Road Safety Evidence Review

Understanding the role of Speeding and Speed in Serious Crash Trauma: A Case Study of New Zealand

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Key Findings

- Speeding is substantially under-estimated as a factor in serious crashes in New Zealand's crash data, and elsewhere
- Under-reporting of speeding in crashes contributes to under-appreciation of speeding risk by media, community and decision-makers
- Combining data sources indicates that speeding is involved in around 60% of fatal crashes in New Zealand
- Speeding kills more people each year in New Zealand than homicides
- Different data sources on speed and crashes appear inconsistent because they address different questions

Abstract

Multiple sources of evidence address the contribution of speed and speeding in crashes: police crash reports, in-depth crash investigations, studies of speed and serious crash risk, assessments of survival and injury rates for various impact speeds, and evaluations of the safety outcomes of speed management interventions. These sources of evidence all indicate that speed is a major factor in crash trauma, but appear to differ in estimates of the extent of the role of speed. This paper employs New Zealand as a country case study, undertaking a targeted assessment of data from the different sources to better determine the roles of speed and speeding in serious crashes. We find that apparent mismatches of estimates of the role of speed from different sources largely arise for two reasons. First, the studies vary in methodology and thus validity, and second the data from the different sources provide answers to fundamentally different questions, which are then incorrectly subsumed into the general question of the role of speed. Finally, we answer the question: 'What is the extent of the role of speed in crashes, and particularly deaths and serious injuries?' by providing answers to the different ways of couching these questions. Depending on the question, correct answers range from 20% to 100% of serious crashes. By combining evidence from different sources, we estimate that speeding is involved in around 60% of fatal crashes in New Zealand, and that speeds above New Zealand's Safe and Appropriate Speeds are involved in around 71% of injury crashes.

Keywords

Speeding, Under-reporting of speeding, Speeding and crashes, Speed and crashes, Speed and injury, Speed management

Introduction

Speed is fundamental to road safety, with many sources of evidence pointing to the profound role of speed in road crashes, injuries, and deaths. The nine key sources of evidence identified and considered in this paper are: (1) Analyses of the probability of survival for different impact speeds for various road users (pedestrians, vehicle occupants); (2) Meta-analyses of the relationships between average travel speeds and fatal, injury, and crash occurrences; (3) Evaluations of speed management interventions in terms of lives, injuries and crashes saved; (4) Analyses of Police based crash data; (5) In-depth crash investigations; (6) Application of safe system principles;

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(7) Application of 'Safe and Appropriate Speeds' or similar policy positions; (8) Naturalistic Driving Studies; and (9) Combined data sources. The purposes of this paper are to:

1. Review these sources of evidence in order to estimate the role of speed in road safety. New Zealand is employed as a case study in order to allow comparison of data from different sources (along with collection of additional data) for the one country. For issues where data are not available directly for New Zealand, the applicability of evidence from elsewhere is considered and employed when suitable, with the rationale for applicability provided. In the absence of a focus on a single country or state, differences in estimates of the role of speed may simply reflect real differences between the various countries from which the data were collected.
2. In addition, it is worthwhile to consider the extent to which the expansive global body of evidence applies to a particular country, because the claim from each country that they are unique and thus somehow the evidence on the importance of speed does not apply to them is ubiquitous: Such claims are common in discussions of road safety in many countries including from Ministers at the Third Global Ministerial Conference on Road Safety, Stockholm 2020 (and for discussion see Delaney, Ward, Cameron & Williams, 2005; Shoukrallah, 2008; Turner, Job & Mitra, 2021, p.4-5).
3. It is important to appreciate the role of speed in serious crashes, not just the role of speeding. This review and analysis considers both speed and speeding. For this purpose, these terms are explicitly defined.

Speeding is taken here to refer to travelling at a speed above the legal limit, including limits which may apply to the particular driver (such as a learner driver) or vehicle (such as a truck or bus). In some countries the offence of speeding may also apply for driving at a speed which is excessive for the conditions. This is not a point of focus in the present paper because police in many countries, including New Zealand, have informed us (personal communication) that this is quite rare or never applied, though other charges may be applied. Speed refers simply to the occurrence of movement measures as distance/time, such as kilometres per hour (kmh). Thus, analyses of the role of speed in crashes relate to changes in risk with changes in speed independent of the speed limit.

Ongoing challenges in the management of speed for road safety are the primary reasons for undertaking this review and analysis. First, speed management is the most contested area of road safety policy and practice (Mooren, Grzebieta & Job, 2014), with speeding identified as the most commonly disobeyed law (Grabar, 2021) and common media resistance to speed management (Litras & Spits, 2010, and in New Zealand, Matthew, 2019). Second, many effective evidence-based policy settings are established yet mostly not adopted, including speed limiting of vehicles or intelligent speed adaptation, speed limits set to safe speeds (Job & Sakashita, 2016; Wambulwa & Job, 2019) and effective use of speed enforcement (OECD, 2006; Job, 2018), including covert speed cameras (Keall, Povey & Frith, 2001). Third, it is vital to assess the various sources and the evidence they provide, because just one source (police based crash data) dominates both professional and media considerations of the role of speeding and often the role of speed as well (e.g., OECD, 2006; Grabar, 2021; and in New Zealand, Matthew, 2019). Finally, the diverse sources of evidence are rarely compared or combined, which may provide opportunities to advance our knowledge of the roles of speed and speeding in road trauma.

Multiple Roles of Speed in Crashes

Speed increases both the risk of a crash as well as its severity. Speed increases crash risk and severity through more mechanisms of action than are generally appreciated. The mechanisms are listed below, separated for effects on crash occurrence and crash severity:

Crash occurrence:

1. As speed increases so too does the distance the vehicle travels in the time the driver (henceforth including rider) takes to see a problem ahead, judge what to do, and react (e.g., brake to a stop), because the vehicle is traveling faster for that available time. Thus, the vehicle is closer to any problem situation identified even before the driver has judged the need to stop and moved to brake;
2. Once the brakes are applied the vehicle takes longer to stop from higher speeds;
3. The driver is less likely to see a hazard in a busy road environment when traveling at higher speed simply because the driver has less time to scan the environment on approach;
4. Drivers may be less inclined to stop and give way when they are travelling at higher speeds due to increased braking and then acceleration afterwards required to return to their original speed. Research shows a linear relationship between driver approach speed and failing to yield to pedestrians at unsignalized crosswalks: at 20 mph around 75% of drivers yield, but at just 10 mph higher speed only 40% of drivers yield to pedestrians (Bertulis & Dulaski, 2014).
5. At night even moderate speed in a poorly lit urban environment can mean the vehicle is travelling at a speed which results in a combined judgement, reaction time, and stopping distance that make it impossible to stop within the distance illuminated by the headlights. Thus, a crash with a pedestrian on the

road or hazard may be unavoidable by the time it is visible (for example, see Grzebieta 2019);

6. At higher speed the driver is less able to manoeuvre and stay in control of the vehicle to get around a problem and avoid a crash;
7. At higher speed the vehicle is less able to negotiate a curve or corner without losing control and running off the road or crossing to the wrong side of the road, risking a head on crash. This is not a rare form of head on crash on rural roads, with studies of head-on crashes showing that curves are associated with more head-on crashes (e.g., Hosseinpour, Yahaya, & Sadullah, 2014), and that head-on crashes are mostly not associated with overtaking (which was involved in less than 8% of head on crashes even on rural roads, with these crashes more commonly caused by driving 'too fast for the conditions': Garder, 2006). The figure is similar for New Zealand with only 7% of overtaking fatal and serious injury crashes involving overtaking (New Zealand Transport Agency Waka Kotahi, 2011).
8. Higher speeds reduce the time from when a risk becomes visible to the driver to when evasive action is required, based on the topography of the road. For example, the speed limit may be low because of curves limiting vision for intersections or junctions just beyond the curve and thus the speed limit is set to allow enough time for entering or crossing drivers (or pedestrians) to do so safely in the time they have before a vehicle which is just out of view behind the curve would reach them, and enough time for a vehicle travelling along the road with the curve to see, judge, and stop. However, a speeding vehicle can reach the intersection too quickly causing a crash. The same logic applies to other road features such as crests of hills which limit vision ahead;
9. Even if in view, other road users may reasonably expect an approaching vehicle to take a certain time to reach them at the prevailing speed limit allowing them time to cross, yet a speeding vehicle may reach them sooner. (This is especially true for older pedestrians who tend to (miss)judge a safe crossing gap by the distance to the approaching vehicle more than the speed of the vehicle: Job, Haynes, Prabhakar, Lee, & Quach, 1998).

