Don’t blame the driver: A systems analysis of the causes of road freight crashes

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Abstract

Although many have advocated a systems approach in road transportation, this view has not meaningfully penetrated road safety research, practice or policy. In this study, a systems theory-based approach, Rasmussens's (1997) risk management framework and associated Accimap technique, is applied to the analysis of road freight transportation crashes. Twenty-seven highway crash investigation reports were downloaded from the National Transport Safety Bureau website. Thematic analysis was used to identify the complex system of contributory factors, and relationships, identified within the reports. The Accimap technique was then used to represent the linkages and dependencies within and across system levels in the road freight transportation industry and to identify common factors and interactions across multiple crashes. The results demonstrate how a systems approach can increase knowledge in this safety critical domain, while the findings can be used to guide prevention efforts and the development of system-based investigation processes for the heavy vehicle industry. A research agenda for developing an investigation technique to better support the application of the Accimap technique by practitioners in road freight transportation industry is proposed.

Keywords: road freight transportation, systems theory, safety, heavy vehicles.

Introduction

Safety in road freight transportation represents a long standing public health problem (e.g. Friswell & Williamson, 2010; Smith & Williams, 2014; Torregroza-Vargas et al., 2014). For example, in the United Stated, 8% of all road deaths have been attributed to heavy vehicle crashes (Kanazawa et al., 2006), whereas in Australia, heavy vehicle driving is considered to be one of the most dangerous occupations (SafeWork Australia., 2011; Transport Workers' Union of Australia, 2011), representing 16% of total road fatalities (BITRE, 2013). These figures are not surprising given that the work environment predisposes professional heavy-vehicle drivers to a number of unsafe working conditions, including a high level of exposure to the road environment and tight delivery schedules (Thompson & Stevenson, 2014).

Despite acknowledgement of the challenging working conditions, investigations of heavy vehicle crashes have primarily adopted a reductionist approach focussed on identifying unsafe driver behaviours, such as inappropriate speed (e.g. Brodie et al., 2009; Chang & Mannering, 1999), fatigue (e.g. Arnold et al., 1997; Feyer, Williamson, & Friswell, 1997; Häkkänen & Summala, 2001; Stevenson et al., 2013) and drug use (e.g. Brodie et al., 2009; Brooks, 2002; Duke et al, 2010; Häkkänen & Summala, 2001; Raftery et al., 2011; Williamson, 2007). While this research has informed the development of targeted preventive strategies, this approach implies that drivers are to “blame” for road freight transportation crashes. The complex system of factors that interact to generate hazardous situations and unsafe driver behaviours has largely been ignored (Salmon & Lenné, in press; Thompson & Stevenson, 2014; Williamson et al., 1996). This reductionist, driver focussed approach to road safety has been criticised as one of the barriers preventing the achievement of further reductions in road trauma (e.g. Salmon & Lenné, in press; Salmon et al., 2012).

Road freight transportation is no different to any other transport system in that it has the characteristics of a complex sociotechnical system. To illustrate this system, a crash caused by fatigue might not only reflect the individual driver's disregard of fatigue management policies and procedures (eg., inadequate rest breaks), but also the supervisor's lack of involvement in journey management (ie., lack of involvement/approval of trip plan), or the type of compensation method used by the organisation to align performance objectives (i.e., deliveries made, tonnage hauled, or km driven) to driver payments. Moreover, the supervisor may be restricted in their level of involvement through their own workload, company policies, and pressures from higher up in the organization and so on. Finally, the company themselves will be influenced by financial and production pressures along with regulatory frameworks. In this sense, the road freight transportation system is representative of a complex sociotechnical system (Rasmussen, 1997; Reason et al., 1990).

According to Salmon et al. (2012) a paradigm shift toward complexity and system thinking is required in road transportation more generally. Road transportation can be classified as a complex sociotechnical system given that (i) it comprises technical, psychological and social elements, which when combined inform goal directed behaviour (ie., involves delivery of goods, people etc) and (ii) the system is influenced by a high degree of uncertainty and independence, forever evolving in an unpredictable manner, challenging the boundaries of safety. Although many have advocated a systems approach in road transportation, this view has not meaningfully penetrated road safety research, practice or policy (Salmon & Lenné, in press). Salmon & Lenne (in press) identified the lack of appropriate systems thinking based crash analysis systems as one of the key barrier preventing systems thinking applications in road safety.

To address this issue, research is needed to capture the complex system of factors influencing road transport crashes, and specifically in the road freight transportation industry.

In this study, we present an application of a systems theory-based approach, Rasmussens's (1997) risk management framework and associated Accimap technique, to the analysis of road freight transportation crashes.

