Fatal footsteps: Understanding the Safe System context behind New Zealand's pedestrian road trauma

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Fatal footsteps: Understanding the Safe System context behind New Zealand's pedestrian road trauma

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Key Findings

- In 2016 in New Zealand, pedestrians accounted for 7.6% of road fatalities and 6.6% of serious injuries
- In nearly all crashes, a combination of Safe System pillars failed to protect the pedestrian
- Across all levels of New Zealand's transport system there is a stronger focus on vehicle occupant safety, priority, and comfort than for pedestrians
- A proactive, systemic approach is required to achieve a tangible reduction in the burden of pedestrian casualties

Abstract

In 2016 in New Zealand, pedestrians accounted for 7.6% (n=25) of all road fatalities and 6.6% (n=257) of serious injuries (Ministry of Transport, 2017). The aim of this research was to analyse a sample of pedestrian deaths and serious injury (DSI) cases to understand the contribution of Safe System gaps in serious harm outcomes. A sample of 100 pedestrian fatality and 200 serious injury crash reports from 2013-2017 were analysed to identify the contribution of the four Safe System pillars (roads and roadsides, vehicle, speed environment, user) in each crash case. The research identified common crash scenarios and highlighted the need for improvements in speed management, safer vehicles, safety campaigns, and infrastructure design. In addition, the research identified latent high-order sociotechnical system factors that obstruct the mechanisms to effectively address these Safe System issues and which ultimately perpetuate the occurrence of pedestrian DSIs.

Keywords

Pedestrian, road trauma, Safe System, sociotechnical system, death and serious injuries

Introduction

Pedestrian road trauma

Pedestrians are an integral part of New Zealand's transport system. Walking reduces traffic congestion, promotes a sense of community, supports a healthy lifestyle (Kelly, Murphy, & Mutrie, 2017; Lee & Buchner, 2008; Newman, Kosonen, & Kenworthy, 2016), and causes the least harm to other people. However, walking for transport is not always easy or safe (Bakovic, 2012; Stoker et al., 2015). In 2016 in New Zealand, pedestrians accounted for 7.6% (n=25) of the road fatalities and 6.6% (n=257) of serious injuries. Many variables associated with pedestrian deaths and serious injuries (DSI) are reported in the literature and these are summarised below.

The association of vehicle speed on pedestrian DSIs, both in New Zealand and internationally is well understood. For example, there is agreement that higher vehicle speeds at the point of impact result in more severe outcomes for pedestrians (Kröyer, 2015; Zeeger & Bushell, 2010), and that a significant reduction in injuries can be achieved when the impact velocity is less than 30km/h (Jurewicz, Sobhani, Chau, Woolley, & Brodie, 2017).

The literature suggests that males are more likely to be killed or seriously injured as pedestrians than females (Prato, Gitelman, & Bekhor, 2012; Stoker et al., 2015); children aged 5-9 years, and people aged over 80 years are most 'at-risk' groups (Ministry of Transport, 2017); and people from marginalised and minority ethnic backgrounds are overrepresented as pedestrian casualties (Baker & White, 2011; Desapriya et al., 2011; Grisé, 2015).

Whilst several demographic factors regarding pedestrian victims are well reported in the literature, there is little demographic information available about the drivers who hit them. Driver information is more available in the form of their behaviour prior to the crash. For example, New Zealand's Ministry of Transport highlights that common contributing factors associated with these crash types are inattention, failure to give way, and not seeing the other party (Ministry of Transport, 2017). There is some evidence that motorists involved in pedestrian crashes are likely to have more driving violations than the general population (Desapriya et al., 2011). Finally, the use of mobile phones or headphones, or the use of alcohol or drugs by either the pedestrian or the driver can increase crash risk (Harwood et al., 2008; Lichenstein, Smith, Ambrose, & Moody, 2012; Zeeger & Bushell, 2010).

Urban areas are the most common locations for pedestrian DSIs. In 2016 in New Zealand this figure was reported at 84% (Ministry of Transport, 2017). This is likely due to the higher proportion of pedestrian activity and traffic exposure than in rural settings (Prato et al., 2012; Zeeger & Bushell, 2010). Common crash locations reported in the literature include: roundabouts on multi-lane roads; unsignalised crossings; shared signal phasing for pedestrians and vehicles (Gitelman, Balasha, Carmel, Hendel, & Pesahov, 2012); crossing the road within 15m of an intersection (Schneider et al., 2010); and crossing mid-block – a particularly a risky location for children when they dart onto the street (Retting, Ferguson, & McCartt, 2003).

The seriousness of the outcome for pedestrians when struck by a vehicle can be mitigated (or aggravated) by the mass, shape, and other design aspects of the vehicle. For example, metal bull bars increase the risk of severe injury or death to a pedestrian in the event of a collision (Anderson, van den Berg, Ponte, Streeter, & McLean, 2006) whilst the inclusion of energy-absorbing vehicle components can minimise the severity of pedestrians' injuries (Crandall, Bhalla, & Madeley, 2002). In addition, although all vehicle configurations have blind spots, trucks have noticeably more blind spots than passenger cars (Summerskill & Marshall, 2015).

For the purposes of this paper, pedestrians are defined as "any person on foot or who is using a powered wheelchair or mobility scooter or a wheeled means of conveyance propelled by human power, other than a cycle" (New Zealand Transport Agency, 2009). Furthermore, this paper specifically describes pedestrian DSIs resulting from being struck by a motor vehicle on New Zealand's roads. This paper does not examine pedestrian DSIs resulting from slips, trips, or falls.