Crash severity:

10. The higher the speed the higher the energy and thus the forces in a crash. Speed is the toxin in crashes, with higher speeds delivering exponentially more energy into the crash (IIHS, n.d.). Speed has this especially powerful (exponential) effects on crash severity because the kinetic energy of a vehicle is not just proportional to its speed but to the square of its speed or velocity. For example, when impact speed increases from 30 to 50 kmh (a 67 percent increase), the energy increases by 178 percent. ;
11. Safety features of the road, such as crash barriers, are located, designed and built to provide protection up to the speed limit (New Zealand Transport Agency Waka Kotahi, 2021), but may become ineffective if hit at speeds above the limit. Thus, as speed increases road features designed to manage crash forces and/or prevent the vehicle from a more severe crash – for example over a cliff or into oncoming traffic (such as crash barriers, medians, and impact attenuators) are less able to perform their safety function effectively. It is no simple matter to build all barriers, medians, etc. to withstand high speeds: this costs more limiting funds available for other road safety work, and may not be possible with the space available on many roads.
12. As speed increases active vehicle safety features such as automatous braking are less able to stop in time to avoid a crash or less able to reduce speed to safe levels of impact by the time the impact occurs;
13. As speed increases, the passive protective features of vehicles are increasing likely to fail: the integrity of the vehicle body may fail crushing the occupants and leaving little survival room; restraint systems (i.e., airbags, seat belts) may be unable to minimize higher levels of force sufficiently to avoid severe injury or death.

Applying the Evidence on Speed and Speeding to New Zealand

This paper presents a case study of New Zealand, which like all countries, has a particular combination of features and challenges in relation to road safety. The uniqueness of countries and regions is often asserted as a reason for not adopting evidence on road safety from other countries (see Turner et al., 2021). There is clearly a case for not simply generalizing the processes which delivered road safety from other countries to New Zealand in instances such as messaging for attitude change which are highly reliant on existing social values, beliefs, and religions. Thus, distinctiveness, local attitudes and existing beliefs must be considered in applying some aspects of speed management. On the other hand evidence from various country has regularly been applied successfully in other countries including New Zealand, including the successes of speed cameras and speed managing infrastructure (Delaney at al., 2005; Turner et al., 2021; Wilson et al., 2010).

In road safety we have more in common than we have that distinguishes us. This is especially true for many but not all elements of speed and road safety. Most critically, the universal laws of physics, the universal vulnerability of the human body to force, and the similarity of human reaction times, mean that the toxic exponential effects of speed on crash risk and crash severity apply the same way in all countries. Thus, universally with other things being equal, higher speeds increase both crash risk and severity and interventions which reduce speeds will reduce

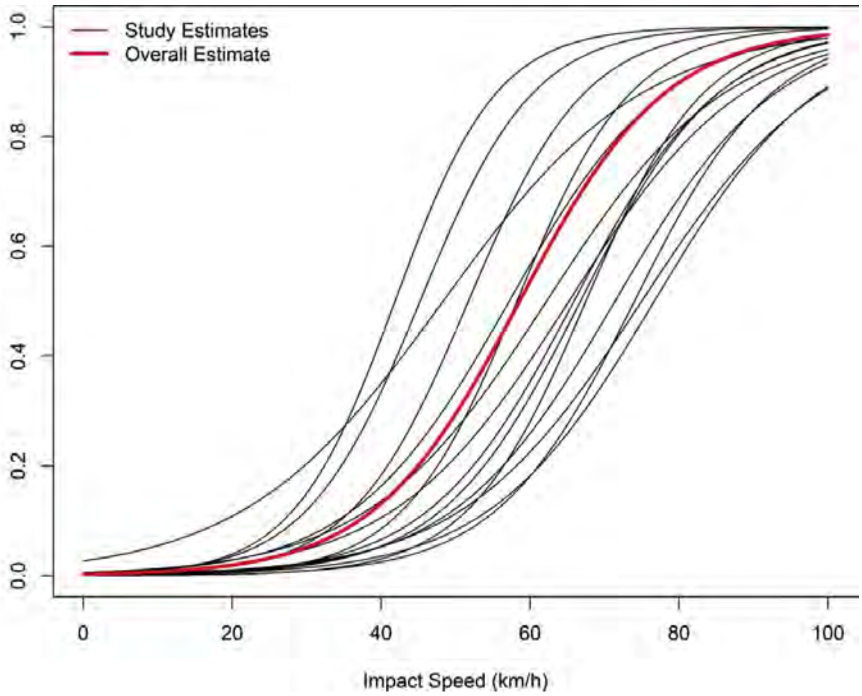

Fig. 5. Plot for S-shaped curves for pedestrian fatality risk by impact speed.

Figure 1. The relationship between pedestrian death risk and the impact speed of vehicles (Source: Hussain et al., 2019)

fatal and serious injury crashes. For this reason, research findings on the effects of speed are especially transferable from one country to another, with an appreciation of some differences in consequence. For example, older cars and those with less effective passive safety (effective seatbelts, effective and fullest set of airbags, etc.) will have lower New Car Assessment Program safety star ratings and will allow severe injuries at lower impact speeds than the best safety rated cars (Van Ratingen et al., 2016). Vehicle fleet age is relevant for New Zealand, because the average age of the fleet is older than many of the high-income countries in which relevant research has been conducted (in New Zealand 14.4 years versus USA 11.6 years, Australia 10.1 years, Europe 7.4 years: Ministry of Transport, 2020). Thus, if anything, severe injuries may occur at slightly lower speeds in New Zealand due to slightly less protection afforded by the vehicles.

Sources of Evidence on the Role of Speed

In addition to the fundamental laws of physics, an expansive and irrefutable body of evidence exists showing the critical role of speed in both crash occurrence and severity (for reviews and meta-analyses see: Elvik, Vadeby, Hels, & van Shagen, 2019; Global Road Safety Partnership, 2008; Job & Sakashita, 2016; Nilsson, 2004; OECD, 2006; Turner, Job, & Mitra, 2021; Wilson, Willis, Hendrikz, Le Brocque, & Bellamy, 2010; World Health Organization, 2017). For studies of New Zealand see Accident Rehabilitation & Compensation Insurance Corporation & Land Transport Safety Authority (New Zealand) (2000), Keall, Povey & Frith (2001), and Makwasha & Turner, (2013). This includes several different approaches to determining the role of speed, each of which is described and briefly reviewed in this section.

Source 1: Analyses of the probability of survival for different impact speeds for various road user types (pedestrians, vehicle occupants) and for different crash configurations

Impact speed refers to the speed of the vehicle (relative to the person or object struck) at the instant of collision.

Data from New Zealand: Several meta-analyses of probability of death for each impact speed have been undertaken. These meta-analyses require the data from many studies combined to produce the best global estimates. Thus, there are no such meta-analyses for New Zealand per se, and the 15 studies accepted as methodologically rigorous by Hussain, Feng, Grzebieta, Brijs & Olivier (2019) the most recent of these studies, do not include any from New Zealand. However, because (1) the laws of physics apply in every country, (2) human bodies have similar frailties across the globe, and (3) these data do not involve social/psychological aspects (which do vary across countries in relation to speed and safety) we can be confident that these findings apply in New Zealand.

In addition, the countries covered in the 15 studies employed by Hussain et al. (China, Germany, Japan, Korea, UK, and USA) represent a range of vehicle fleets. In addition, the analysis of speed and serious injury risk by Jurewicz, Sobhani, Woolley, Dutschke & Corben (2016) does focus on Australia and New Zealand.

The initial analysis of fatality probability by impact speed was presented by Wramborg (2005) and is commonly reproduced (e.g., Global Road Safety Partnership, 2008). More recently, Hussain et al. (2019) reported a more exacting analysis including studies undertaken since Wramborg's analysis. Their curve for pedestrian impact crashes (reproduced in Figure 1) show a highly similar shape to that of Wramborg, but the curve is slightly shifted to higher speeds for the same fatality risk. These curves highlight the vital role of speed, with dramatic increases in risk of death as impact speeds increase. For example, Hussain et al. (2019) found that each 1km increase in impact speed produced an 11 percent increase in the likelihood of a pedestrian fatality and a 7% increase for serious injury. Jurewicz et al.'s (2016) analysis of serious injury risk and impact speed reveals a similarly powerful effect of speed on risk. Finally, a recent study by Doecke, Baldock, Kloeden & Dutschke (2020) accessed more current technology to assess the speed- serious injury relationship, employing speed data from vehicle event data recorders from crash involved vehicles. This study confirmed the powerful effects of speed on the risk of serious injury.

