A novel methodological approach for understanding the complex relationship between payment structures, enforcement response, and fatigue among heavy-vehicle drivers

Jason Thompson[1] and Mark Stevenson[1]

[1]Monash University Accident Research Centre (MUARC), Monash Injury Research Institute, Monash University, Melbourne, AUSTRALIA

Abstract

Investigations of heavy vehicle crashes have predominantly taken a reductionist view of accident causation. However, there is growing recognition that broader economic factors play a significant role in producing conditions that promulgate increased crash risk, especially in the area of fatigue. The aim of this study was to determine the utility of using agent-based modelling to understand how driver payment methods may influence driver fatigue, crash-risk, and the response of enforcement agencies to major heavy-vehicle crashes. Results showed that manipulation of payment methods within agent-based models can produce similar patterns of driving behaviour among simulated drivers as that observed in real world studies. Drivers operating under simulated 'per-km' and 'per-trip' piece rate incentive systems were significantly more likely to drive while fatigued and subsequently incur all associated issues (loss of license, increased crash risk, increased fines) than those paid under flat-rate 'per hour' methods. Further, the pattern of enforcement response required under 'per-km' and 'per-trip' systems was significantly higher in response to greater numbers of major crashes than in flat-rate, per hour regimes. Agent-based models may be a useful means of determining the potential effect of economic policy settings within freight or other transport systems ahead of policy implementation or change.

Background

Around 250 are people killed as a result of crashes involving a heavy vehicle each year (BITRE, 2013), making heavy-vehicle driving one of the most dangerous occupations in Australia (Transport Workers' Union of Australia, 2011). Driver fatigue is a major contributor to accidents with up to 40% of crashes involving heavy vehicles believed to be caused by fatigue and sleepiness (Haworth, 1998).
Efforts geared toward investigating factors leading to heavy vehicle crashes have predominantly taken a reductionist view of accident causation, focusing on direct technical (e.g., mechanical faults, safety equipment), demographic (e.g., age, experience), and behavioural (e.g., sleepiness, speeding) causes of accidents (Brodie, Lyndal, & Elias, 2009; Brooks, 2002; Duke, Guest, & Boggess, 2010; Häkkänen & Summala, 2001; Raftery, Grigo, & Woolley, 2011; Williamson, 2007). More recently, however, there has been growing recognition that broader economic and organisational factors such as financial pressures and compensation methods play a significant role in producing conditions that encourage fatigue-related driving and may promulgate increased crash risk (Thompson & Stevenson, 2014; Williamson, Feyer, & Friswell, 1996).

The relationship between compensation methods and safety within the trucking industry has been the subject of numerous academic, industrial, and governmental enquiries (Australian Trucking Association, 2011; Belzer, Rodriguez, & Sedo, 2002; Kanazawa, Suzuki, Onoda, & Yokozawa, 2006; Mayhew & Quinlan, 2006; Monaco & Williams, 2000; Quinlan, 2001; Quinlan & Wright, 2008; Rodriguez, Targa, & Belzer, 2006; Williamson, 2007; Williamson et al., 1996). The overwhelming message of such studies is that incentive-based 'piece-rate' compensation methods that tie performance objectives (i.e., deliveries made, tonnage hauled, or km driven) to driver payments result in greater risk of fatigue (Thompson & Stevenson, 2014; Wright & Quinlan, 2008). It has also been argued that piece-rate methods encourage workers to ignore other activities such as rest-breaks, maintenance and/or safety checks because - under compensation structures that where only time spent driving is paid for - these activities represent greater opportunity costs (Burawoy, 1979). Findings from such formal academic literature has also recently gained broader community recognition in Australia through high-profile media coverage of drivers who describe ‘impossible deadlines’ and unsustainably low wage rates that force drivers to extend driving hours, leading to excess fatigue and crashes (Cooper, 2013; Laird, 2014; Long & Harley, 2014).

Despite convincing evidence of the influence of compensation methods on driver fatigue, the links between payment rates and safety are often publicly challenged by industry groups (McKillop, 2014). Disparate views are forwarded regarding whether fatigue constitutes an ongoing concern at all, or if it does, how fatigue management systems should be regulated. Worker representative bodies such as transport unions have generally advocated additional system regulation to ensure safety standards are met or maintained (Rumar, 1999; Transport Workers' Union of Australia, 2011). Owner-drivers, trucking companies and industry bodies, however, have shown preference for more flexible, self-regulated environments that place responsibility on individual companies and drivers for safety, whilst also promoting principles of driver education and enforcement of existing laws and regulations (Australian Fleet Managers Association, 2011; Australian Logistics Council, 2011).

Ironically, increased public focus and scrutiny of existing safety laws often comes in response to the failure of self-regulation to ensure safety standards are upheld. Tragic road incidents can provide the impetus for what appear to be sudden phase transitions between ‘business as usual’ operations occurring below critical levels of safety to almost complete overhaul of safety operations and processes within individual organisations or industries. For example, in 2013 a fuel tanker crash and explosion that resulted in two deaths and five serious injuries instigated a major New South Wales government safety audit of a large, Australian trucking company, Cootes Transport. The mechanical failures that contributed to the incident revealed an operation that was running below accepted levels of safety. Upon inspection, over 40% of Cootes’ fleet was issued with formal mechanical safety warnings (ABC News, 2014b) and over 300 charges were laid against Cootes in relation to breaches of safety (Dingle, 2014). Further charges of dangerous and negligent driving were also laid against the driver (ABC News, 2014a). Rather than a welcome example of existing law and regulation enforcement, however, representatives of the parent company described the safety audit as an instance of ‘unprecedented government scrutiny’ driven by ‘negative press that government officials react to and feed’(O'Sullivan, 2014b). The representative also warned that because of the safety audit, company profits would be negatively affected (due in part to increased maintenance costs) as would up to 540 jobs (O'Sullivan, 2014a).

Whilst the case above is particular to mechanical safety rather than fatigue, it is perhaps a clear example of a company’s sensitivity to the opportunity cost of having trucks ‘off the road’ (Burawoy, 1979). Further, whilst an audit process can demand inspection of a company’s fleet and identify tangible safety defects, it is a far more difficult task in relation to fatigue where the phenomenon is unobservable and dynamic, and where both causes and ‘safe levels’ of fatigue are contested.

The tension played out publicly between government and industry stakeholders regarding the causal factors contributing to fatigue has obscured understanding of the contribution that individual elements make to fatigue risk among heavy-vehicle drivers. Despite the introduction of chain of responsibility laws designed to emphasise the role that all parties with influence over compensation methods and workload demands have in crashes caused by fatigue, in reality, drivers rather than companies bear the brunt of fines and penalties metred out by law enforcement agencies in response to breaches of fatigue regulations (Desai, Ellis, Wheatley, & Grunstein, 2003; O'Neill, 2014). Counterproductively, this has had the consequence of setting some drivers’ opinion against additional chain of responsibility laws designed with their and the community’s safety in mind (e.g., Long & Harley, 2014).