New Zealand's Safe System

The Safe System approach was adopted by the New Zealand Government in 2010 as part of the Safer Journeys Strategy, a 10-year road safety strategy. The concept of the Safe System acknowledges road user fallibility and vulnerability and argues that a mistake should not cost someone their life, or lead them to be seriously injured. Under this approach, responsibility for the system is shared by everyone, including but not limited to: policy makers; users; planners; vehicle manufacturers; and engineers. Broadly, the Safe System framework can be understood through four 'pillars': safer roads and roadsides; safer speeds; safer vehicles; and safer road users (New Zealand Government & National Road Safety Committee, 2016).

The Sociotechnical System

Sociotechnical Systems Theory emphasises the causal relationships between different hierarchical levels in complex systems. For example, Rasmussen's (1997) work on risk management in workplace settings describes a system hierarchy made up of six levels: government, regulators/associations, company, management, staff, work. This approach has also been applied to crash analyses, and highlights how the relationships between decisions, actions, and failures at different system levels lead to particular outcomes, rather than individual people or isolated errors (Mackie, Hawley, Scott, & Woodward, 2016).

Aim

The aim of this research was to analyse a sample of pedestrian DSI cases to understand the contribution of Safe System gaps in serious harm outcomes. The following research questions were examined:

1. How do DSI crashes differ in relation to underlying Safe System factors?
2. What common scenarios for pedestrian DSI crashes exist, and how can these be understood through the sociotechnical system?

Methods

The goal of the analysis was to use a Safe System framework to analyse pedestrian DSI crash cases that occurred in New Zealand between 2013-2017. In this section we describe the empirical data used, the analysis framework applied to these data, and the method used to understand the contribution of higher-level sociotechnical system factors to crash scenarios.

Data

Data from New Zealand's Crash Analysis System (CAS) database in the form of Traffic Crash Reports (TCRs) produced by NZ Police were retrieved. TCRs are completed by police officers at the scene of all road crashes. They record the available information about where, when, how, and why the crash happened.

It is recognised that crash data contains potential biases including: the language of the form; the 'at the scene' nature of the data entry; and the accuracy of injury reporting and therefore best practice would be to validate police data against hospitalisation data (Abay, 2015; Cryer et al., 2001; Tarko & Azam, 2011). However, due to financial and data access constraints, that approach was not possible in this study. To complement the TCR data, thee other sources were referred to. They were: the Safer Journeys Risk Assessment Tool, a GIS mapping software hosted by the New Zealand Transport Agency which gave details of the road environment; Google Street View, which gave photographic context of the crash location; and Monash University's Vehicle Safety Ratings report (Newstead, Watson, Keall, & Cameron, 2017) to understand the implicated vehicle's aggressivity rating and safety rating.

Crash analysis framework

Between 2013-2017 there were 1,471 pedestrian DSIs on New Zealand's roads (Ministry of Transport, 2017). Each DSI case is ascribed a unique number by the NZ Police in the CAS database. A list of crash numbers was obtained and each casualty case was assigned a randomly generated number using the MS Excel RAND function. These were sorted from the smallest to largest number and the first 100 fatalities (99 crashes) and the first 200 serious injures (199 crashes) were selected for analysis. Thirteen crash cases were excluded: six occurred in a workplace, not on the public road network; three had insufficient data in the TCR; two involved people falling from inside a moving vehicle; and two were incorrectly coded as pedestrians but were cyclists. To replace those excluded cases, the next random number in the list was used.

The TCR reports and the other crash-associated data sources described above were coded into 64 variables (49 polychotomous, 10 dichotomous, 5 open-ended) by a single analyst following a Safe System coding framework which, in its design, acknowledged that DSI crashes happen when a combination of system failures occur (Larsson & Tingvall, 2013). Each case was examined using variables relating to the four Safe System pillars: Speed; Roads and Roadsides; Vehicles; and Users (Hirsch et al., 2019; Mackie et al., 2017). The 'User' pillar was split into two to more equally represent drivers and pedestrians. Each Safe System pillar could be 'triggered' or implicated in a crash in response to certain factors that lay outside the Safe System being present. While multiple factors could trigger the pillar, the pillar itself could only be triggered once per casualty case. The coding framework, including each variable coded and the factors that triggered the Safe System pillars is presented in Figure 1.

Some explanatory notes from Figure 1 are listed below:

- Speed pillar
    - Safe and Appropriate Speed (SAAS): This is a metric in the Safer Journeys Risk Assessment Tool. It suggests the optimal operating speed for most roads in New Zealand based on that road's function, design, safety, and use.
- Vehicle pillar
    - W/COF: A regular vehicle check in New Zealand to ensure that the vehicle meets specific safety standards. Warrant of Fitness (WoF) or Certificate of Fitness (CoF). This was selected to reflect the maintenance of the vehicle and its ability to perform to the standards of its manufacturer.
    - Aggressivity Rating: This rating provides an estimate of the risk of an unprotected road user or driver of another car being killed or seriously injured when they are involved in a crash with the model vehicle (Newstead et al., 2017).
- Roads and Roadsides pillar
    - ONRC: The 'one network road classification' as described in the Safer Journeys Risk Assessment Tool. The road function and land use were measures used in lieu of 'rural' vs 'urban' as it was deemed they had more sensitivity in their definitions.
- User pillar
    - Occupation: TRCs often give a specific occupation (i.e. accountant). The coder then classified these based on These classifications were determined by the Australian and New Zealand Standard Classification of Occupations (ANZSCO) Version V1.2 "classification of occupation". Additional categories were included for students, retired people, volunteers, beneficiaries, people who were unemployed, and tourists.