Source 2: Meta-analyses of the relationships between average travel speeds and fatal, injury, and crash probabilities

Many studies allow an assessment of the relationship between mean speeds of travel and outcomes: reported crashes, injuries, and deaths. These individual studies may cover changes in speed and safety with meta-analyses of many studies allowing more reliable identification of the speed-safety relationships across a large range of speeds. As in Source 1, shared human physical vulnerability to force and the laws of physics mean that these findings apply in New Zealand. In addition, the countries covered in these meta-analyses are wider because relevant studies have been reported from more countries, including research from New Zealand, for example in Elvik's analyses considered below.

Nilsson reported the first detailed meta-analysis of the relationship between changes in speed and fatal, serious injury and all injury crashes, based on many international studies. Subsequent re-analyses and follow-up research evaluations led by Elvik validate these fundamental influences of speed on safety, including finding that the effects of speed are even stronger than indicated in Nilsson's initial research (Elvik, 2013; Elvik et al., 2009; Elvik et al., 2019), though the effects of speed may be larger on rural roads than in urban environments (Cameron & Elvik, 2010). The best fit for the relationship between speed and serious crash risk appears to be exponential across the full range of speed changes.

These meta-analyses show the power of small changes in speed in producing powerful changes in crash trauma. Changes in speed has even greater impacts on higher severity crash outcomes with small changes in speed having dramatic impacts on fatal outcomes; each 1% increase in travel speed results in around a 4% increase in deaths. The most critical refinement of these estimates from Elvik's comprehensive analyses is that the nature of the mean change in speed matters- that is, the way the distribution of speeds changes matters. Elvik (2019) showed that, for example, if the mean speed change is largely due to reducing the speeds of the higher level speeders then the safety value is substantially greater. This is particularly important, because this is exactly what speed cameras tend to achieve (see Elvik 2019; Montella, Imbriani, Marzano, & Mauriello, 2015 also found reduced variance in speeds with speed cameras; and in New Zealand, Keall, Povey & Frith, 2001 found greater reductions in higher level speeds with more effective speed enforcement). Finally, these meta-analyses consistently show more powerful effects of speed on more serious crashes (fatal, to injury to non-injury) establishing the importance of speed for both crash severity and crash occurrence. However, the exact extent of the role of speed in occurrence is difficult to determine, because the research is based on reported crashes and crash severity influences the probability that a crash will be reported (see Hauer, 2006).

Source 3: Evaluations of speed management interventions in terms of lives, injuries and crashes saved

Many evaluations have been reported of the speed and safety effects of different types of speed cameras, other interventions to promote general deterrence of speeding (such as campaigns and changes in penalties or processes) various forms of road engineering to reduce speeds, lower speed limits, and vehicle based technologies to manage speed (Delaney et al., 2005; and for reviews see Turner et al, 2021; Wilson et al., 2010).

Several relevant studies have been undertaken in New Zealand, and are reviewed here. For example, Makwasha & Turner (2013) evaluated the implementation of gateway treatments designed to slow traffic entering urban areas. They found a statistically significant 23% reduction in serious outcome crashes due to the gateways. However, they do not report the exact level of speed reduction. Thus, it is not possible to determine the speed-crash relationship from this study. For the purpose of assessing the power of speed in determining safety outcomes, the most relevant examples for New Zealand include measures of speeds as well as safety outcomes.

Keall, Povey & Frith (2001) included comprehensive measures of changes in speed, crashes, injuries, and deaths in evaluating the addition of covert mobile speed camera enforcement to ongoing high visibility mobile camera enforcement. Two sets of results allow examination of the power of speed in changing crash outcomes in New Zealand. First, the effects of covert enforcement were evaluated over the rural road network of the region being treated. Results showed a 1.6kmh (also a 1.6% reduction) net speed reduction which produced a net 19% reduction in casualties (injuries and deaths). According to Nilsson's relationship this speed reduction will generate a 5% to 6% reduction in deaths and serious injuries combined. Keall et al. also assessed effects at camera enforcement locations, finding a 3.1kmh (3.2%) net reduction in speed resulting in a 29% reduction in casualties. Nilsson's relationship suggests an 11% to 12% reduction in casualties. Thus, in both cases, if New Zealand is to be considered different, these results indicate that speed matters even more to road safety in New Zealand than the global findings. However, Keall et al. found that higher level speeds were reduced more than mean speeds (evident from larger reductions in 85th percentile and higher percentile speeds than in mean speeds). As noted earlier, Elvik's (2019) more detailed analysis of distributions of speeds shows that this pattern should produce a stronger safety benefits. Keall et al's results are consistent with this pattern, though even with the adjustment for the larger reduction in high level speeds, these results in New Zealand suggest an especially powerful role for speed in crash trauma.

A strong evaluation was also conducted of the implementation of traffic activated variable speed limit signs at 10 intersections in New Zealand (Mackie, Brodie, Scott, Hirsch, Tate, Russell & Holst, 2017). In this intervention traffic on side roads joining main roads was electronically detected on approach, and the variable speed limit signs on the main road were activated reducing the speed limit to 70kmh. This reduced speeds by around 7-9kmh on average and this resulted in a dramatic reduction in crash trauma: fatal and serious injury crashes were reduced in net by 79% and total crashes by 51%. This study included control intersections and the (much smaller) reductions in crashes at those locations were subtracted from the total reductions at the treated intersections to control for any general improvement effects. The authors conclude that these safety gains are so large that they indicate other benefits of the treatment beyond speed reductions, such as increased alertness. Based on meta-analyses of speed-crash relationships, just under a 50% reduction in fatal crash might be expected with slightly less reduction for serious injury crashes. An added beneficial effects such as alertness (Mackie et al., 2017) is not an unreasonable speculation. However, there is no direct evidence for this account, leaving open the possibility that these large benefits are simply due to speed being a key factor in intersection crashes in high speed limit zones (in New Zealand).

Source 4: Analyses of Police based crash data

Perhaps the most obvious readily available and most used in the media (e.g., Margeit, 2021; Matthew, 2019; Meredith, 2017) source of data on the role of speed in crash trauma are crash data, which in New Zealand and almost everywhere arise from Police reports of crashes. This relates specifically to the role of speeding (travelling at a speed above the legal limit). Typically, police estimated data on the involvement of speeding in crashes increase in proportion from property damage only crashes to injury crashes, and rise again for fatal crashes. For serious injury and fatal crashes, the proportion for which speeding is identified as a factor typically ranges around 20% to 35% across countries and states (for example: IRTAD, 2019; Michigan Department of State Police, 2013). One of the clearest signs that there is something wrong with these statistics comes directly from police themselves: In Brazil official statistics are in the usual 20-35% range for speeding in fatal crashes, yet police officers report that believe that the real number is around 80% (Job, Lancelot, Gauthier, de Melo e Silva, Howard, Ledesma & Carneiro, 2015). In NSW, the under-reporting of speeding in fatal crashes is so well recognized by the NSW Centre for Road Safety and NSW Police that added criteria are employed at the stage of data entry to identify speeding in crashes with the aim of at least partly correcting this under-reporting (NSW Centre for Road Safety, 2017). Thus, official crash statistics in the state of New South Wales (NSW) provide a higher proportional involvement of speed– usually around 40% (NSW Centre for Road Safety, 2012, 2020). Recognition of under-reporting of speeding as a crash factor goes beyond police, with commentaries highlighting

Table 1: The role of speeding in crashes arising from Police-based crash data by severity in New Zealand, and in Auckland (Sources: Present analysis of 5 years of crash data in New Zealand: 2016-2020). Note: These numbers are corrected later and should not be taken as a guide to the role of speed

Crash Severity	% involving speeding from Police-based crash data New Zealand	% involving speeding from Police-based crash data Auckland
Fatal Crash	29.7	36.4
Serious Injury Crash	20.6	19.6
Minor Injury Crash	16.4	16.0
Non-injury	12.4	10.2
All reported crashes	14.0	12.0

the issue (Job, 2020) and data demonstrating the problem (Doecke, & Kloeden, 2014).

New Zealand is experiencing exactly the same situation: Police report-based crash statistics indicate speeding is a factor in a typical cascading sequence of more involvement in more serious crashes (see Table 1). Auckland is considered on its own, due to indications that the influence of speed in crash occurrence and severity may not be as powerful in urban environments as it is on rural roads (Cameron & Elvik, 2010). New Zealand Police officers have informed the authors (personal communications) that speeding is substantially under-represented in the data compared with reality. This is explored further later in this paper.

Source 5: In-depth crash investigations

In-depth crash investigations, including crash reconstruction, allow more comprehensive processes for determining the role of different factors in a crash than can be identified by police in 'normal' crash investigation processes, including more accurate determination of the role of speed (Grzebieta, Rechnitzer & McIntosh, 2013). Such investigations are beyond the scope of normal police investigations (Doecke, & Kloeden, 2014), as well as beyond levels of resourcing available for Police. In reality there may be three levels of crash investigation: the initial assessment and crash data recording by Police normally at the crash scene soon after the crash; a further more detailed investigation by Police for certain serious crashes; and a comprehensive in-depth investigation/reconstruction undertaken for research purposes or for legal cases (Grzebieta, 2019; Grzebieta et al., 2013).