The discussion above demonstrates that clarity of findings linking payment structures to fatigue has failed to translate into comparably effective or accepted industry regulations, policies or workplace practices; certainly none that are as clear or defined as those relating to mechanical safety. In fact, national regulations introduced in order to standardise fatigue regulation across much of Australia have concerned police as much as reassured them (Carey, 2013).

Methodological restrictions

The majority of methodological strategies designed to provide insight into the impact of compensation methods have attempted to draw linear 'dose-response' relationships between remuneration and outcomes such as average speed, driving hours, income, or fatigue (e.g., Sharwood et al., 2013; Sharwood et al., 2012; Thompson & Stevenson, 2014). Although instructive, there is a risk that designs considering only simple relationships between variables may mask the underlying dangers of various compensation methods for heavy-vehicle drivers operating within complex economic and workplace systems. For instance, although mean speed or mean time taken between driving breaks could potentially be similar between compensation methods, it may be that various methods create incentives for greater likelihood of infrequent but extreme driving behaviours (e.g., driving overnight without sleep in order to make schedule) that might otherwise be masked by 'averaged' figures. Added to this is that, whilst devastating and unacceptably frequent, heavy-vehicle transport is so ubiquitous that accidents are still relatively rare in terms of per km, per trip, or flat-rate events (National Transport Commission, 2011). Capturing them in sufficient volume to consider the long-term implications of any policy or safety setting is therefore extremely challenging.

To overcome the methodological issues contained within this area of road safety and system-design, an improved method of understanding the complex set of factors that contribute to driver fatigue and the response of regulators is required. Rather than system complexity and relative infrequency of observed crashes then masking efforts to improve safety by making discussion of potential remedies more opaque, the methodology should assist us to understand relationships more clearly and assist efforts to understand effective policy or regulatory interventions and the consequences of these interacting factors more broadly. Such methodology may be particularly pertinent to road traffic and road safety research when relationships between variables are often non-linear, involve feedback mechanisms, or demonstrate binary outcomes (e.g., a crash, a death, or an injury) (Khalesian & Delavar, 2008). It is also particularly pertinent in areas of safety where 'in-situ' experimentation with policy or safety settings is potentially hazardous and ethically impossible.

This study will investigate the association between compensation methods, fatigue, and regulation using a novel methodological approach. Building on a review and integration of formal research and industry literature, we will construct a complex systems analysis using agent-based simulation to generate a working theoretical model of the relationship between remuneration structures, fatigue risk, regulation and enforcement within the heavy-vehicle industry. The model will alter compensation methods among drivers within a simulated freight transport system (STS), mirroring the manner in which they are designed to incentivise driver behaviour. The model will then observe emergent behaviours of simulated heavy-vehicle drivers under various compensation methods to determine those that produce the highest levels of fatigue-related crash-risk and highest rates of enforcement response by regulators. The utility of using agent-based modelling to replicate the effect of compensation methods or other policy settings on safety within the heavy vehicle industry will then be discussed.

Method

In order to simulate the effect of compensation methods on levels of driver fatigue, we constructed a simulated transport system (STS) using NetLogo (Wilensky, 2013). The STS consisted of 200 trucks, 25 randomly located consignors, and a dynamic number of enforcement agents located on a single plane. The behaviour of each driver, enforcement agent, and consignor in the system was influenced by a combination of established and assumed relationships between variables present in the truck safety literature (see Figure 1).

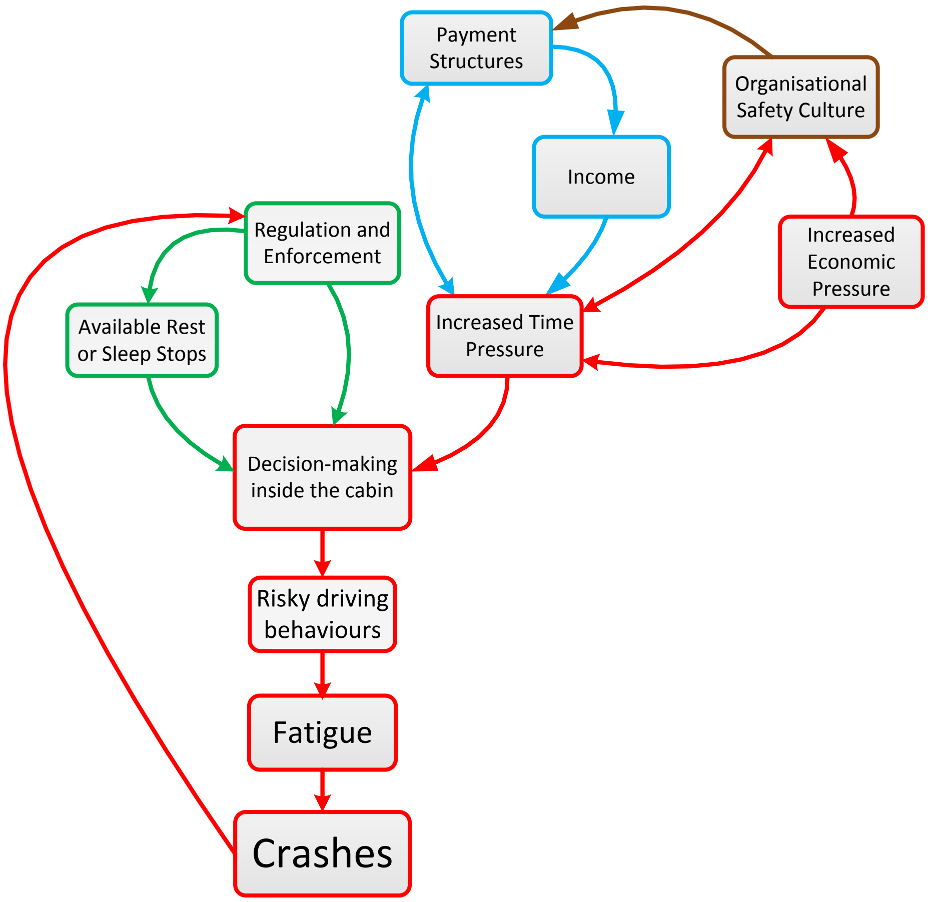


Figure 1. Proposed relationships between factors contributing to the likelihood of crashes present in academic, industrial, and governmental research and enquiries

Drivers within the STS were presented with three behavioural options at any time as they moved between consignors; 1) drive, 2) rest, or 3) sleep. Driving areas were represented by dark grey areas in the system, rest areas were represented by medium-grey areas, and sleep areas were represented by light-grey areas (see Figure 2).

Drivers were compensated under three separate methods; per-trip rates, per-km rates, and flat-rate rates. Both ‘per-trip’, and ‘per-km’ compensation rates represented examples of ‘piece-rate’ regimes common in the heavy-vehicle industry and described elsewhere (Belzer et al., 2002).