A spreadsheet for data entry was designed to eliminate coding error by including drop-down lists rather than allowing open-ended responses. In addition, the pillar trigger cells were automatically populated once the data were entered for each variable. To ensure rigour, ten 'test' cases were initially coded by the analyst, then independently by the first author. The set-up of the spreadsheet meant that coders were forced to assign a certain number of cases to each category and because of this, a fixed-marginal kappa was used (Siegel & Castellan,

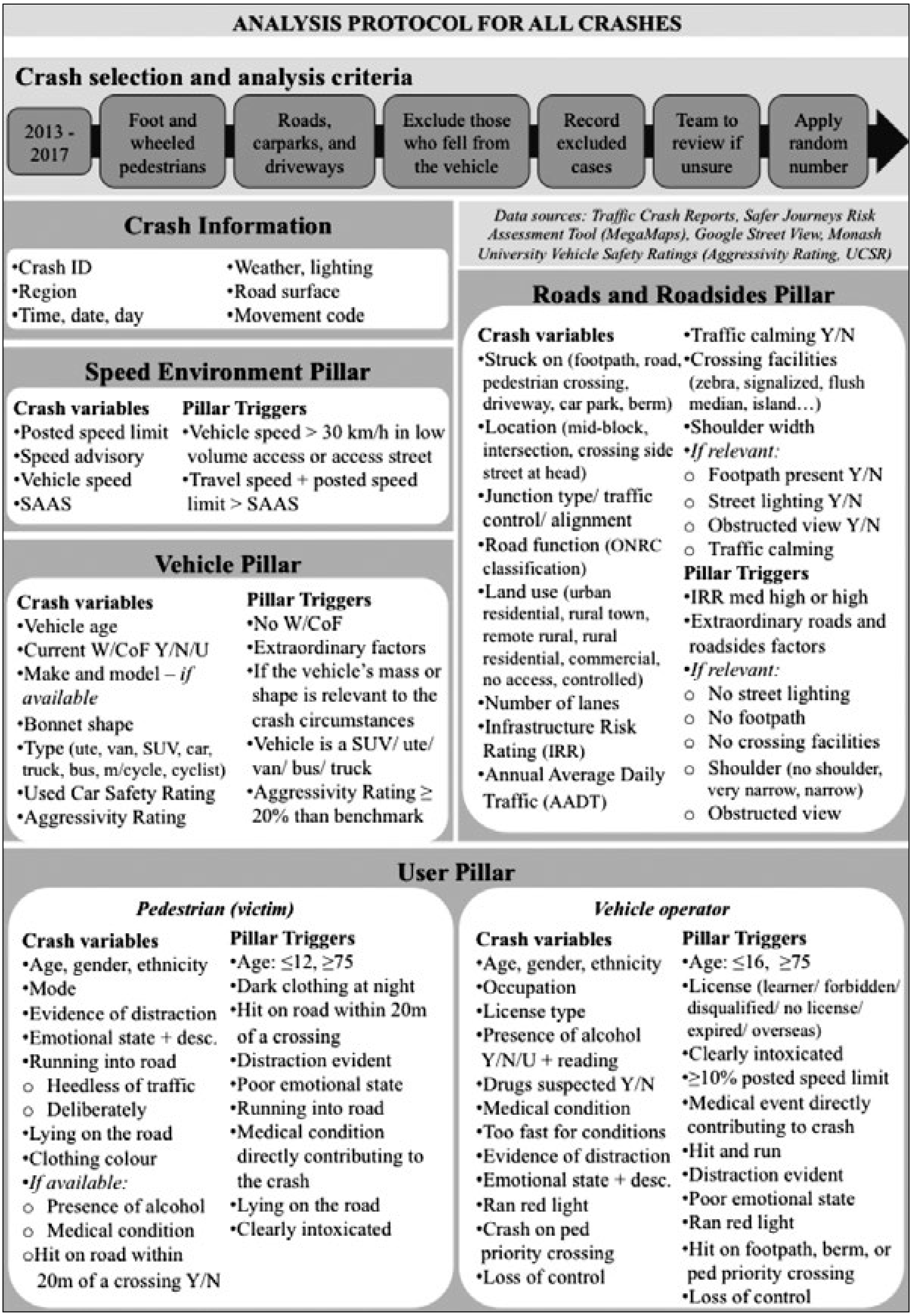

Figure 1. Variables for the Crash Analysis

1988). Across all variables the average score was 0.9. Based on the kappa results, all discrepancies in coding were discussed and solutions agreed. In the majority of cases, simple changes were made to the spreadsheet to minimise the identified discrepancies in future coding.

Understanding higher-level system factors

Common crash scenarios were identified from the output of the empirical analysis. To understand the transport system delivery issues which resulted in the system failures that led to these scenarios, the TCR analysis was supplemented with a workshop of expert industry and community group stakeholders (n=11), a meeting with members of a local government authority's Walking and Cycling Team (n=2), and a review of key policy, guidance, and planning documents. In the workshop and meeting, the scenarios were discussed following Rasmussen's model of risk management (Rasmussen, 1997) and the Cycling Safety System Model (Mackie, Hawley, Scott, & Woodward, 2016). For this research, Rasmussen's model was adapted for a road safety context with five system levels: road users; environmental context; practices and standards; government policy; and societal norms and culture.

Whilst useful for understanding the road user and environmental factors present in pedestrian crashes, TCRs do not provide a rich, contextual understanding of the sociotechnical system factors that come together to result in people being killed or seriously injured. For example, whilst factors relating to the vehicle design or user behaviour could be implicated as contributing to the crash, the TCR analysis cannot extend to demonstrating areas of systems or policy failure such as vehicle import laws, or road rules.

