it is better aligned with the perceived risk of travel injury than a distance- or trip-based metric.

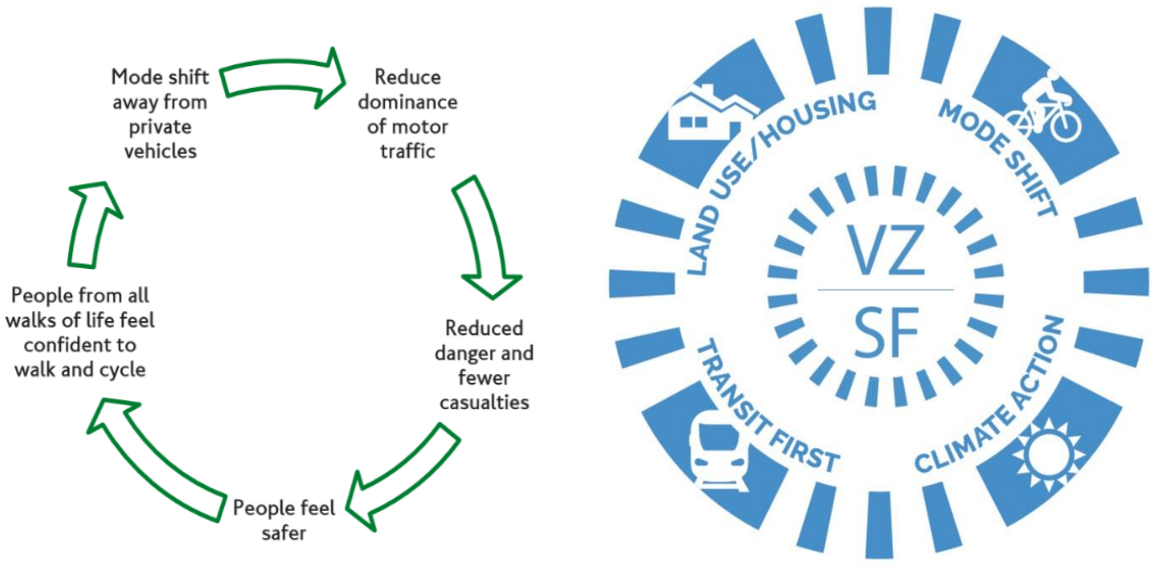
Mindell and colleagues [57] also argued that the risk by distance travelled does not capture large differences in the average speed, which enable a comparison of different mobilities for drivers, cyclists, and pedestrians, and that a time-based comparison minimises the distorting impact of different comparisons of other modes with long distance car journeys. The travel time budget (TTB) concept argues that the amount of time that people spend travelling remains almost constant, at an average daily travel time of around one hour, and that individual travel choice is dictated by a tendency to stay within this TTB [58,59], with faster travel modes resulting in longer distances travelled. Mindell and colleagues [57] further argued that the TTB concept can be used to support the use of risk based on time as being the most appropriate for comparing modes with different average speeds.

The findings here support the use of a variety of exposure measures to capture many of these claims from previous authors and provide a comparison of the relative risks by mode of travel across the three measures of the exposure of time, distance, and number of stops. Thus, these findings are potentially useful for a relative comparison of transportation risk studies.

4.4. Road Safety and Sustainability

The current study provides the information necessary to understand the consequences of modal shift on injury outcomes. The results show that there will be challenges in increasing the share of sustainable modes of walking and cycling if injury rates for these two modes remain the same. However, road safety management should align with broader ethical, social, economic and environmental goals to tackle other problems associated with road traffic. Modal shift, combined with targetd road safety interventions, can achieve benefits in improved safety, improved health (and fitness), reduced congestion and improvements to the environment [20,60].