Behaviour of drivers in response to economic incentives

Drivers within the system were incentivised to seek work that, where conditions enabled it, kept their income at or above the mean income for all drivers in the system. Consignors offered potential jobs to drivers of varying value based on the experimental conditions outlined below.

‘Per-km’ incentive condition

Under the ‘per km’ incentive condition, drivers looked for jobs that were equal to or greater than the mean value of all jobs on offer in the system. Each consignor’s mean distance from all vehicles was multiplied by a standard ‘per-km’ rate with a random-poisson distribution in order to calculate the offer provided by the consignor. The effect of this was that consignors further away from the mean distance of all consignors to heavy vehicles typically offered higher per-km rates to drivers. This motivated them to seek consignors that were at a greater distance from themselves and offering higher per-km rates. The rate offered by consignors was reset every 50 time-steps in order to reflect market supply / demand dynamics in the face of gravitation of heavy vehicles toward high-paying consignors.

'Per-trip' incentive condition

Under the 'per-trip' piece-rate condition, drivers looked for consignors that were offering a net return for delivery greater than the mean offer of consignors, regardless of location or distance. Similar to the 'per-km' condition, above, consignors revised their offer every 50 time-steps to a randomly allocated, normally distributed dollar figure with a random-poisson distribution.

'Flat-rate' incentive condition

Under the 'flat-rate' condition, drivers travelled to random consignors within the network and were remunerated for a standard 40 hour week. To ensure consistent variability within the distribution of payment offers within each compensation method, payment rates offered to drivers under 'per-km', 'per-trip', and 'flat-rate' were centred around a normal-poisson distribution and converted to z-scores for analysis.

Pressure

To further replicate the effect of compensation methods that incentivised fast delivery times and higher incomes, drivers were also exposed to a 'pressure' factor reflective of literature pointing to opportunity costs associated with time off the road, falling behind on schedules, and low incomes (Belzer et al., 2002; National Transport Commission, 2006; Williamson, Feyer, Friswell, & Sadural, 2001). Pressure on drivers increased if they were 1) travelling below the mean speed of other drivers, 2) earning less money than the mean income of other drivers, and 3) if they experienced delays when loading or unloading at consignors. Pressure decreased on drivers if any of the reverse scenarios were true. The effect of 'pressure' on drivers was to affect decision-making in relation to driving, resting, or sleeping. Drivers under high pressure (due to below average speed or lower than average incomes) were less likely to rest or sleep when presented with the opportunity to do so. A flow-chart depicting the decision-making process of drivers in response to competing incentives, and pressure within the system is shown in Figure 2.

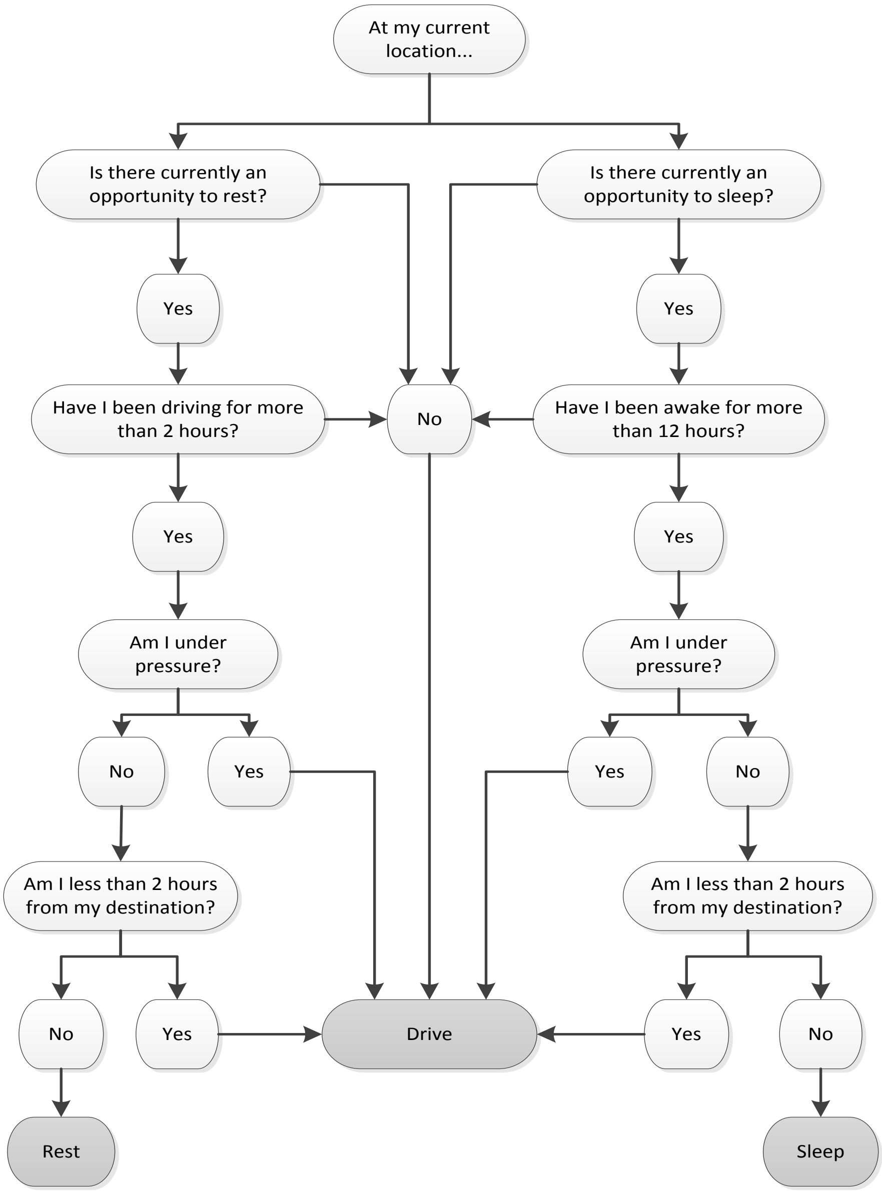


Figure 2. Decision-making protocol for drivers within the simulated transport system (STS)

Economic pressure, fatigue regulation, and enforcement

Economic pressure

Economic pressure was placed on the system through generation of additional productive dark-grey 'driving' areas. When drivers passed over these areas they did not have the opportunity to rest or sleep, driver speed increased by 1 speed unit up to a maximum of 10 speed units, and the number of hours spent driving increased by 1 unit.

Fatigue regulation

Levels of fatigue were managed by introducing additional light grey 'sleep' areas, and medium-grey 'rest' areas into the transport system. When drivers passed over sleep areas, they had the option to stop and sleep for a period of time equivalent to 8 hours. Drivers took advantage of the opportunity to sleep on condition that they; 1) were not under pressure, 2) were more than 2 hours away from their destination, and 3) they had not already slept in the previous 12 hours.