The combination of the crash analysis and system expert review enabled a 'causation pathway analysis' to map out how different levels of the transport system contributed to crash scenarios (Mackie, Hawley, Scott, & Woodward, 2016). The mapping exercise identified how intrinsic high-level system failures can be traced to DSI outcomes for everyday people. In doing so, this method acknowledged that crashes can be defined, not only by the four pillars of the Safe System, but also by various levels of the sociotechnical system – the processes, practises, organisational structures, and policies that ultimately create the context for pedestrian DSIs. This approach fits with the Safe System principle of 'Shared Responsibility', where all actors in the system take responsibility for ensuring safe outcomes.

Results

Crash analysis results

Temporal and geographic patterns

Most DSI crashes occurred during the day, with markedly fewer (25%) between 8pm and 8am. Crashes that did take place at night were more likely to involve pedestrian fatalities. Of all cases analysed, 76% occurred on a weekday.

Figure 2 compares pedestrians' personal risk (per million hours walked) and collective risk (percentage of all crash cases) by region. Personal risk was high in regions

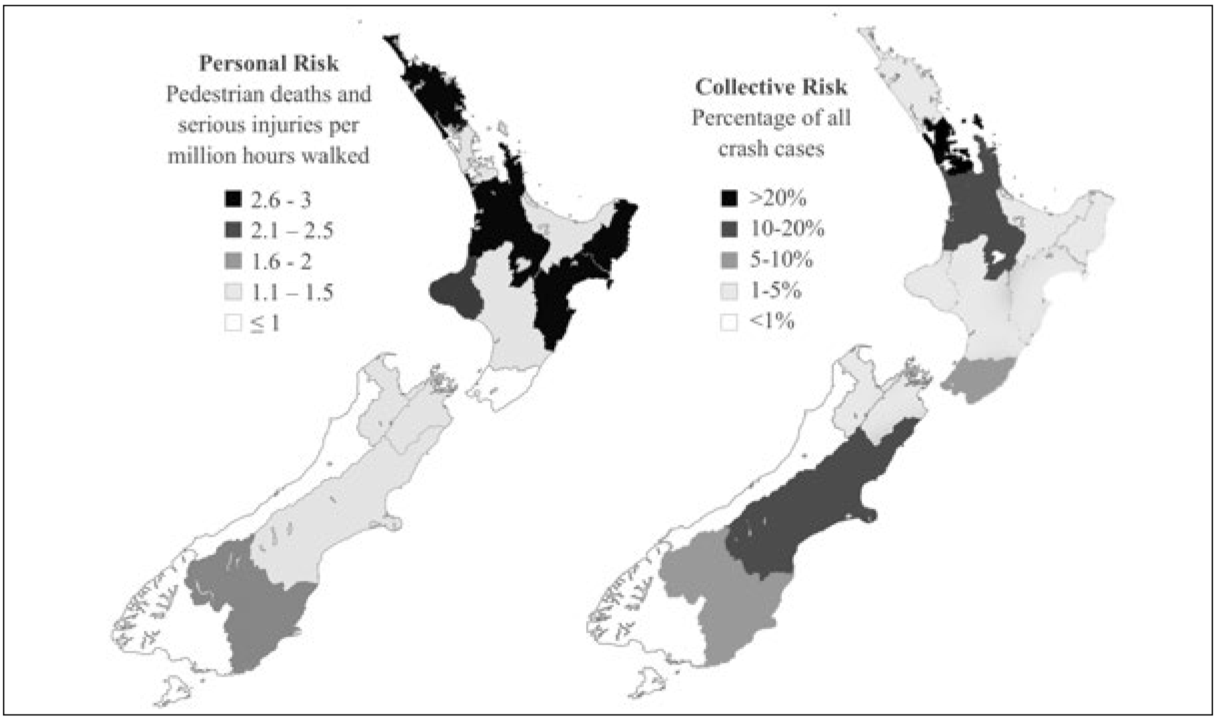

Figure 2. Personal Risk (Ministry of Transport 2015) and Collective Risk (crash cases from this study)

featuring large rural populations with limited pedestrian-focused infrastructure. Collective risk was highest in Auckland where crashes were centralised in the CBD, West Auckland, and South Auckland.

Speed Environment factors

The speed environment was activated in 39% of serious injury cases and in 63% of fatal cases. Crashes where vehicle operating speeds were 50 km/h or under were more survivable (71% of serious injury cases, 59% fatal cases). This finding mirrors the literature which shows that the higher the vehicle speed on impact, the more severe the outcome for the pedestrian due to their vulnerable, unprotected nature (Desapriya et al., 2011; Jurewicz et al., 2017; Kröyer, 2015; Zeeger & Bushell, 2010). Nevertheless, pedestrian casualty still occurred at slow speeds, typically in road environments where there was limited visibility or where complex decision-making was required, such as in driveways or car parks. Dominant injuries at these speeds involved crushing, and falling and hitting the head. Victims were typically young children and older adults. In this sample, 18% of fatal cases and 6.5% serious injury cases occurred when a vehicle was travelling at 30km/h or less.

Vehicle factors

This pillar was activated in 53% of the serious injury cases and in 68% of the fatal cases. The location on the vehicle where the pedestrian was struck was strongly associated with injury severity and different crash contexts. Pedestrians struck on the side of the vehicle (20% serious injury cases, 2% fatal cases) tended to be in lower speed environments (50 km/h or under). Rather than suffering from the full force of the vehicle, these crashes typically involved a pedestrian receiving a blow off a wing mirror, or having a lower limb run over. For this reason, the severity tended to favour serious injury outcomes.