Rasmussen's (1997) risk management framework and Accimap technique

Rasmussen's (1997) risk management framework (see Figure 1) is underpinned by the idea that accidents are caused by: the decisions and actions of all actors within the system (e.g. government departments, regulators, CEOs, managers, supervisors), not just front line workers alone; and multiple contributing factors, not just one bad decision or action. Safety is maintained through a process referred to as 'vertical integration', where decisions at higher levels of the system (i.e., government, regulators, company) are reflected in practices occurring at lower levels of the system, while information at lower levels (i.e., work, staff) informs decisions and actions at the higher levels of the hierarchy (Cassano-Piche et al., 2009; Svedung & Rasmussen, 2002).

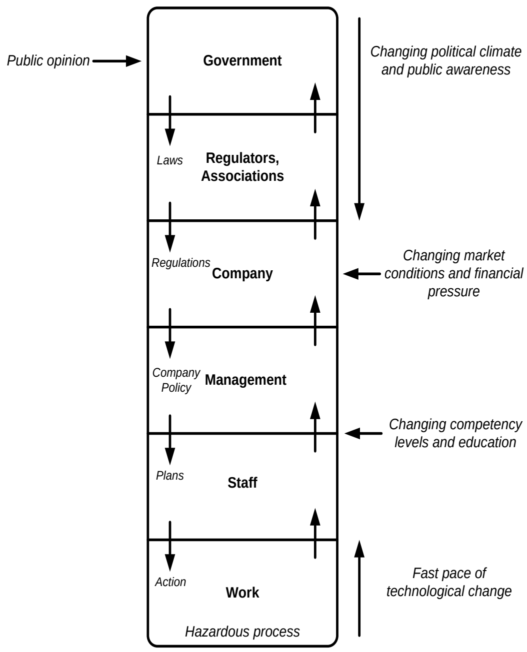

Figure 1. Rasmussen's risk management framework (adapted from Rasmussen, 1997).

To support the use of the framework for incident analysis, Rasmussen developed the Accimap technique (Rasmussen, 1997; Svedung & Rasmussen, 2002). An Accimap is typically used to graphically represent how the conditions, and decisions and actions of various actors within the system interact with one another to create the incident under analysis. In other words, an Accimap is used to represent the systemic factors leading up to an incident. The Accimap describes the system in question as comprising of six levels (government policy and budgeting; regulatory bodies and associations; local area government planning & budgeting; technical and operational management; physical processes and actor activities; and equipment and surroundings). These levels can be adapted to reflect different situations and domains of interest (Waterson & Jenkins 2010). Factors at each of the levels are identified and linked together based on cause-effect relationships. The Accimap technique has been applied to represent large-scale organisational accidents in multiple domains (e.g. Branford, 2011; Cassano-Piche et al., 2009; Jenkins et al., 2010; Johnson & de Almeida, 2008; Salmon et al., 2014; Salmon et al., 2013; Vicente & Christoffersen, 2006), including freight transport (Salmon et al., 2013) and to multiple incident analyses (Goode et al., 2014; Salmon et al., 2014). Applying the Accimap technique to the analysis of road freight transportation accidents would allow for the identification of causal factors beyond the heavy vehicle driver. As stated by Salmon et al. (2012), applying systems-based accident analysis methods to road transportation "moves road traffic crash analysis from a 'hunt for the broken component' to a 'hunt for the interacting system components' mentality" (p. 1834). This hunt for the broken component mentality has previously been identified as a key barrier that prevents safety enhancements within complex sociotechnical systems (Dekker, 2011).

Rasmussen's framework makes a series of predictions (ie., described in the discussion section of the paper; Table 1) regarding performance and safety in complex sociotechnical systems. These predictions describe the characteristics of complex socio-technical systems and have previously been used to evaluate the applicability of the framework and the Accimap technique in new domains (e.g. Cassano-Piche et al., 2009; Jenkins et al., 2010; Salmon et al., 2014). There is some evidence that supports the conclusion that the road transportation is a complex socio-technical system (Salmon et al., 2012); thus, Rasmussen's framework and Accimap technique are appropriate for analysing road freight transportation crashes. In the current study, Rasmussen's predictions will be used to evaluate whether the most detailed publicly available data on road freight transportation crashes [investigation reports from the National Transport Safety Bureau (NTSB) in the United States], adequately describes all aspects of road freight transportation system performance. That is, whether the current investigation process supports the application of systems accident analysis methods in this domain.