Several relevant in-depth crash investigation studies have been reported by the Centre for Automotive Safety Research. Two studies employed in depth analysis of crashes in urban and in rural environments to more accurately determine the role of speed including comparisons with speeds of control (non-crash involved) vehicles travelling through the crash locations (Kloeden, McLean & Glonek, 2002; Kloeden, Ponte & McLean, 2001). These studies both revealed powerful effects of speed. For example, in the urban environment traveling just 5kmh above the speed limit resulted in a doubling of serious (injury or fatal) crash risk.

Doecke & Kloeden (2014) employed evidence on the role of speeding in 144 crashes which occurred in South Australia obtained from crash reconstructions to validate (or not) the recording of speeding as a factor in crashes applying the methods employed in NSW, and standard reporting processes based on police reports of contributing errors. They found that speeding (the error of 'excessive speed') as recorded according to the NSW criteria lacked strong accuracy in identifying crashes where a vehicle was speeding. However, this method was more accurate than simply relying on speeding as recorded based on Police reporting. Thus, crash investigations shows that Police reporting for exceeding the speed limit is poor, but other simple methods applied when entering data are better for overall representation of the proportion of crashes which involve speeding, but are not strongly accurate for individual crashes.

This important and rare study also highlights the alarming level of under-reporting in Police data. Based on calculations from the raw data provided in the paper, the traditional data recording based on police identifying speeding as contributing to the crash resulted in an under-estimate of speeding as factor by 94.9%. While accuracy on a crash by crash bases was still weak, the NSW method resulted in a much closer match on actual proportion of crashes involving speeding, though still with an under-estimate of 10.3%. The generalizability of this study is limited by the representativeness of the crashes investigated. However, it nonetheless highlights the high level of under-reporting of speeding in police crash reports.

Finally, in Thailand, an in-depth crash investigation study found that 68% of crashes investigated involved speeding-much higher than expected from police data (Klinjun, Kelly, Praditsathaporn & Petsirasan, 2021).

Source 6: Application of safe system principles

Safe System principles (sometimes also called Vision Zero) include the vision of (and mechanisms for achieving) zero road deaths and serious injuries (for details see: Belin, 2016; Job, 2017; Larsson, Dekker & Tingvall, 2010). These principles are the basis of influential global road safety strategies and guides (Bliss & Breen, 2013; ITF, 2016; OECD, 2006; Wambulwa & Job, 2019), including both the 2011-2020 and the 2021-2030 global plans developed by the United Nations and the World Health Organization (WHO, 2011; WHO & United Nations Regional Commissions, 2021); and are demonstrably successful in Sweden (Belin, 2016) and beyond (Marsh, De Roos & Webster, 2016; Mooren, Grzebieta, Job &Williamson, 2011). Safe System has been adopted repeatedly by the New Zealand Government in road safety strategies (New Zealand Government, 2019; Ministry of Transport, 2010).

Fundamental within the safe system principles is that road safety will never be solved by expecting imperfect people to behave perfectly on the road: humans make mistakes, and should not die for momentary lapses of concentration or misjudgements. Thus, the forces to which the human body is exposed in the event of a crash must be managed down to level which are survivable. If the roads and roadsides (barriers, etc.) combined with the level of protection offered by vehicles cannot manage the forces down to this level, then the speed is too high for safe system. As a guide safe system principles indicate speed limits and operating speeds to be achieved to deliver safe system (30kmh to protect pedestrians, cyclists, and motorcyclists; 50kmh where side impact crashes are possible; and, 70kmh where head-on crashes are possible: for example, in New Zealand, see Frith, 2012). However, more fundamentally, the principles indicate that wherever a death or serious injury occurs by default the speeds involved in the crash were too high for the level of crash force and the force mitigation (protection) available in the crash. Thus, application of the safe system principles dictates that speed is a contributing factor in all deaths and serious injuries. This position is often explicitly articulated: "Speed is a contributing factor in all RTAs [road traffic accidents]." (Moore, 2020); or stated as speed being a factor in severity of all crashes (OECD, 2006); including by experts in New Zealand: "The speed component of a Safe System involves the development of road typologies to eliminate fatal and serious injury crashes by avoiding speeds above critical thresholds." (Frith, 2012).

Source 7: Application of 'Safe and Appropriate Speeds'

New Zealand's current and previous road safety strategies adopt safe system principles with the ultimate aim of delivering zero deaths. As part of the journey to this objective, New Zealand has identified 'Safe and Appropriate Speeds' for the road network determined using the New Zealand Speed Management Guide (New Zealand Transport Agency Waka Kotahi, 2016). Analyses identify that 87% of the country's road network has speeds which do not match the safe and appropriate limits, with 86% having limits higher than the safe and appropriate levels (Ministry of Transport, 2019; New Zealand Government, 2019). In this respect, New Zealand's approach aligns with most high income countries on speed limits, with the best performing road safety countries increasingly adopting 30kmh urban limits to protect vulnerable road users though with 50kmh limits on some urban roads, and rural limits which increasingly approach safe system levels (Weijermars & Wegman, 2011).

With the above information and data on the distributions of travel speeds relative to speed limits in New Zealand, it is possible to estimate the proportion of fatal and serious injury crashes which involve speeds which are above safe and appropriate speeds. This can be achieved by determining what proportions of drivers are travelling at speeds above or within Safe and Appropriate Speeds.

The Steps below and Table 2 show how this can be done for the three different road groups based on Safe and Appropriate Speeds. The calculations for each step are presented in Table 2.

Step 1- Define the driving speeds which are above or within the Safe and Appropriate Speed, for the roads: This is achieved by determining the difference between the speed limit and the Safe and Appropriate Speed, and by considering those who are speeding by amounts which would be above the Safe and Appropriate Speeds. As a conservative (conservative here means making estimates which are more likely to under-estimate the crash risk contributed by driving above the safe and appropriate speed, rather than over-estimate it) guide to the difference between existing speed limits and safe and appropriate limits, for the 86% of roads where the limit is higher than the Safe and Appropriate level, the lowest possible difference is 10kmh (because speed limits are set in 10kmh increments). For any cases where the prevailing limit is 20kmh or more above the safe and appropriate speed, the present calculations will be highly conservative. We also assume on a similar basis that for the small proportion for roads (1%) with limits below the safe and appropriate levels, the limit is 10kmh below the safe and appropriate level.

Step 2 - Determine the proportions of drivers travelling in relevant categories of speeding or at speeds below the limit: To achieve this we must estimate the distribution of travel speeds relative to the limit in New Zealand, for which we have two sources. The first source is Mackie et al. (2017, Figure 4) for the 70kmh limit (in 2016 when the changes have had time to settle in for motorists) noting that this does not assume that 70kmh is above the safe and appropriate speed, but rather uses the distribution of actual speeds as a guide to travel speeds relative to speed limits in New Zealand. This distribution indicates that around 48% of drivers are above the limit of 70kmh averaging (conservatively) around 75kmh, a further 42% are travelling between 61 and 70kmh averaging around 66kmh, with the remaining approximately 10% travelling at or below 60kmh, averaging conservatively around 58kmh. The second source is additional analyses undertaken for this paper of speed surveys on New Zealand Roads from 2014 and 2015 (the latest available). These indicate that the proportion of vehicles above the speed limit, averaged for rural and urban roads, is 40%, slightly lower than in the distribution from Mackie. These surveys also show that 2.5% of drivers are exceeding the speed limit by more than 10kmh, while Mackie's data indicate a higher percentage. Because the speed surveys are more representative with both urban and rural roads, and because the distribution from Mackie is for a variable speed limit sign which is not typical, these are adopted, the calculations below are based on the present analysis of New Zealand speed surveys. Thus, the following relevant percentage of travel speeds are adopted: (1) 2.5% of drivers are exceeding the speed limit by more than 10kmh, (2) 40% of drivers are above the speed limit (including those exceeding by more than 10kmh), (3) 50% are within 10km below the speed limit, and (4) 10% are below the speed limit by 10kmh or more.