Crashes where pedestrians were struck by the rear of the vehicle (11% serious injury cases, 6% fatal cases) were associated with low-speed reversing. Fatal reversing crashes typically involved larger vehicles such as trucks or SUVs, and/ or fragile or small stature pedestrians such as children or elderly adults. Reversing crashes mostly occurred in driveways or car parks where the driver's vision was obscured by the vehicle's blind spot, or environmental factors such as fences or shrubs.

The majority of pedestrians were struck on the front of the vehicle (68% serious injury cases, 92% fatal cases). Of these front-strike crashes, the bonnet shape had consequences for the outcome severity. Pedestrians hit by vans, trucks, utes, and SUVs had a higher proportion of fatal outcomes (55% of fatal cases) in comparison to those hit by medium sized sedans and mini cars (40% fatal cases). In 5% of cases the vehicle was a motorcycle.

The vehicle's aggressivity was identified in 183 of all crash cases. Within these, the vehicle's aggressivity was implicated in two thirds of fatal cases and one half of serious injury cases. These vehicles were overrepresented by SUVs, utes, and vans.

Roads and Roadsides factors

This pillar was activated in 65% of serious injury cases and 65% fatal cases. The most commonly occurring location – 80% of cases – was urban environments where, in comparison to rural areas, there are higher numbers of vehicles, pedestrians, and journeys.

Fatal cases were commonly associated with a lack of street lighting at night (24% fatal, 2% serious injury) and the absence of a substantial roadside shoulder (12% fatal, 2% serious injury). These cases were mostly located in rural, high-speed environments which are predominantly designed for the passageway of cars, with little consideration for pedestrian travel. Often, people walking rurally have no other option than to walk on, or close to the edge of the road. The risk is amplified at night time due to the lack of street lighting.

Serious injury cases were more commonly associated with urban street environment issues. For example, a lack of crossing facilities was identified as a contributing factor in 33.5% of serious injury cases and 21% of fatal cases. This was particularly of note on four-lane urban roads where serious injury crashes occurred four times more frequently than fatal crashes. These crash cases were predominantly associated with no pedestrian crossing amenities resulting in pedestrians stepping out from between parked vehicles or stepping off a refuge and filtering through slow moving traffic on congested urban roads (often striking the side of the vehicle).

In 13% serious injury and 12% fatal cases, drivers failed to stop at a pedestrian priority crossing such as a signalised crossing or a zebra crossing. Only flat zebra crossings, and no raised zebra crossings were implicated in these crashes. This reinforces Safe System principles whereby vertical deflection is provided to slow speeds by appealing to instinct as a priority, not relying only on cognitive aspects like signs or symbolic markings.

User factors

Overall, of the four Safe System pillars, the user pillar (drivers and pedestrians) was triggered most frequently – in 97% of all cases. Drivers were activated in 59% of serious injury cases and 63% of fatal cases whilst pedestrians were activated in 70% of serious injury cases and 84% of fatal cases. Although the pedestrian pillar was the most frequent pillar to be triggered, this does not mean that the pedestrian had primary responsibility in each of these crash cases. Rather, certain factors about the pedestrian were deemed to contribute to the cause or outcome of the crash.

The most common factor associated with drivers was distraction or inattention (43% all cases). It was associated

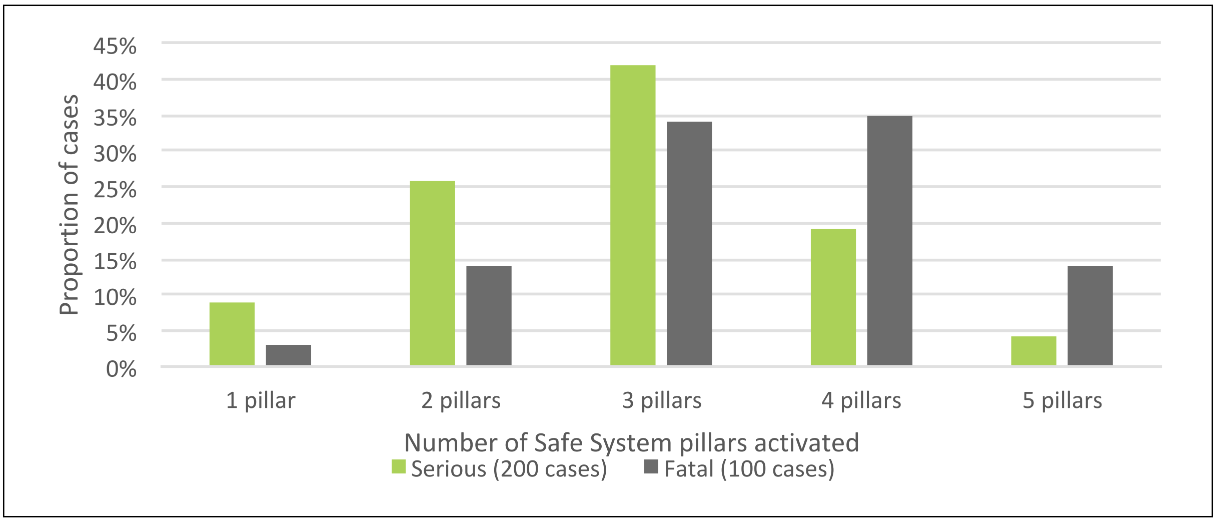

Figure 3. Proportion of fatal and serious cases involving multiple Safe System pillars

with half of the fatalities and one third of serious injuries and involved: looking for a gap in traffic but not checking for pedestrians (20 cases); general inattention (18 cases); driver failing to see the pedestrian (18 cases); and insufficient checking when reversing (15 cases). Distraction or inattention was also the most common pedestrian-implicated factor (37% all cases) and was evenly distributed between DSI crashes. The most common types of pedestrian distraction or inattention were: inadequate checking when entering the road space (55 cases); unsupervised children entering the road space or playing (17 cases); general inattention (10 cases); and using a phone or headphones (8 cases).