The results from this study highlight a transport safety policy dilemma. As pointed out by McAndrews and collagues [38], should governments prioritize safety investment to protect high numbers of travellers or fewer travellers with higher risk by shifting to a lower risk category, or provide a safer environment for those vulnerable users and then accelerate the modal shift? The Safe System approach prioritizes human health above all else and mandates the priority of protecting the most vulnerable road users. By adopting a Safe System approach, it stresses the provision of additional requirements to make the roads safe for all users requiring safe infrastructure for vulnerable users where people want to walk, cycle and use public transport [7,8,60–62]. By starting with the creation of a safe environment that would increase the road share for vulnerable users and reduce the road share for cars, it should be possible to achieve both the desired modal shift and improved safety outcomes. Figure 2 shows examples of adopting modal shift and the creation of a Safe System for existing areas and during land use planning as part of Vision Zero road safety strategies. It was stated clearly in the action plan of Vision Zero in cities where modal shift for public and active transport is on the top priority such as in London [62] and San Francisco [60]. Such an approach can achieve combined benefits to address congestion and road safety, and that the promotion of certain modes of public transportation and restriction on car use may contribute to making cities more sustainable, both in terms of the time spent traveling and the probability of being involved in a crash [63].



(**a**) London Vision Zero Action Plan (**b**) San Francisco Vision Zero Complementary Goals

Figure 2. Example of modal shift within road safety strategies. (**a**) London Vision Zero Action Plan [62], (**b**) San Francisco Vision Zero Action Strategy [60].

4.5. Strengths and Limitations

Given the lack of previous studies in Australia, this paper is a milestone document that contrasts differences in safety risk by the various modes of travel for the nine transportation modes under investigation. This study has quantified the risks of fatal and/or serious injury outcomes for the most common travel modes in Victoria and is believed to be one of the first studies to use the three different exposure measures used here. The exposure data were obtained from the STOPS database within VISTA, which provided the amount of travel by each mode within a full journey and overcomes the limitations of having the overall trip exposure based only on the main mode of transport, as reported earlier [27] in previous studies. The study also involved matching public transport crash and serious injury data not captured previously by road injury data systems. Such an approach enabled better estimates of injury risks when travelling by public transport. The rates from this study can be further developed to be used in journey planning apps to quantify risk differences in various journey options where safety can be used as an attribute in modal choice decision making.

This study, however, has limitations related to the data available for analysis. Matching across different databases inevitably requires assumptions, many of which being difficult to validate. In addition, the comparisons could not account for differences in land use and road condition by travel mode. Subject to data availability, future studies could examine specific routes to enrich the aggregated results from this study to evaluate the change in risk rates under the influence of road condition variables. Speed differences in comparing different modes of travel, especially within a specific mode (i.e., car travel), could not be controlled for as these data are not available. Finally, serious injury data related to pedestrian, cyclist and motorcyclists are likely to be under-reported in this study since more accurate data were not available from hospitalised databases for use in this study [64].

5. Conclusions

This study aimed to identify the safety performance of different travel modes using an expanded set of road safety risk indicators. Quantifying risk differences by different exposure metrics can assist in decision making. If a travel mode has a high risk but only accounts for a small number of casualties, then, even if an intervention substantially reduces the risk, the reduction in the number of casualties will still be small. Nevertheless, the benefit to the high-risk individuals in a particular travel mode (e.g., motorcycling) and the extent of trauma in this travel mode may still justify intervention to prioritise safety investment [8,9,38,62]. As noted, while absolute numbers of fatalities and serious injuries are widely used as road safety indicators, these only show the extent of the injury and do not account for the risk of injury. Risk is usually determined with respect to some measure of exposure (i.e., the likelihood of being injured relative to various work or home environments). In transportation, the injury risk can be determined against a range of different exposure indices, providing a better understanding of the relative safety of different travel modes. The results help in understanding the road safety outcomes from different scenarios of modal shift and change. By focusing more attention on measures which improve safety, health and environmental outcomes, the increased synergy between initiatives will lead to more sustainable system that achieve combined social, economic and environmental targets.

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