Step 3- Determine the relative speeds of each of the categories of speed which are above the Safe and Appropriate Speed: This is achieved by calculating the percentage difference in speed from the speed limit. From the detail of Mackie's speed distributions and the speed survey distributions from the 2014 and 2015 speed surveys we are able to estimate the mean difference between the speeds of each of these categories of travel speed and the speed limit (taken as a base for risk). Those exceeding the limit by over 10kmh are averaging 14kmh above the speed limit, those above the speed limit are averaging 6kmh above the average, those within 10km below the speed limit are averaging 4kmh below the limit, and those below the speed limit by 10kmh or more are averaging 12kmh below the limit. As an average to represent rural and urban speed limits, a limit of 70kmh is adopted for these calculations. Thus, those exceeding the limit by over 10kmh are averaging 20% above the speed limit, those above the speed limit are averaging 9% above the average, and those within 10km below the speed limit are averaging 6% below the limit.

Step 4- Calculate the relative serious crash risk of each of these categories of speed, above and below the Safe and Appropriate Speed: This is achieved by applying the evidence from Source 2 (Meta-analyses of speed and crash risk) to the percentage differences in speed calculated at Step 3.

Applying the estimated increase in fatal and serious injury crashes risk from the wealth of data in Source 2 above (each 1% increase in speed results in 3.5% increase in serious crash risk) means that those travelling 20% above the limit have an average risk per vehicle which is 70% (20% times 3.5% increase in risk) higher than if travelling at the speed limit. These calculations, all made by apply the 3.5% for each percentage difference, are presented in Table 2.

Step 5- Assign the relative risks calculated at Step 3 to the proportions of drivers in each speed category: This amounts to determining net risk by combining exposure (proportion of drivers) and risk (relative crash risk determined by differences in travel speed).

Step 6- Calculate contribution to injury crashes: This is calculated by distributing net risk for each category of drivers above the Safe and Appropriate Speed to the known contribution to serious crashes for each category of road. The distributions of injury crashes on the three categories of road are: 50.7% on roads with speed limits above the Safe and Appropriate Speed, 45.7% on roads with speed limits equal to the Safe and Appropriate Speed, and 3.6% on roads with speed limits below the Safe and Appropriate Speed (Ministry of Transport, 2019).

Step 7- Calculate the proportion of injury crashes contributed by drivers above the Safe and Appropriate Speed, but not speeding: One group of drivers are travelling at speeds above the Safe and Appropriate Speed but not speeding: The drivers travelling within the speed limit but not more than 10kmh below the limit on the roads for which the speed limit is above the Safe and Appropriate Speed. Their risk contribution is calculated in Table 2, last row.

A study in New Zealand by Mackie et al., (2017a) finds results which validate this analysis. Mackie et al. (2017a) investigated 100 fatal crashes and 200 serious injury crashes that occurred across 2015/16 to understand what system failures may have contributed to the crash and the severe outcomes. The analysis was based on safe system boundary conditions, some of which were derived for similar assessments in Sweden (Stigson, 2011) and South Australia (Wundersitz, 2014). For speed the triggers for system failure were that the travel speed or the speed limit were above the recognised Safe and Appropriate Speed for the road, the travel speed was above the advisory speed (typically for curves) or the section of road was identified as being a priority for speed management work. Based upon these criteria, Mackie et al. (2017a) found that the speed system failure contributed to the crash and outcomes in 75% of the fatal crashes and 70% of the serious injury crashes. It is noteworthy that speeding (exceeding the speed limit) or driving too fast for the conditions, were not included in these percentages, but were assigned to a behavioural failure category. Thus, with speeding adding more to these numbers, these percentages will be higher. With serious injuries being much more common than deaths, the average from Mackie's study will be slightly above 70%, compared with 71.8% from the present analysis. Thus, these two quite different sources of data provide well aligned answers.

Source 8: Naturalistic Driving Studies. In naturalistic driving studies cohorts of drivers agree to be continuously tracked with video and/or other recordings of their driving. Despite the value of these studies in many aspects of road safety, they are not reviewed in detail here, because few such studies exist assessing speeding and crash risk, and because of the methodological risks associated with drivers knowing they are being monitored and so possibly reducing their speeding and other behaviours. While these studies do show that people become used to the monitoring and appear to return to normal driving, the full extent of this return to how they would have driven without any monitoring is not established, because pre-monitoring behavioural records are not available.

Even with these limitations a clear relationship between speeding and increased crash risk is still observed in naturalistic driving studies (Kamrani, Arvin & Khattak, 2019). This finding is to be expected even within the noted limitations, because even if speeding is less common than it would otherwise be, the risk it brings remains. Thus, the methodological limitations do not influence the identification of a speeding-crash risk relationship, though the limitations do influence the estimation of speeding crash prevalence.

Other analyses of speed behaviour from naturalistic driving studies do not directly assess speed and crash risk of the drivers in the study, but employ the speeds chosen by drivers in the study to assess road features. For example,

Table 2: The logic for determining the proportion of drivers in various categories of speed above and below Safe and Appropriate Speeds

	Road for which the speed limit is above the Safe and Appropriate Speed	**Road for which the speed limit is equal to the Safe and Appropriate Speed**	**Road for which the speed limit is below the Safe and Appropriate Speed**
From Step 1: Speed cut off point defining Safe and Appropriate Speed	10kmh below the speed limit	The speed limit	10kmh above the speed limit
From Step 1: Defining those above the Safe and Appropriate Speed	Speeding Drivers + Drivers who are travelling within 10kmh of the limit	Speeding Drivers	Drivers speeding by at least 10kmh above the limit
From Step 2: Calculated % above and below the Safe and Appropriate Speed	40% + 50%	40%	2.5%
From Step 3: Average speeds of each of the categories of speed relative to speed limit, above and below the Safe and Appropriate Speed	40 at 9% higher speed + 50 at 6% lower speed	40 at 9% higher speed	2.5 at 20% higher speed
From Step 4- Calculate the relative serious crash risk of each of these categories of speed, above and below the Safe and Appropriate Speed	40 at 31.5% higher risk + 50 at 21% lower risk	40 at 31.5% higher risk	2.5 at 70% higher risk
From Step 5-Net risk determined by assigning relative risks calculated at Step 4 to the proportions of drivers in each speed category (= risk * exposure)	40*1.315= 52.6% of risk + 50*.79=39.5% of risk Total = 92.1% of risk	40*1.315= 52.6% of the total risk on these roads	2.5*1.70= 4.25% of the total risk on these roads
From Step 6- Contribution to injury crashes, determined by distributing net risk for each category of above or below the Safe and Appropriate Speed for the known contribution to serious crashes for each category of road	92.1% of the 50.7% of injury crashes = 47.6% of all injury crashes in NZ	52.6% of the 45.7% of injury crashes = 24.0% of all injury crashes in NZ	4.25% of the 3.6%% of injury crashes = 0.2% of all injury crashes in NZ
TOTAL of injury crashes in New Zealand contributed to by travel speeds above the Safe and Appropriate Speed for the road	47.6% + 24.0% + 0.2% = **71.8%**		
TOTAL of injury crashes in New Zealand contributed to by travel speeds above the Safe and Appropriate Speed by drivers not travelling above the speed limit.	50% of drivers on roads for which the speed limit is above the Safe and Appropriate Speed, with a risk 21% lower than the speed limit. 50% of drivers * .79 risk *50.7% of injury crashes = 20.0%		

Dhahir & Hassan (2019) used this method and found that the speed reduction parameters of curves (assessed through the chosen speeds of drivers in the study) are more significant variables in predicting crash frequency than all curve geometric parameters. This adds weight to the vital importance of managing speed on curves which is more important than the risk features of the curves.

Apparently Inconsistent Results

The above eight sources of evidence on speed and speeding are not as directly comparable as they may appear to be (see below), but are commonly seen as indicating different levels of importance to speed (often misinterpreted as solely speeding) in road safety. For example, at the extreme ends Police-reported crash data indicate that speeding is involved in around 30% fatal crashes and 20% of serious injury crashes in New Zealand, while the estimate developed above indicates that 71% of fatal and serious injury crashes involve vehicles travelling above safe and appropriate speeds, whereas safe system principles produces a figure of 100% of serious crashes involve speed as a factor. Leaving aside small variations in the data collected within any of the different sources, there are two more fundamental reasons (each reviewed below) for the apparently different answers derived from the different sources:

1. The results from these data sources are influenced by methodological issues and the quality of data available
2. These data sources really address different questions, yet these different questions have gone almost entirely unnoticed, resulting in misinterpretations and use of the data to address core questions, for which the data are unsuitable.

Influences of Methodological Issues and Data Quality/Information Availability

Results of various sources are influenced by both methodological issues and fundamental data quality/availability.