Although only 5% of all cases involved drivers travelling greater than or equal to 10% over the posted speed limit, a greater proportion (11% cases) were classified in the TCR as 'travelling too fast for the conditions'.

Overall, males were more crash-involved than females. Males were drivers in 75% of fatal crashes, compared to 57% of serious injury crashes. Likewise, male pedestrians were victims in 65% fatal cases and 52% serious injury cases.

For drivers, the most common gender and age groups were males aged between 41 and 50 years (14.6% of all crashes) and females between 21 and 30 years of age (7.3% all crashes). Using The New Zealand Household Travel Survey's breakdown of minutes spent walking each week per person by age group (Ministry of Tansport, 2015), pedestrian age exposure was determined. Pedestrians aged over 74 years had the highest rate of DSIs per minute of walking exposure. This was followed by people aged 25-34, despite being represented by the second lowest rate of walking per person per week. People aged between 45-74 had the lowest rates of death and serious injury per minute of walking exposure. Of note were male pedestrians aged 13-20 who represented the highest number of cases (n=30). Just over a third of these cases

Table 1. Common crash scenarios identified in this research

Crash scenario	Number of cases		% all DSI cases
	Serious	Fatal	
Attempting to cross an urban road mid-block with no nearby crossing facilities.	57	19	25.3%
Struck on pedestrian priority crossing (either a flat zebra or a signalised crossing).	28	10	12.6%
Children under 12 years of age struck on the road. Associated with playing, escaped supervision, sudden change of speed and/ or direction.	27	5	10.6%
Lack of street lighting at night in rural residential or remote rural environments. Often associated with pedestrian emotion, distraction, or intoxication.	4	24	9.3%

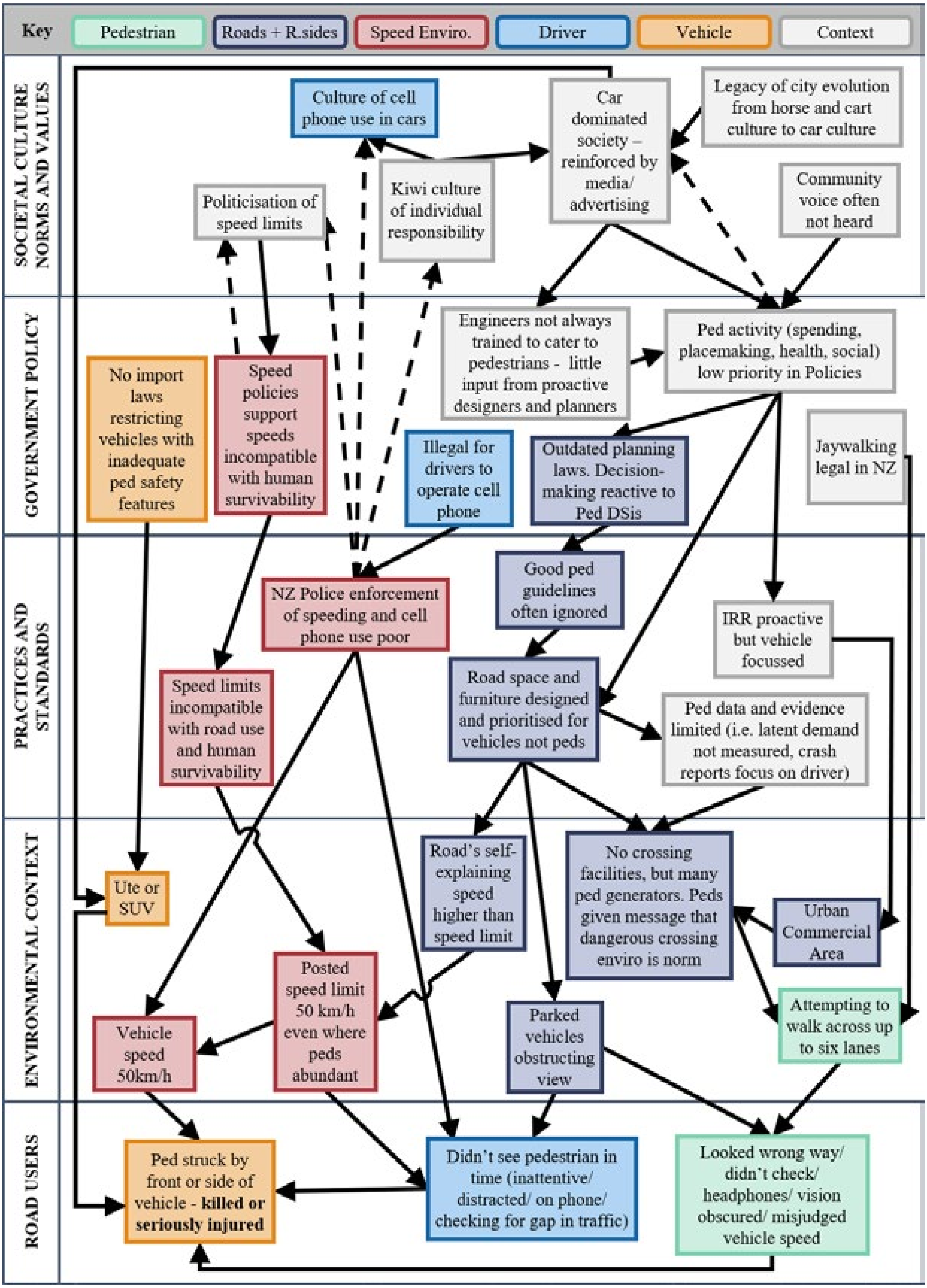

Figure 4. Mapping system failures for 'mid-block crossing with no facilities' (25.3% cases)

involved antisocial behaviours such as playing 'chicken' with the traffic and being involved in fights on the street.