Similarly, when drivers passed over medium-grey 'rest' areas, they took advantage of a rest break on condition that they; 1) were not under pressure, 2) were greater than 2 hours away from their destination, and, 3) they had not taken a break in the previous 2 hours.

Enforcement

The constant pressure exerted on the system to increase productivity, combined with the introduction of rest and sleep opportunities resulted in a dynamic exchange between these opposing factors, reflective of that described between regulators, enforcement agencies, and industry in the introduction. To further replicate the role of regulation and enforcement agencies (e.g., police, roads authorities) within the system, enforcement units in the form of white vehicles were also introduced into the system under conditions that replicated infrequent, but serious clusters of heavy vehicle crashes.

A single enforcer unit was present within the transport system at time 0. If the system then experienced a major crash event defined as those where two or more crashes co-occurred, the number of enforcers increased sharply by 25 units to reflect community and regulatory response. The number of enforcers then reduced at the rate of 1 unit per time step for each subsequent step where < 2 accidents were observed. The role of enforcers in the system was to 'chase' heavy vehicle drivers within the system whose levels of fatigue were high (> 4 hours driving without a break and/or > 16 hours driving without sleep). If enforcement units 'caught' heavy-vehicles with characteristics that matched these conditions, they drivers received a fine equivalent to 20% of their weekly income. The effect of this was also to reduce the speed of the driver (through stopping their progress, which increased the pressure on the driver. Drivers fined a total of 3 or more times within a 100 time-step window recorded a 'loss of license'. Drivers who had received 2 fines in the previous 100 time-steps observed all available opportunities to rest or sleep if they were above recommended thresholds (3 hours continuous driving for rest-breaks, 14 hours without sleep for sleeping), regardless of pressure. Consistent with motivations present in the literature (National Transport Commission, 2006), the effect of this was to simulate drivers' intent to avoid further demerit points that would result in loss of license.

Crash risk

In order to simulate risks associated excess fatigue, drivers that had driven without a break (either as a rest or sleep) in excess of 4 hours were assigned an 'at risk' status, reflecting findings from Stevenson et al. (2014). For every time-step that passed with a positive 'at-risk' status, heavy vehicle drivers had a 0.1% chance of involvement in a fatigue-related crash. The longer drivers spent in an 'at risk' state, the greater exposure to crash risk they had.

System visualisation

To aid interpretation of the current system state through visualisation, each heavy-vehicle within the system laid a path of colour that matched their present fatigue state. When the system appeared predominantly red, drivers were under high levels of fatigue. When it appeared predominantly green, drivers had lower levels of fatigue. When large white areas appeared in the system, this indicated a large enforcement presence (see Figures 3a-c)

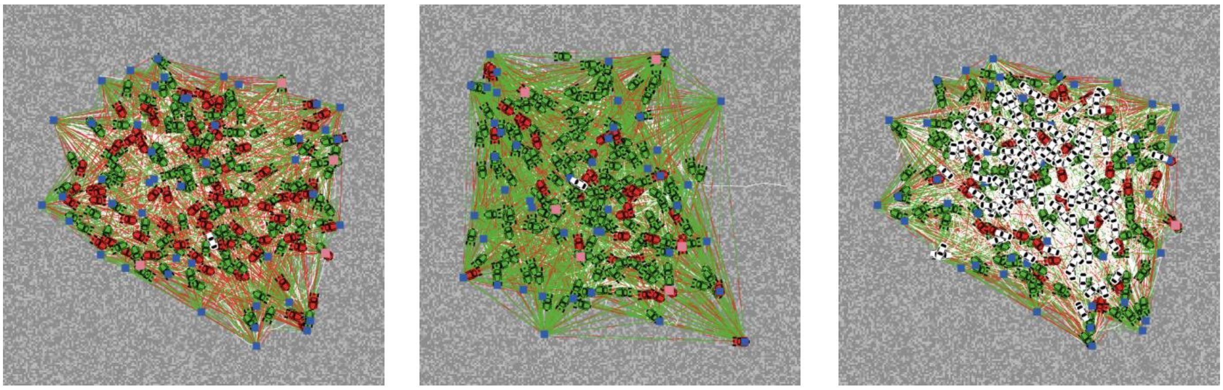


Figure 3a, 3b, and 3c. Demonstration of conditions within the simulation when heavy vehicle drivers were under high levels of fatigue (a), low levels of fatigue (b), and conditions under which a large enforcement presence was deployed in response to major collisions (c)

Experimental conditions

The experiment consisted of a series of 100 x 1000 time-step simulations conducted under each of 3 'per-km', 'per-trip', and 'flat-rate' compensation payment condition. Monitors within the system tracked the behaviour of drivers and enforcement agencies under each condition across the following variables:

- Average number of fines incurred by drivers at any time
- Mean and standard deviation of hours spent without sleep by drivers
- Mean and standard deviation of hours spent driving without taking a rest break
- Proportion of drivers with the system that had driven for greater than 4 hours without rest
- Mean pressure that drivers were under in the system
- Mean speed of drivers
- Mean income of drivers
- Mean distance of drivers to their target consignor
- Number of crashes that had occurred in the system at any time
- Number of drivers that had lost their license due to being caught at least 3 times with high levels of fatigue
- Total crashes over the course of the simulation
- Total number of deliveries made by drivers to consignors

Results

Table 1 shows the mean and standard deviations for all variables under study under each of the three driver payment methods groups (per-km, per-trip, and flat-rate). It should be stated that due to the vast amount of data produced by the current model (and agent-based-models generally), they are often over-powered and hence, ill-suited to interpretation through traditional statistical methods. We therefore present the results of multivariate analysis of variance (MANOVA) procedures to demonstrate the patterns observed in the data rather than as a strict statistical guide to interpretation of differences between experimental groups across observed variables.

Results of the MANOVA demonstrated a significant multivariate effect across compensation group for all variables under study (F (20, 578) = 295.9, p<.001). Post-hoc analysis demonstrated the direction of effects between payment groups (see Table 1). Significant differences were observed between payment groups across each observed variable (p<.001) indicating that drivers within systems operating under per-km piece-rate methods were most likely to demonstrate the longest periods driving without sleeping or taking a rest-break. Drivers operating within per-km payment systems also experienced the highest mean levels of pressure and highest mean speeds. As a result of the both the pressure to continue driving and the incentive to drive further distances, less overall deliveries were made by per-km drivers than either ‘flat-rate’ or ‘per-trip’ drivers. Results also showed that drivers in per-km payment systems also experienced the greatest number of fines, highest rates of loss of license, most number of crashes, and greatest requirement for enforcement agencies to respond to major crashes.

Results for per-trip drivers tended to mirror those of per-km drivers, however, their behaviour across all driving behaviours of concern were consistently less risky in line with reduced pressure on per-trip drivers. Consequently, average number of fines, losses of license, total crashes, and average number of regulators introduced into the system as response to major crashes were also lower in response. Consistent with their motivation to deliver any consignment to any destination at a reasonable profit while maintaining at least average speeds, per-trip drivers completed the most deliveries of all groups at mean speeds just under those of per-km drivers.