Methodological issues

Several methodological issues can be expected to influence the speed-serious crash risk relationships observed. These have been considered elsewhere (Job submitted; Wilson et al, 2010) and so are only briefly considered here, for their implications for the present focus. Relevant methodological issues include: differences in in the definitions of a serious injury (for examples see Table 1 in Hussain et al., 2019); small numbers of for example fatal crashes due to small lengths of road included in studies allowing larger impacts of random variations; the absence of control groups or control locations (Job, submitted); the lack of comprehensive crash investigations/crash reconstructions noted above; confounding factors which may arise due to other road safety related changes during evaluations (see Keall et al., 2001 for an example which is likely to have caused on under-estimate of the benefits of the covert enforcement being evaluated in New Zealand); failures of other elements of deterrence, such as penalties which are insufficient to significantly deter, which will weaken the effects of speed enforcement (see Job, submitted); and some challenges with employing data from Event Data Recorders, as described below in the paper.

These are variations across studies, and not reasons to dismiss the breadth of evidence for the powerful role of speed in crash occurrence and outcomes. In addition, many systematic reviews and meta-analyses as cited above, control for such methodological factors by rigorously selecting the best studies, and find powerful effects of speed and speed management. The highly consistent finding, that speed is a powerful determiner of serious crash risk, cannot be explained by these variations. However, the range of findings in evaluations of speed enforcement appears to largely arise from these variations (Job, submitted). Without them, a smaller range of findings is logically expected.

Fundamental data quality/availability issues

Data quality and availability issues are most likely to apply to police-based crash data in New Zealand, and in every country. Most fundamentally, many even serious crashes are simply not recorded in police based crash systems or even in medical/health-based systems, with low-income countries missing 84% of deaths in their official data (Job & Wambulwa, 2020), and even high income countries missing many serious injury crashes from police based crash data systems (Watson, Watson & Vallmuur, 2015). Furthermore, the missing data reflect systematic biases to certain crashes types (those involving vulnerable road users, single vehicle crashes) and certain locations (remote and regional) being more likely to be omitted in police based crash data (Wambulwa & Job, 2019; Watson et al., 2015). These limitations of crash data systems also influence other forms of evaluation, and may result in an underestimate of the role of speeding in crashes if omitted crash types and locations are more likely to involve speeding than other crashes.

This is not a criticism of police, but rather and acknowledgement of the major challenges faced in their crash reporting task. For example, in a single vehicle crash on a remote road the driver may be motivated not to report the crash and risk penalties including loss of licence. For reported crashes, there are major challenges in attempting to determine the causes of a crash after the event, with limited resources available to police for most crashes and with most surviving drivers inevitably motivated to present their behaviour as lawful, rather than admitting to faults such as speeding. In the view of most motorists there is not a lot that a police officer can do to determine speeding at a crash scene, and indeed they are largely correct in this view. Of course, there are exceptions with independent witnesses, or for example a crash in which a modern car has hit a pole and torn in half in 50kmh zone clearly involved forces well beyond those possible from impact at 50kmh. However, police face an unenviable task when attending a fatal pedestrian crash where there are no uninvolved witnesses. The pedestrian is dead and thus unable to provide his/her account of events, whereas the driver is likely to be uninjured, though shocked, and able to provide his/her account. The driver is most unlikely to admit that he/she was speeding or distracted, and likely to claim that the pedestrian darted out (Job, 2020). While police may doubt the account, proving it wrong is deeply challenging, especially in countries which do not undertake detailed crash reconstruction. Without crash reconstruction which may uncover factors such as speeding the driver is unlikely to be charged and thus the crash will not be recorded as speeding. Many such crashes do involve speeding yet few will be recorded as such. In New Zealand, speed is reported as being a contributing factor in only 8% of pedestrian fatalities. Across the majority of attended crashes in New Zealand which do not involve a Serious Crash Analyst, speed will only be reported by police as a factor if it is obvious from the circumstances and/or there are witness or offender accounts to support speed as a factor. Thus, in many systems police may not report any known error factor or contributing factor for some even serious crashes, because it is not possible to determine these in without extensive crash reconstruction and even then the nature of the error (speeding, fatigue, distraction) cannot be determined in every case.

Finally, Police based databases may suffer from another source of missing speeding as a factor. In some cases of serious crashes identified by police as involving speeding, police may not charge the driver with speeding, preferring to apply a more serious charge such as ‘dangerous driving’ which may include driving a vehicle recklessly or at a speed or in a manner which is dangerous to the public (Doecke & Kloeden, 2014). Thus, because a ‘dangerous driving’ charge may or may not involve speeding, speeding may not be recorded as a factor in the database.

Source 9: Estimating the real role of speeding in crash causality by combining data sources to correct police based crash data

An important question arises from the above evidence that in crash databases, including in New Zealand, speeding (travelling at speeds above the limit) is missed as a factor in many crashes: This being the case, what is a best estimate of the real extent of speeding in crash causality in New Zealand? Note that this question is particular to crash causality, not the mechanisms of injury, which are almost universally not considered by police in crash reporting, with systems which do not have a formal variable or system/criteria for this, including in New Zealand.

Data from our analysis of 5 years of data from the New Zealand crash data system were provided in Table 1. As noted earlier, clear indications, including from New Zealand Police, are that the role of speeding in crashes is under-estimated. It is possible to make reasonable estimates of the extent of this under-reporting in New Zealand from several sources of related evidence. This may be achieved from two forms of analysis: (1) studies of the safety benefits of eliminating or greatly reducing speeding; (2) Crash investigation studies which employ more rigorous sources of data to determine the role of speeding, compared with police data on the role of speeding.

The safety benefits of eliminating or greatly reducing speeding: The best was to determine the role of a particular causal factor in crashes is not to conduct post-event analyses with unreliable sources or unavailable data, but to eliminate the causal factor and observe to what extent the crashes are reduced. Speed cameras offer the closest opportunity to this, if changes in the extent of speeding are known. Job & Sakashita (2016) noted that the evaluation of the first 28 speed cameras installed in NSW resulted in an 89% reduction in fatal crashes, a 20% reduction in injury crashes, and a 19.7% reduction in all crashes, arising from a 71% reduction in speeding. However, crash data in NSW (NSW Road Safety Strategy Branch, 2003: with the year selected to be in the time of the evaluation) indicate the following involvements of speeding: 43% for fatal crash, 16% for injury crashes, and 17% for all crashes, including the additional criteria employed in NSW to identify speeding related crashes (see NSW Road Safety Strategy Branch, 2003). On the basis that the speed cameras do not treat other causes of crashes, the camera evaluation data indicate the following involvements of speeding: 89% for fatal crash, 20% for injury crashes, and 19.7% for all crashes. Comparing the results of largely eliminating speeding at speed camera locations, with the official data indicates the following levels of underestimate of the role of speeding: 52% for fatal crash, 25% for injury crashes, and 14% for all crashes. Other factors deserve noting: These percentages may be an over-estimate on the basis of factors such as regression to the mean, and these locations not being representative. Balancing these issues, these may be an under-estimate of speeding involvement in serious crashes because reductions were achieved without eliminating all speeding.

The most comprehensive study of a speed enforcement intervention in New Zealand is by Keall et al. (2001) however, it reports changes in mean speed but not the extent of elimination of speeding. Thus, the results reported cannot be used to estimate the role of speeding in New Zealand, applying the same logic as above on the evaluation of speed cameras in NSW.

More rigorous sources of data to determine the role of speeding in crashes: Elsegood, Doecke, & Ponte (2021) employed speed data from vehicle Event Data Recorders to assess the extent of speeding in crashes in South Australia. They found that speeding was involved in 24.5%, and 37.8% for free speed vehicles (vehicles not slowed by other traffic in front of them). This was in a sample with only one fatal crash and 3.6% hospitalized injury crashes, with 82% of crashes occurring in metropolitan areas, thus also under-representing single vehicle crashes, which are much more likely to involve speeding. For example, Doecke, Elsegood & Ponte (2021) found that the rate of speeding in single vehicle crashes was twice that of rear-end crashes, and more than twice that of intersection crashes. Finally, speeds from event recorders were taken for one vehicle not all vehicles in multi-vehicle crashes: the rear vehicle in rear end crashes, and the vehicle which has right of way in intersection crashes. Strangely, this means that if the vehicle with right of way is not speeding but the vehicle which fails to give way is speeding in an intersection crash, then this crash which clearly involved speeding will not be recorded as a speeding crash. Thus, based on the sample, these data offer a reasonable guide to the role of speeding in high income countries in non-injury crashes in metropolitan areas only, except for the issue of speeding only being assessed for one vehicle.