Driver and pedestrian ethnicity was available in 79% of cases. Although Pākehā (New Zealanders of European descent) were involved in the highest number of all cases (55% drivers, 46% pedestrians), they were underrepresented as a proportion of New Zealand's population (74%) (Statistics New Zealand, 2013). Māori, who comprise 15% of New Zealand's population (Statistics New Zealand, 2013) were represented in 13% driver cases and 17% pedestrian cases. Pasifika were represented in 7% driver and 6% pedestrian cases and comprise 7% of New Zealand's population (Statistics New Zealand, 2013). Within these ethnicity bands, Pākehā are more likely to be drivers and Māori are more likely to be pedestrians. In addition, there is a discrepancy in the number of Pākehā cases to their proportion of the population. For Māori, this is an equity issue and is linked to factors such as vehicle access, education, and other social biases of colonisation.

Pedestrians wearing dark clothing at night time were identified in 13.6% of all cases. This was determined by pairing the TCR code for dark clothing with the time of day. Dark coloured clothing in low light conditions is understood to reduce pedestrian conspicuity (Tyrrell, Wood, Owens, Whetsel-Borzendowski, & Stafford-Sewall, 2016). In these cases, a fatal pedestrian outcome was 2.5 times more likely than a serious injury outcome. In half of those cases, the roads and roadsides pillar was also activated for a lack of street lighting and the absence of a substantial roadside shoulder or footpath, demonstrating the effect of multiple system failures on outcome severity.

This study was concerned with the contribution of system pillars to crash outcomes, and the research design did not incorporate 'reckless behaviour' into the analysis protocol (Mackie et al., 2017). However, data were filtered to understand the relative contribution of people who were inebriated or emotionally unstable. Whilst being intoxicated by alcohol as a pedestrian is not illegal in New Zealand, alcohol intoxication is associated with unpredictable behaviours and was therefore included if the pedestrian was present in the live lane. Examples of emotionally unstable driver behaviours included: hit and run, using a vehicle as a weapon, and road rage. For pedestrians, these behaviours included: being suicidal or being involved in a fight. The relative involvement of drunk or/and emotionally unstable drivers was 13.5% serious injuries and 12% fatalities. For pedestrians this figure was 12.5% serious injury cases and 26% fatalities.

Overall, multiple Safe System pillar failures were often implicated in pedestrian DSIs - more so in fatal crashes than in serious injury crashes (Figure 3). This reflects contemporary accident theory (Reason, 1990), which states that adverse events occur when multiple system failures allow it.

Higher-level sociotechnical system results

The pattern of multiple Safe System pillar failure being associated with a higher proportion of fatalities as presented in Figure 3 reinforces the importance of critically examining the connections between individual pillar failures. By mitigating each pillar's contribution to crashes, the overall crash burden may be reduced. Four common crash scenarios emerged from the analysis (Table 1), representing 58% of the DSI cases. Crash data from the TCRs was valuable in providing this understanding of the road user and environmental context and how factors combined to form scenarios.

System failures – through all levels of the sociotechnical system – behind the common crash scenarios were examined during the system expert review. Through this process, causation pathways were mapped to identify how different levels of the transport system contributed to crash scenarios (Mackie, Hawley, Scott, & Woodward, 2016). The mapping exercise identified how intrinsic high-level system failures can be traced to DSI outcomes for everyday people. A simplified flow-chart of the output from the mapping exercise for the 'mid-block crossing' scenario is provided in Figure 4.

Discussion

This research revealed that the majority of DSIs occurred when the pedestrian was simply going about their daily business and a lapse in attention or error occurred on the part of the pedestrian, driver, or both. Invariably, in nearly all of these crashes, other factors within the Safe System failed to protect the pedestrian. These included road environments that did not provide a safe location for pedestrians to cross, speed environments that were not appropriate for human fragility, and vehicle designs that were not forgiving. Within each of the common crash scenarios there was also evidence of sociotechnical system failure from across all levels. These include: social attitudes and norms; political structures such as government policies; and local council design standards and practices. Below we discuss practical recommendations for each Safe System pillar and within this discussion outline some higher-level sociotechnical system changes that could be made to minimise pedestrian DSIs.

Various models of human behaviour, public health, and road safety suggest that the built environment is the greatest determinant of health or safety outcomes (Newman et al., 2016; Sobhani, Jurewicz, Makwasha, Alavi, & Nieuwesteeg, 2016). Yet, in many examples where the roads and roadsides pillar failed, it was evident that the design of the road environment was focussed on perpetuating the landscape of automobility through promoting the priority, efficiency, and safety of vehicles, often in contravention to safe pedestrian outcomes.