The behaviour of drivers within ‘flat-rate’ systems demonstrated consistently lower levels of risk across all variables under study. Measurement of pressure associated with ‘flat-rate’ payment conditions demonstrated that ‘flat-rate’ drivers also experienced the lowest levels of pressure and were hence, more likely to take rest and sleep breaks when available. Total deliveries made by ‘flat-rate’ drivers were just under those made by per-trip drivers but greater than the total made by per-km drivers. Flat-rate drivers experienced far fewer losses of license which was proportionately far lower that differences across other observed measures. This was perhaps due to a multiplicative effect of greater observance by flat-rate drivers of rest and sleep breaks, a reduction in consequent fatigue-related crashes and major incidents, and lower enforcement presence as a result. Graphical representation of all observed variables under each payment method can be observed in Appendix 1.

Table 1. Differences observed for all drivers and enforcement agencies based on compensation methods employed within the simulated transport system

Observed variables	Payment method	Mean	Std. Error
Fines	Flat rate	0.0	0.0
	Per trip	0.2	0.0
	Per km	0.3	0.0
Enforcement strength	Flat rate	18.3	1.8
	Per trip	31.4	1.8
	Per km	44.2	1.8
Mean hours driving without sleep	Flat rate	7.3	0.0
	Per trip	10.5	0.0
	Per km	11.0	0.0
Mean hours driving without rest	Flat rate	2.2	0.0
	Per trip	5.3	0.0
	Per km	6.0	0.0
Mean speed	Flat rate	77.6	0.1
	Per trip	83.8	0.1
	Per km	84.4	0.1
% drivers with > 4 hours continuous driving	Flat rate	16%	0%
	Per trip	36%	0%
	Per km	40%	0%
Mean lost licenses	Flat rate	1.0	3.0
	Per trip	27.6	3.0
	Per km	57.2	3.0
Total crashes	Flat rate	119.9	0.9
	Per trip	137.4	0.9
	Per km	143.4	0.9
Mean pressure	Flat rate	0.1	0.0
	Per trip	2.2	0.0
	Per km	2.6	0.0
Total deliveries	Flat rate	2783	12
	Per trip	2860	12
	Per km	2288	12

*Note: Differences between each payment group across all observed variables were significant at $p<.001$.

Observation of enforcement response over time between systems operating under different payment methods demonstrated that significant increases in enforcement resources deployed in response to major collisions could occur in any one of the three payment conditions. These ‘spikes’ in regulation and enforcement were reminiscent of those observed in real-world situations (e.g., the 2013 Mona-Vale crash) where critical incidents result in a sudden increase in enforcement activity. It is important to note that whilst major crashes occurred in each payment condition, they were more likely to occur in the ‘per-km’ and ‘per-trip’ condition than the ‘flat-rate’ condition (see Figure 3). Similarly, due to the infrequent nature of major collisions and the requirement for a number of elements to occur simultaneously for a ‘major collision’ to occur, systems operating under ‘per-km’ and ‘per-trip’ payment methods also enjoyed lengthy periods of high productivity, high pressure, and high fatigue without encountering any major collisions or attention from enforcement agencies.

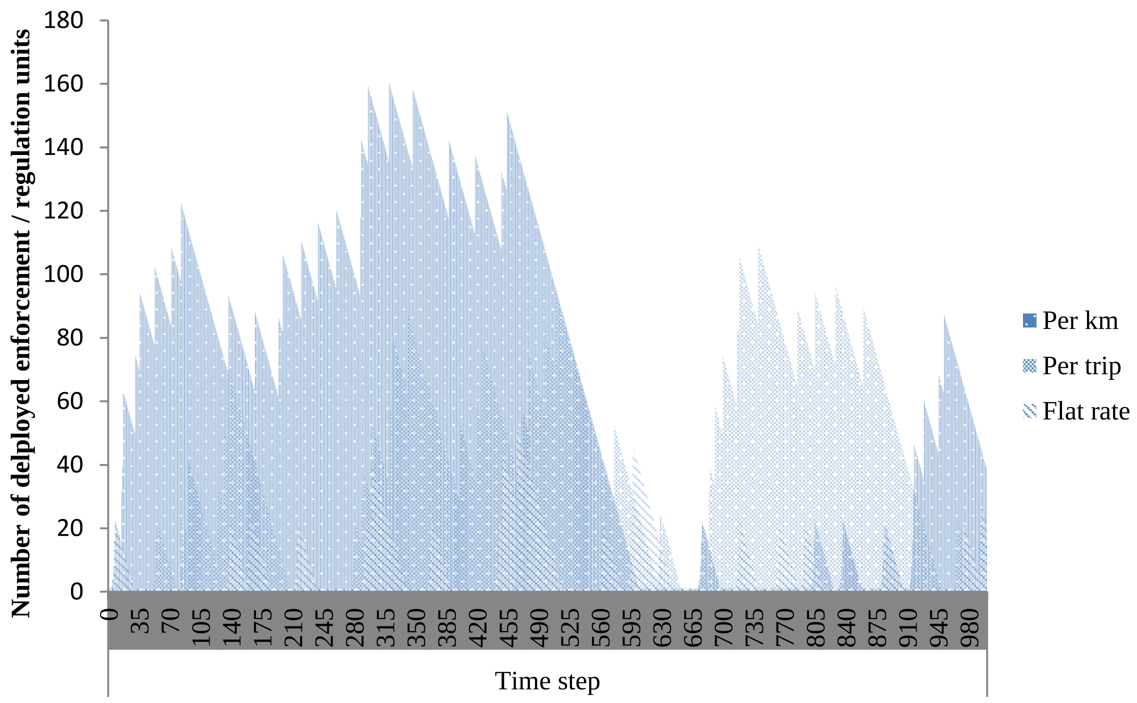


Figure 3. Example of change in deployed enforcement units over time for a single simulation run within a system operating under per-km, per-trip, and flat-rate payment methods

Discussion

The aim of this study was to determine whether an agent-based model that manipulated payment methods for drivers within a simulated heavy-vehicle freight network could usefully replicate the reported emergent fatigue-related driving behaviour of both drivers and enforcement agencies within a real-world system. The results observed here appear consistent with observational studies conducted over the past 20 years indicating that 'piece-rate' payment methods increase pressure on drivers that may lead to decision-making resulting in riskier driving practices (Thompson & Stevenson, 2014; Williamson et al., 1996; Wright & Quinlan, 2008). As such, we believe that agent-based modelling may provide a useful means of understanding the effect of broad policy and economic settings on fatigue, crash risk, and the response of enforcement and regulatory agencies.