Doecke, Elsegood & Ponte (2021) reported a study of speeding in fatal and serious injury crashes, again based on sound data from vehicle event data recorders. However, the authors apply two further statistical treatments to estimate the role of speeding in South Australia. First, various weightings were applied with the aim of better representing crashes in South Australia. Second, for each crash, a theoretical (and generally empirically reasonable) set of calculations were made, attempting to assess what would have happened if the speeding vehicle had been travelling at the speed limit, with assumed reaction times, braking distances, and survival rates for impact speeds, etc. to calculate the new impact speed and survivability. Thus, it is critical to appreciate that their conclusion that speeding contributes to 18% of fatal and serious road trauma in South Australia, does not mean that speeding was only involved in 18% of fatal and serious injury crashes. Rather, it means that for some speeding-involved fatal crashes a re-calculation of the speeds and forces involved assuming that the speeding vehicle was travelling at the speed limit may mean that the crash forces are still severe. Thus, some fatal crashes for example which did involve speeding will not be in the 18% because the calculations indicate that the crash forces would still have been fatal even if the speeding vehicle had been travelling at the speed limit. However, considering the multiple mechanisms by which speeding could contribute to the error (such as failing to have time to scan and detect), it is difficult adjust for these errors and thus be confident of this re-calculation process. Thus, the best answer from this study to the question: 'what proportion of fatal and serious injury crashes involved speeding?' is available from the raw data provided before these weighting for South Australia representativeness and crash survivability calculations were applied. The raw data were provided (Doecke et al., 2021), and show that for fatal crashes 50% involve speeding, and for hospitalized injury crashes 33% involve speeding.

For both studies, the use of vehicle event data recorders has the advantage of allowing for an objective assessment of speeds immediately prior to a crash. However, this also presents significant disadvantages which may under-estimate the role of speeding. Most critically, these recorders are more prevalent in more modern vehicles with requirements for them being gradually rolled out over many recent years in various manufacturing countries (UNECE, 2021; US Government, 2008), which biases the sample both of vehicles and drivers. Not only are more modern vehicle more likely to have the recorder, but also these were required in more advanced countries earlier than less safe vehicle manufacturing countries. Thus, the vehicles with the recorders tend to be newer and safer vehicles which afford more protection in a crash, meaning that the data in these studies comes from safer-than-average vehicles reducing the risk of fatality or serious injury. Second, as a consequence of the roll-out of requirements over time and over different countries in which the vehicles are produced, vehicles with a recorder on average cost more to purchase. Thus, drivers of these vehicles will tend to be older – with more money- and safer. Third, it is also possible that no data can be recovered from a data recorder and indeed cases were dropped for this reason in these studies. This may occur in more serious crashes which involve loss of electrical power early in the crash, with regulations setting impact speeds which the event recorder is required to survive (e.g., 50mph: US Government, 2008). Thus, crashes at higher speeds (more likely to involve speeding) are more likely to be omitted from the study due to loss of data. Fourth, the methodological issue described above for the Elsegood et al. study relating to assessing speeding only for one vehicle in multi-vehicle crashes, apply in both these studies. Based on the above methodological concerns, the real rate of speeding involvement in fatal crashes is over the 50% estimate and the real rate of speeding involvement in serious injury crashes is over the 33% estimate by Doecke et al (2021). Police based crash data from South Australia estimate that speeding is involved in only around 25% of fatal crashes (24% in 2018 and 26% in 2017: see Table 2 of Department of Planning, Transport & Infrastructure, 2019). Speeding involvement data are not provided for other crashes or in more specific detail. Thus, the more rigorous data from Doecke et al. (2021) indicate that the police based estimate is missing as many fatal crashes in which speeding is involved, as are being reported (50% versus 25%).

Crash Data from New Zealand: Table 3 provides the police based estimates of speeding involvement in crashes (from present analyses) with corrections applied based on the level of error revealed in the studies from NSW (Job & Sakashita, 2016) and SA (Doecke, 2021),

Table 3: The role of speeding in crashes from Police-based crash data in New Zealand and in Auckland, with the correction factors calculated above applied (Sources: present analysis of 5 years of crash data in New Zealand; analysis of data above to develop correction factors)

Crash Severity	% involving speeding from Police-based crash data New Zealand	% involving speeding from Police, corrected for estimated under-reporting from speed camera study (Job & Sakashita, 2016)*	% involving speeding from Police, corrected for estimated under-reporting from Event Data Recorder study (Doecke et al., 2021)*	% involving speeding from Police-based crash data Auckland	% involving speeding from Police, corrected for estimated under-reporting from speed camera study (Job & Sakashita, 2016)*	% involving speeding from Police, corrected for estimated under-reporting from Event Data Recorder study (Doecke et al., 2021)*
Location	NEW ZEALAND			AUCKLAND		
Fatal Crash	29.7	61.9	59.4	36.4	75.8	72.8
Serious Injury Crash	20.6	NA	NA	19.6	NA	NA
Minor Injury Crash	16.4	21.9#	NA	16.0	21.3#	NA
Non-injury	12.4	NA	NA	10.2	NA	NA
All reported crashes	14.0	16.3	NA	12.0	14.0	NA

*The correction factor applied arises from directly from the estimated police data misses of speeding. Thus, if the police data miss 50% of speeding cases, then the correction is to double the reported percentage.

#In NSW crash data, serious and minor injuries are not separated. The correction factor for all injuries is applied here only to minor injuries because most injuries are minor.

analysed immediately above. The correction factors from these studies are applied to New Zealand based on similar police reporting procedures, and thus similar rates of missing speeding in crashes. The in-depth crash investigation study by Doecke & Kloeden (2014) provides a much higher correction factor: that police reporting misses 94.9% of speeding crashes. In addition, crash data specific to Auckland (the largest city in New Zealand) are included in order to allow a guide to speeding as a factor in metropolitan environments, and because of concerns noted above that the data from Doecke et al. may over-represent metropolitan crashes.

The results in Table 3 highlight that the under-estimation of speeding in crashes is more substantial for fatal crashes than for other crashes. The correction factors show close consistency from the two sources for fatal crashes, and indicate that in New Zealand around 59% to 62% of fatal crashes involve speeding (henceforth, simplified to around 60%).

What Question are These Different Data Sources Answering?

The extent of the role of speed in crashes is addressed in multiple ways with data answering critically different questions all fitting within the general rubric of speed and crashes. These questions vary in terms of the outcome variable: typically fatalities (or fatal crashes), serious injuries, minor injuries, or all crashes. Less obviously, they also differ in terms of the independent variable: impact speed, travel speed, speed, and speeding. In addition, different changes in individual speeds producing the same change in mean speed also produce different effects (Elvik et al., 2019). The different data sources described above answer different questions. It is vital to appreciate this, because evidence from the different sources, but especially police based crash data are often misinterpreted as essentially addressing the question: To what extent is speeding contributing to serious crashes?

Table 4: The questions which are addressed within the rubric of the role of speed in road safety, the data sources which best answer them, and best estimates of the answers

The question	Best source of data to answer this question	Example References for the Source	Best Estimate of the Answer for New Zealand
To what extent is travel speed a major determiner of fatal crash risk	Source 2: Meta-analyses of speed and fatal crash risk Source 3: Evaluations of speed management interventions in terms of lives, injuries and crashes saved	Cameron & Elvik, 2010; Delaney et al., 2005; Elvik, 2013; Elvik et al., 2009; Nilsson, 2004; Turner et al, 2021; Wilson et al., 2010	Each 1% increase in speed produces a 4% increase in deaths
To what extent is travel speed a major determiner of serious injury crash risk	Source 2: Meta-analyses of speed and serious injury crash risk Source 3: Evaluations of speed management interventions in terms of lives, injuries and crashes saved	Cameron & Elvik, 2010; Delaney et al., 2005; Elvik, 2013; Elvik et al., 2009; Nilsson, 2004; Turner et al, 2021; Wilson et al., 2010	Each 1% increase in speed produces a 3.5% increase in serious crashes
To what extent is impact speed a major determiner of fatality risk	Source 1: Analyses of the probability of survival for different impact speeds	Hussain et al., 2019; Wramborg, 2005	Each 1km increase in impact speed produces an 11% increase in the likelihood of a pedestrian fatality.
To what extent is impact speed a major determiner of serious injury risk	Source 1: Analyses of the probability of survival for different impact speeds	Doecke et al., 2020; Jurewicz et al., 2016	Each 1km increase in impact speed produces a 7% increase in the likelihood of pedestrian serious injury.
What proportion of fatal crashes involve speeding as a factor?	Source 9: Combining data sources to correct Source 4: police based crash data under-estimations, employing Sources 3 and 5	Analyses from the present paper.	Around 60%
What proportion of serious injury crashes involve speeding as a factor?	Source 9: Combining data sources to correct Source 4: police based crash data under-estimations, employing Source3 and 5	Analyses from the present paper.	NA
What proportion of fatal crashes involve speeds above Safe and Appropriate Speeds?	Sources 7: Application of 'Safe and Appropriate' speed limits	New Zealand Transport Agency Waka Kotahi, 2016; New Zealand Government, 2019	Available from present analyses for fatal and serious injury combined: 71%
What proportion of serious injury crashes involve speed above Safe and Appropriate Speeds?	Sources 7: Application of 'Safe and Appropriate' speed limits	New Zealand Transport Agency Waka Kotahi, 2016; New Zealand Government, 2019	
What proportion of fatal crashes involve speed above safe system in principle speeds?	Source 6: Application of safe system principles	Belin, 2016; Job, 2017; OECD, 2006	100%