Providing a road and roadside environment that is both enabling and forgiving to pedestrians is vital to ensure safe outcomes as well as positive perceptions and associated behaviours for people pursuing active transport modes such as walking and wheeling. At some point, all drivers are also pedestrians, so this is a universal need. Redeveloping metrics to acknowledge the social and economic value of pedestrians (i.e. carbon savings, purchasing power) – and valuing these outcomes above vehicle metrics (i.e. vehicle kilometers travelled, travel time savings) – would be a useful way to influence a change in the political language around pedestrians and vehicles, and, ultimately decisions around funding and design of spaces that prioritise people.

This study identified the roads and roadsides pillar as having the potential to provide a safety net or buffer when other pillars fail. Improvements could include: raised pedestrian-priority crossings along desire lines to key destinations; wider footpaths with good visibility; addressing shared signal phasing; and improving shoulder width and street lighting on rural roads (Desapriya et al., 2011; Griswold, Fishbain, Washington, & Ragland, 2011; Jurewicz et al., 2017; Makwasha & Turner, 2017; Retting et al., 2003). In particular, future efforts to mandate the incorporation of the understanding of play, placemaking, desire lines, and accessibility issues into street design may be beneficial to make streets places that are healthier and safer (Desapriya et al., 2011; Grisé, 2015; Grisé, Buliung, Rothman, & Howard, 2018).

The analysis reinforced the long-held understanding that crash risk and pedestrian injury outcomes are strongly associated with vehicle speed (Kröyer, 2015; Zeeger & Bushell, 2010). Collectively, these findings reinforced that pedestrians are less likely to survive impacts over 30km/h and therefore the speed zoning of some urban environments, such as in Town Centres, some secondary collector roads, and at school bus stops may need to be reviewed. Government initiatives, such as New Zealand's Speed Management Programme, need to better reflect evidence on speed management measures so that pedestrian safety is continually prioritised and improved. Despite this, the findings showed that pedestrian casualty also occurs at slow speeds. This reinforces the need for a system that not only advocates for slower operating speeds, but also provides a further safety-net through other Safe System pillars, such as mandating reversing cameras in new vehicles, planning for person-centered car park designs, and promoting education around driveway risks.

The fragility of pedestrians was also demonstrated through an examination of the vehicle pillar, with more fatal cases associated with a large mass vehicles, or those with aggressive bonnet shapes. The vehicle contribution to safety should continue to reduce as the presence of more forgiving vehicle fronts, object detection, autonomous emergency braking, reversing cameras, intelligent speed assistance, and other pedestrian-specific safety features become more prevalent over time as technology improves and the fleet is upgraded. However, the 14-year average age of the New Zealand fleet coupled with current vehicle imports laws mean that these emerging technologies will not be widespread in the New Zealand fleet for several years. This can be combated to some degree by proactive vehicle import policies by the New Zealand Government. Safe vehicle systems could be encouraged through changes to import policy, motor vehicle safety standards, and vehicle regulations (Schmitt & Muser, 2016). These could favour vehicles which, in addition to occupant protection, include systems designed to protect vulnerable road users. Some vehicle safety systems could include: pedestrian friendly frontal shape, good direct vision (windscreen and side windows); good indirect vision (mirrors, rear windscreen, reversing cameras) (Cook et al., 2011); and the use of force-absorbing materials on lights, windscreens, and bonnets (Schmitt & Muser, 2016).

Limitations

There are limitations in analysing crash data from police reports alone. Firstly, it is understood that inbuilt system bias exists in police reporting of crashes (Tarko & Azam, 2011). This is partly due to the 'on the spot' nature of the reports, which must be filled out at the scene of the crash. In addition, the language of the CAS forms are inherently biased against the pedestrian (e.g. a pedestrian can only enter the road 'heedless of traffic' or 'deliberately'). This bias can be addressed to a degree by linking police data with hospitalisation data, which contains more detail about the crash from the perspective of the pedestrian's injury outcomes (Cryer et al., 2001). In New Zealand, a national dataset linking road crash data and hospital admissions which could be used by practitioners, researchers, and policymakers is needed. Secondly, non-injury collisions are often under-reported and near-miss events are unlikely to be reported. In comparison, injury crashes occur relatively irregularly. Therefore, focus on these exceptional events only does not provide a thorough understanding of everyday pedestrian risk. Given the low rate and nature of road crashes, it is often difficult to draw statistically significant inferences from these rare and sometimes unique events (Hydén, 1987). While patterns within DSI crashes are useful to some extent, an additional analysis of minor injury and non-injury crashes may yield benefit for developing solutions.

Conclusions

This study gives a better understanding of the context behind pedestrian and traffic conflict and therefore has the potential to contribute to Safe System thinking – to help extend thinking beyond the traditional focus of susceptibility to crash forces and to focus more on developing systems that are robust, forgiving, and anticipate and therefore mitigate problems. Through the sociotechnical system mapping, and the Safe

System review, the research highlights how, across all sociotechnical system levels of transport in New Zealand, the safety, priority, and comfort of people driving vehicles is prioritised over that of pedestrians.

These in-built biases affect the latent system conditions that increase the likelihood of pedestrian DSIs. Ultimately, the values and policies of the high-level transport system require a paradigm shift away from a focus on individual behaviour and towards an ingrained and comprehensive Safe System ethos. These intrinsic system issues could be addressed through higher-level system reforms that prioritise pedestrian safety. These include: giving pedestrian safety and access higher priority in road safety planning, design and investment; managing vehicle speeds down to survivable levels; reducing the aggressivity of the vehicle fleet; promoting pedestrian safety through advertising campaigns; and taking a whole-of-system approach to pedestrian safety. A proactive and systemic approach is required before meaningful street changes and a tangible reduction in the burden of pedestrian casualties in New Zealand can be achieved.

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