Despite its successes, the current model's ability to replicate patterns shown in the real world is not enough to determine whether the means by which it achieves such replication is mechanistically accurate. Central to the validation of socio-technical models such as these is that they should also be built on an analysis of expert opinion, and should produce results consistent with previously published academic and grey literature (van Dam, Nikolic, & Lukszo, 2012). Lastly, it is considered not enough to simply replicate final results but to 'grow' observed phenomena in realistic ways (Epstein, 1996). That is, the end results should not only arrive at patterns observed in the real world but should progress there over time in a manner consistent with experience. For example, it would not be sufficient in the current model to simply state that deployment of regulation and enforcement responses was greater in the 'per-km' or 'per-trip' conditions. To be truly reflective of realistic patterns, the system needs to grow conditions under which pressure on drivers was high resulting in decision-making that led to risky driving practices, and then cascading into increased fatigue, major crashes, and heightened response from regulators as depicted in Figure 1. Similarly, the model should also reflect periods where the majority of drivers are operating outside standard fatigue safety boundaries, but major collisions do not occur. We believe that this model effectively achieves these criteria.

Perhaps most importantly, the current model quantifies and makes clear a phenomenon that, at least within the academic literature, has been assumed to be present but rarely quantified: pressure. Pressure within the current model a key driver of decision-making at all stages. In effect, it is the antithesis to safety. When pressure is low, decision-making follows accepted rules and regulations. When pressure is high, fatigue rules and regulations are more likely to be ignored (see Figure 2). The ability to quantify workplace environment and policy settings that build or lessen pressure on drivers and to directly observed this assumed relationship, as well as its real-time effect on decision-making and system safety is one of the great advantages of this current model.

Despite the apparent face-validity of the model, it contains many limitations. Firstly, the fact that single rather than multiple payment methods operate in each simulated system may exacerbate observed effects. In reality, individual drivers unhappy with their employment or payment arrangements may have option to change employers or opt for alternative payment methodologies. Further the scale that the model works upon is in no way realistic. Although efforts have been made to provide measurement units (e.g., speed, hours, income, etc.) that are assist understanding, they cannot be considered accurate. The utility of the model in its present form, therefore, should be considered directional rather than predictive.

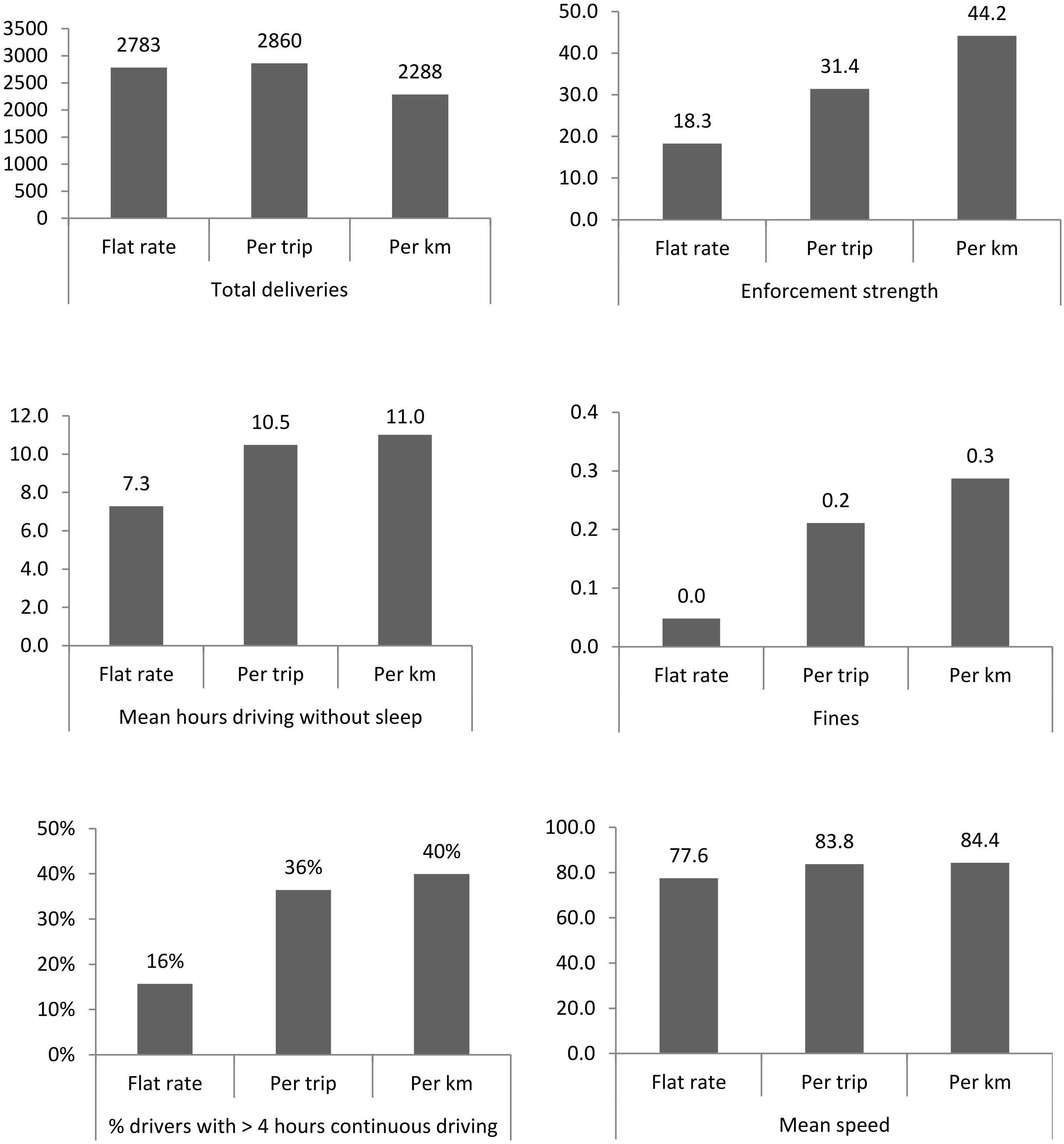
High-profile crashes attract great media and community attention, and companies' responses to such incidents are heavily scrutinised. It remains the case that high-level factors contributing to conditions of compromised safety are often not identified as possible contributory factors in the immediate aftermath of tragedies. For example, in response to a very recent triple fatality in north-east Victoria, the Chief Executive Officer of BP Australia, whose company's truck was involved in the crash said that, "While the precise cause of this tragic incident may not be known for some time, it is essential we do all that we can to understand how this occurred and to ensure that it cannot happen again" (BP Australia Press Office, 2014). BP went on to state that they had immediately recalled all trucks within their Australian fleet and were cooperating with regulators assigned to investigate the incident.