The question	Best source of data to answer this question	Example References for the Source	Best Estimate of the Answer for New Zealand
What proportion of serious injury crashes involve speed above safe system in principle speeds?	Source 6: Application of safe system principles	Belin, 2016; Job, 2017; OECD, 2006	100%
In what proportion of fatal crashes are police confident that speeding was factor implying that the driver (if alive) would be charged with speeding and that speeding could be legally defended to be a factor on the basis of police investigation?	Source 4: Analyses of Police based crash data	Table 1 in the present paper; NSW Centre for Road Safety, 2017	29.7%
In what proportion of serious injury crashes are police confident that speeding was factor implying that the driver (if alive) would be charged with speeding and that speeding can be legally proven to be a factor in crash causation, on the basis of police investigation?	Source 4: Analyses of Police based crash data	Table 1 in the present paper; NSW Centre for Road Safety, 2017	20.6%
Do drivers who are prepared to have their driving continuously monitored still speed while being monitored	Source 8: Naturalistic driving studies	Dhahir & Hassan, 2019; Kamrani et al., 2019	Yes
Does the speeding of drivers being constantly knowingly monitored still increase crash risk?	Source 8: Naturalistic driving studies	Kamrani et al., 2019	Yes

(e.g., Grabar, 2021; and in New Zealand, Matthew, 2019). This interpretation is quite understandable due to the presentation of the data in crash databases as answering this question, meaning that the fault may really lie with the databases, the visibility of these sources, and the weaker accessibility of other information. Table 4 provides the various questions which fit within the broader rubric of the role of speed in crashes, with the outcome variable limited to fatal crashes and serious injury crashes in order to keep focus on the most costly crashes in all respects: human loss, grief, suffering, and economic costs (see Wambulwa & Job, 2019). Table 4 also connects these questions with the various data sources, and provides a best estimate of the answer to these questions based on the present review and analysis for New Zealand.

Discussion and Conclusions

This paper reviewed the data providing information relevant to assessing the role of speed in crashes, in terms of their relevance and validity. New Zealand was adopted as a case study in order to focus results in one country as far as possible, to avoid differences which simply arise from country variations. This review identifies many distinct data sources. Detailed analysis of the different sources revealed that apparent inconsistencies can be resolved by (1) appreciating that the different sources address fundamentally different questions, (2) observing the differences in the methodologies and data availability for the different sources, and (3) combining sources to answer some of the key questions on the roles of speed in serious crashes. Least appreciated in terms of the nature of the questions addressed is the importance of the different aspects of speed which are measured: mean travel speed, mean crash impact speed, speed, and speeding.

The various sources of data are consistent in showing the vital role of speed in serious crashes, and in showing that the effects of speed are more profound for fatal crashes than for injury crashes, with non-injury crashes less influenced. This is true for sources 1, 2, 3, 4, 5, and 9, with other sources providing less explicit data on this issue.

For New Zealand, Police reports entered into Waka Kotahi, NZ Transport Agencies Crash Analysis System (CAS) provide the lowest estimate of the role of speeding in crashes, but are well recognized (including by Police) in New Zealand as in many countries, to be a substantial under-estimate of the role of speeding in serious crashes. Police based crash data are significantly limited by the focus on speeding not speed as a factor, particularly in relation to what are well recognised as unsafe speed limits; necessarily adopting a more legalistic criterion for the involvement of speeding; and, missing key evidence through being retrospective assessments at crash scenes with limited resources for comprehensive crash investigations in many cases. Correction factors for the under-estimation of speeding as a factor were developed here by combining data from more rigorous sources of evidence of speeding in crashes. Present analyses indicate that speeding is a vital and substantially under-estimated factor in fatal crash in New Zealand, and that the large majority of fatal and injury crashes involve speeds above New Zealand's designated safe and appropriate speeds.

There are limitations to the additional calculation methods employed here to determine real role of speeding in crashes, and to determine the contribution of speeds above Safe and Appropriate Speeds to crash trauma in New Zealand. First, the results of these calculations are influenced by crash data limitations such as crashes not being reported. Second, the estimates made may vary slightly with assumptions made, noting that assumptions made here may under-estimate the role of speeding and speed in serious crashes. Third, the test-retest reliability of these estimates is not known because this is the first time such estimates have been made. However, there are indicators of reliability. Two separate studies were employed to generate corrections to police under-reporting, yet these correction factors align well, resulting in for example estimates of speeding in fatal crashes of 59.4% and 61.9%. Similarly, an independent sources of evidence for the extent of speeds above safe and appropriate speeds in injury crashes, also align well with the estimate calculated here: 70% and 71.8%.

The finding that speeding is involved in around 60% of fatal crashes is of profound importance. It highlights that speeding is the primary and indeed majority behavioural factor in serious crashes. It also allows an estimate of the number of lives lost in New Zealand in speeding crashes. Over the years 2018-2021, crash deaths averaged 355 per year. The presently calculated estimate that 60% involved speeding, means that on average 213 people were killed each year in speeding related road crashes. By contrast, over many years, homicides (murders plus manslaughter) in New Zealand averaged 67 per year (New Zealand Police Headquarters, 2019). Three times as many people die due to speeding than die in homicides in New Zealand each year, yet speeding is treated relatively lightly, and commonly viewed as not particularly serious (Mooren et al., 2014).

Recommendations

The following recommendations are made, which are applicable in New Zealand in particular but also in most countries:

1. Speeding (speeds above the legal speed limit) involves the problem of speed. However, speed is an issue in many cases of death and injury which do not involve speeding. Based on the present analyses, the core but distinct issues of speed and speeding are both critical in road safety and both must remain points of focus for saving lives and avoid serious injuries.
2. Speeding kills more than three times more people each year in New Zealand than homicides, and deserves more resourcing and aggressive management through road design and engineering to reduce speeds, promotion and expansion of effective enforcement and creation of stronger general and specific deterrence.
3. Speed (not just speeding) also deserves more effective management for improved safety. Bringing existing speed limits in New Zealand into alignment with Safe and Appropriate Speeds combined with strong compliance will save many lives and avoid many serious injuries. Developing and promoting speed limits to evidence based policies more closely aligned with safe system principles will save many lives and injuries globally.
4. The clear evidence for under-estimation of speeding in police reports highlights that estimations of the role of speed in crash trauma in New Zealand should not be based on police based crash data.
5. It is worthwhile to consider how the crash data can be presented to highlight the under-reporting of speeding and thus avoid the erroneous message in them that speeding is a much smaller factor than it really is in serious crashes.
6. While acknowledging the under-reporting of speeding in police reports, police should not be expected to simply fix this. This is not a fault with New Zealand police officers or police globally, but a consequence of inherent limitations to post-hoc

investigation processes as well as the functional focus on legal prosecution, a core role for police.

7. It is not clear from this analysis that increased resourcing in crash investigation is cost effective compared with a continued focus on a safe systems approach to saving lives and injuries.
8. However, the important role of police based crash data in the management of road safety, in community understanding of road safety and in advocacy must be acknowledged. Thus improvements to the system should be explored to, in part, address the under-reporting problem. To assist police, in consultation with police, it is worthwhile to consider revising police criteria for speeding as a factor and to consider separating the need for better estimation of this factor from the burden of proof. This could involve accepting the experience and expertise of police by providing uniform guidance and separate fields for police to identify (1) when speeding is clearly not involved, (2) when speeding is suspected as a potential contributing factor, and (3) when the more usual criterion of proof of speeding is met. Implications of the use of these data in legal cases will need to be considered.
9. Revise processes for the interpretation and use of crash data in relation to speeding by adopting and explaining correction factors for the under-estimation of the role of speeding in crash data.
10. Discuss these issues with the community, the media, and decision makers. The conversation on speed may be valuably increased in sophistication, to encapsulate the role of speed in trauma not just the role of speeding.
11. There may be value in undertaking more research directly in New Zealand to more precisely establish correction factors for under-estimation in police based data. However, more than sufficient evidence exists to support improved speed management being implemented without delay.

There will be value in other countries undertaking the correction processes presented herein to better determine the role of speed and speeding in serious crashes, to better guide road safety priorities and communications with the community and decision makers.

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