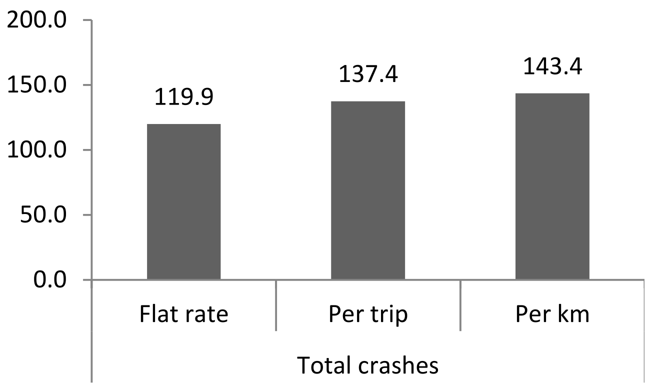
Whilst the investigation into this tragedy is ongoing (ABC News, 2014c) and BP's statement of concern and compassion for families is without fault, their statement specifically emphasises the company's focus on determining the "precise cause" of the crash (e.g., immediate pre-cursors such as mechanical failure or driver error). By simple omission, it de-emphasises a broader consideration of conditions under which mechanical failures or driver errors are more or less likely to occur. If companies truly wish to "do all that (they) can to understand how (it) occurred …. and ensure it cannot happen again", it is important that consideration of possible contributing factors not be immediately limited to mechanical or driver faults as final weak links in a chain of reductionism (Beresford, 2010). Consideration must also be given to potential economic and workplace conditions that create environments in which weak links are likely to proliferate.

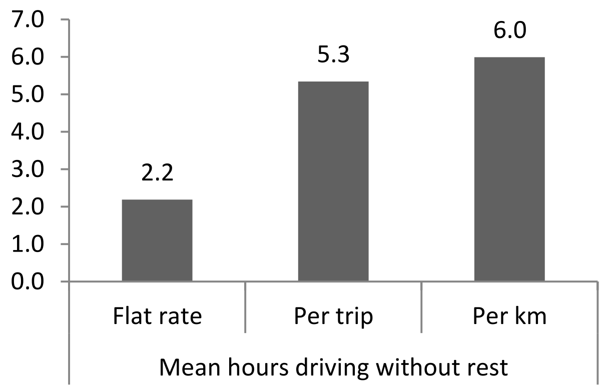
Conclusions

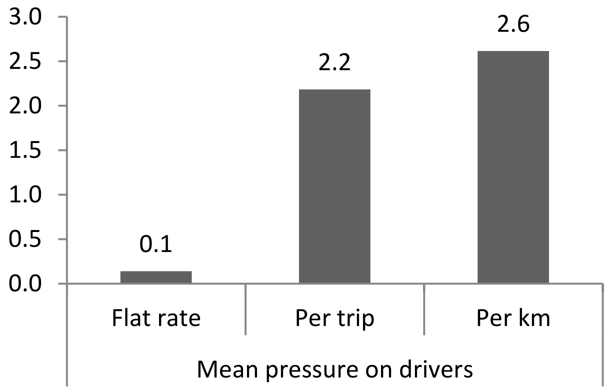
Incentive-based compensation methods that associate performance objectives with payments result in greater risk of fatigue-related driving behaviour (Thompson & Stevenson, 2014). The mechanism by which payment conditions are assumed to affect behaviour is through the production of pressure on drivers to continue beyond regulated or advised fatigue limits (Williamson et al., 2001; Wright & Quinlan, 2008). Agent-based modelling may provide researchers with a useful mechanism for studying relationships between factors present in the heavy-vehicle transport system and their effect on system safety and regulatory response. Furthermore, with adequate complexity and expert agreement as to assumed relationships between important variables within any model, agent-based modelling may provide policy-makers with innovative tools to understand the potential effect of remuneration regulation decisions on driver and community safety ahead of time.

Appendix 1. Mean differences observed for all drivers and enforcement agencies based on compensation methods employed within the simulated transport system.




200.0
150.0
100.0
50.0
0.0
119.9
137.4
143.4
Flat rate
Per trip
Per km
Total crashes


7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2.2
5.3
6.0
Flat rate
Per trip
Per km
Mean hours driving without rest


3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.1
2.2
2.6
Flat rate
Per trip
Per km
Mean pressure on drivers

References

ABC News. (2014a). Cootes tanker crash: Charges laid against driver in deadly crash in Sydney's north last year. *ABC Online*. http://www.abc.net.au/news/2014-03-12/charges-laid-against-driver-in-tanker-crash/5314158

ABC News. (2014b). Cootes Transport trucks facing NSW roads ban over hundreds of safety defects. *ABC Online*. Retrieved from abc.net.au website: http://www.abc.net.au/news/2014-03-06/cootes-transport-given-two-weeks-to-show-why-it-should-continue/5303716

ABC News. (2014c). VicRoads begins inspections of BP truck fleet following fatal crash. Retrieved August 8th, 2014, 2014, from http://www.abc.net.au/news/2014-08-08/vicroads-inspects-bp-truck-fleet-following-fatal-crash/5657904

Australian Fleet Managers Association. (2011). Submission to the Safe Roads Safe Roads directions paper. Melbourne: Australian Fleet Managers Association.

Australian Logistics Council. (2011). Submission: Safe Roads Safe rates direction paper. In KM Corke and Associates (Ed.). Australian Capital Territory: Australian Logistics Council.

Australian Trucking Association. (2011). Submission: Safe Rates Directions Paper: Australian Trucking Association.

Belzer, M. H., Rodriguez, D., & Sedo, S. A. (2002). Paying for safety: An economic analysis of the effect of compensation on truck driver safety.

Beresford, M. J. (2010). Medical reductionism: lessons from the great philosophers. *QJM, 103*(9), 721-724. doi: 10.1093/qjmed/hcq057

BITRE. (2013). *Road Deaths Australia, 2012 Statistical Summary*. Canberra: Commonwealth of Australia.

BP Australia Press Office. (2014). BP statement on Wodonga accident [Press release]. Retrieved from http://www.bp.com/en_au/australia/media/media-releases/statement-wodonga-accident.html

Brodie, L., Lyndal, B., & Elias, I. J. (2009). Heavy vehicle driver fatalities: Learning's from fatal road crash investigations in Victoria. *Accident Analysis & Prevention, 41*(3), 557-564. doi: http://dx.doi.org/10.1016/j.aap.2009.02.005

Brooks, C. (2002). *Speed and heavy vehicle safety*.

Burawoy, M. (1979). *Manufacturing consent: Changes in the labor process under monopoly capitalism*: University of Chicago Press.

Carey, A. (2013). Truckies may exploit new laws to work longer hours. *The Age*. http://www.theage.com.au/national/truckies-may-exploit-new-laws-to-work-longer-hours-20131109-2x8uv.html

Cooper, A. (2013). Truckie Garry Mitchell's diary reveals fatigue before fatal crash. *The Age*. http://www.theage.com.au/national/truckie-garry-mitchells-diary-reveals-fatigue-before-fatal-crash-20131109-2x8wi.html

Desai, A. V., Ellis, E., Wheatley, J. R., & Grunstein, R. R. (2003). Fatal distraction: a case series of fatal fall-asleep road accidents and their medicolegal outcomes. *Medical journal of Australia, 178*(8), 396-399.

Dingle, S. (2014). Cootes Transport charged with 300 offences in NSW local court. *ABC Online*. Retrieved from ABC News website: http://www.abc.net.au/news/2014-02-18/cootes-transport-charged-with-300-offences-in-nsw-local-court/5268196

Duke, J., Guest, M., & Boggess, M. (2010). Age-related safety in professional heavy vehicle drivers: A literature review. *Accident Analysis & Prevention, 42*(2), 364-371. doi: http://dx.doi.org/10.1016/j.aap.2009.09.026

Epstein, J. M. (1996). *Growing artificial societies: social science from the bottom up*: Cambridge: MIT Press.

Häkkänen, H., & Summala, H. (2001). Fatal traffic accidents among trailer truck drivers and accident causes as viewed by other truck drivers. *Accident Analysis & Prevention, 33*(2), 187-196. doi: http://dx.doi.org/10.1016/S0001-4575(00)00030-0

Haworth, N. (1998). Fatigue and fatigue research: the Australian experience. *Accident Research Centre, Monash University*.

Kanazawa, H., Suzuki, M., Onoda, T., & Yokozawa, N. (2006). Excess workload and sleep-related symptoms among commercial long-haul truck drivers. *Sleep and Biological Rhythms, 4*, 121–128.

Khalesian, M., & Delavar, M. (2008). A multi-agent based traffic network micro-simulation using spatio-temporal GIS. *Intl. Archives Photogrammetry, Remote Sensing & Spatial Info. Sci, 12*(7), 31-35.

Laird, P. (2014). Too many loads on our roads when rail is the answer. *The Conversation*. http://theconversation.com/too-many-loads-on-our-roads-when-rail-is-the-answer-24118

Long, S., & Harley, W. (Writers). (2014). This Trucking Life [Film], *Four Corners*. Australia: Australian Broadcasting Corporation.

Mayhew, C., & Quinlan, M. (2006). Economic pressure, multi-tiered subcontracting and occupational health and safety in Australian long-haul trucking. *Employee Relations, 28*(3), 212-229.

McKillop, C. (2014). Truckies hit back at Four Corners' claims. *ABC Rural*. Retrieved from abc.net.au/news website: http://www.abc.net.au/news/2014-02-04/truckies-hit-back-at-four-corners-claims/5238038

Monaco, K., & Williams, E. (2000). Assessing the Determinants of Safety in the Trucking Industry. *Journal of Transportation and Statistics, 3*, 69-80.

National Transport Commission. (2006). Speed behaviours of heavy vehicle drivers: a national study. Melbourne, Australia: National Transport Commission.

National Transport Commission. (2011). Heavy Vehicle National Law regulation Impact Statement. Melbourne.

O'Neill, S. (2014). Pushing it up the chain: Why big business can't ignore truck safety. *The Conversation*. http://theconversation.com/pushing-it-up-the-chain-why-big-business-cant-ignore-truck-safety-23178

O'Sullivan, M. (2014a). 540 jobs to go as McAleese halves Cootes fuel truck fleet. *The Sydney Morning Herald*. Retrieved from The Sydney Morning Herald website: http://www.smh.com.au/business/540-jobs-to-go-as-mcaleese-halves-cootes-fuel-truck-fleet-20140218-32wyk.html

O'Sullivan, M. (2014b). Relentless government scrutiny blamed for Cootes halving is fuel-haulage fleet. *The Age*. Retrieved from www.theage.com.au website: http://www.theage.com.au/national/relentless-government-scrutiny-blamed-for-cootes-halving-is-fuelhaulage-fleet-20140218-32ykt.html

Quinlan, M. (2001). *Report of inquiry into safety in the long haul trucking industry*: Motor Accidents Authority of New South Wales.

Quinlan, M., & Wright, L. (2008). Remuneration and safety in the Australian heavy vehicle industry: a review undertaken for the National Transport Commission.

Raftery, S. J., Grigo, J. A., & Woolley, J. E. (2011). Heavy vehicle road safety: A scan of recent literature. *Journal of the Australasian College of Road Safety, 22*(3), 18-24.

Rodriguez, D. A., Targa, F., & Belzer, M. H. (2006). Pay incentives and truck driver safety: a case study. *Industrial and Labor Relations Review*, 205-225.

Rumar, K. (1999, January 26th, 1999). *Transport safety visions, target and strategies: Beyond 2000.* Paper presented at the European Transport Safety Lecture, Brussels.

Sharwood, L. N., Elkington, J., Meuleners, L., Ivers, R. Q., Boufous, S., & Stevenson, M. (2013). Use of caffeinated substances and risk of crashes in long distance drivers of commercial vehicles: case-control study. *BMJ, 346*. doi: 10.1136/bmj.f1140

Sharwood, L. N., Elkington, J., Stevenson, M., Grunstein, R. R., Meuleners, L., Ivers, R. Q., . . . Wong, K. K. (2012). Assessing Sleepiness and Sleep Disorders in Australian Long-Distance Commercial Vehicle Drivers: Self-Report Versus an "At Home" Monitoring Device. *Sleep, 35*(4), 469-475. doi: Doi 10.5665/Sleep.1726

Stevenson, M. R., Elkington, J., Sharwood, L., Meuleners, L., Ivers, R., Boufous, S., . . . Wong, K. (2014). The role of sleepiness, sleep disorders, and the work environment on heavy-vehicle crashes in 2 Australian states. *Am J Epidemiol, 179*(5), 594-601. doi: 10.1093/aje/kwt305

Thompson, J., & Stevenson, M. (2014). Associations between methods of heavy vehicle driver compensation and fatigue-related driving behaviour. *Traffic Injury Prevention, In Press*.

Transport Workers' Union of Australia. (2011). Make Our Roads Safer For All Australians: Submission to the House Standing Committee on Infrastructure and Communications with regard to the Road Safety Remuneration Bill 2011. Sydney: Transport Workers' Union of Australia.

van Dam, K. H., Nikolic, I., & Lukszo, Z. (2012). *Agent-based modelling of socio-technical systems* (Vol. 9): Springer.

Wilensky, U. (2013). Netlogo (Version 5.0.4). Il: Centre for Connected Learning and Computer-Based Modeling, Northwestern University. Retrieved from ccl.northwestern.edu/netlogo

Williamson, A. (2007). Predictors of psychostimulant use by long-distance truck drivers. *Am J Epidemiol, 166*(11), 1320-1326.

Williamson, A., Feyer, A., & Friswell, R. (1996). The impact of work practices on fatigue in long distance truck drivers. *Accident Analysis & Prevention, 28*(6), 709-719.

Williamson, A., Feyer, A., Friswell, R., & Sadural, S. (2001). Driver fatigue: A survey of professional long distance heavy vehicle drivers in Australia. Canberra: Australian Transport Safety Bureau.

Wright, L., & Quinlan, M. (2008). Safe payments–Addressing the underlying causes of unsafe practices in the road transport industry. *Melbourne, National Transport Commission*.