In summary, this study will apply the Accimap technique to represent the complex system of contributory factors identified across multiple NTSB road freight transportation crash investigation reports. This approach will allow us to start to analyse and explain the linkages and dependencies within and across system levels in the road freight transportation industry and identify common factors and interactions across organisations. A secondary aim is to evaluate the suitability of the NTSB investigation process for supporting systems accident analysis using Rasmussen's predictions regarding performance and safety in complex sociotechnical systems (as described in Table 1).

Method

The study was given an ethics exemption by the Monash University's Human Ethics Committee.

Applying Rasmussen's approach to road freight transportation crashes

Accimap will be used to represent the contributory factors identified in road freight transportation crash investigation reports sourced from the National Transport Safety Bureau

(NTSB) in the United States. The NTSB is an independent Federal agency charged by Congress with investigating significant transportation incidents, including highway, rail, marine and pipeline. In highway incident investigations, the Board conducts independent investigations with the role of identifying the probable causes of highway incidents and safety recommendations aimed at preventing future incidents. The findings and recommendations from these investigations are presented in detailed reports which are then published on the NTSB's website. To enable the Accimap technique to be used in the analysis of these reports, the six systems levels were adapted to reflect road freight transportation. This led to the definition of the following system levels:

1. Government policy and budgeting: decisions, actions and legislation relating to road transportation;
2. Regulatory bodies: activities, decisions, actions etc made by personnel working for road transportation regulatory bodies, as well as policies and guidelines;
3. Other organisations and clients: activities, decisions, actions etc made by commerical organisations that impact on road freight transportation activities, such as clients and other organisations that operate within the road environment;
4. Road freight transportation company: activities, decisions, actions, etc made by supervisory and management personnel at the road freight transportation company, as well as company policies, planning and budgeting. Factors at this level typically occur prior to the crash itself but can also include decisions and actions made during, or in response to, the crash. Contributory factors related to policy, planning and budgeting typically occur well before the crash itself, and may even exist years before the crash occurred;
5. Drivers and other actors at the scene of the crash: actions and decisions undertaken 'at the sharp end' prior to, and during, the crash. This level therefore, describes factors related to

actors directly involved in the heavy vehicle operation (e.g. driver of the heavy vehicle, co-drivers, passengers and the vehicle convoy) as well as other actors at the scene of the crash (e.g. other drivers, enforcement, road and rail work crews); and,

6. Equipment, environment and meteorological conditions: This level describes contributory factors associated with the vehicle and equipment (eg., in-vehicle telemetry), the physical road environment (eg., road surface conditions), and the ambient and meteorological conditions prior to or during the crash.

Data source

The full text of all NTSB highway crash reports issued since 1996 are publicly available online. Therefore, the analysis was restricted to reports published from 1996 to 2013. Twenty-nine reports within this date range were downloaded from: https://www.ntsb.gov/investigations/reports_highway.html. Reports were selected for analysis if the incident involved a heavy vehicle that was employed for the purpose of road freight transportation. Preliminary reports were excluded from the analysis on the basis that they did not present final findings. Based on these criteria, 27 reports were selected for analysis.

Data coding

The reports were analysed by three analysts using NVivo 10, which is a qualitative analysis software tool. Coding was conducted over five stages. First, two researchers identified the contributing factors, and the relationships between them, present within each report. The factors and relationships identified had to be explicitly stated within the report (i.e. researchers were not allowed to draw inferences about the existence of factors or relationships between factors, such as work scheduling and fatigue). Second, the factors and relationships were then aggregated using a thematic analysis approach (adapted from Braun & Clarke, 2006). This involved descriptively coding responses into themes to develop a coding template. The coding template was hierarchically structured with two levels: the first level described the actor involved (e.g. the heavy vehicle driver, the State Department of Transportation); and the second level identified the specific issue (e.g. fatigue, communication, policies and procedures). For example, the statement "*the NTSB concludes that because he was distracted from the driving task by the use of his cellular telephone at the time of the accident*" was coded as the theme "Heavy vehicle driver: distraction due to cell phone use". Relationships between factors were also coded. For example, "*the probable cause of this accident was the driver's incapacitation, owing to the failure of the medical certification process to detect and remove a medically unfit driver from service*" was coded as a relationship between "Medical oversight programs" and "Heavy vehicle driver: Physical or medical condition." Third, two researchers reviewed the coding template to ensure the themes were distinct from each other. The few disagreements were resolved through consensus discussion. Fourth, the data was then re-coded by two analysts using the final coding template to ensure reliability. Finally, two researchers independently classified the themes according to the adapted Accimap framework and the results were then compared, with the few disagreements resolved through consensus discussion. Frequency counts representing the number of times each theme and relationship appeared across the reports were then performed, and an aggregate Accimap was constructed.

The seven predictions of Rasmussen's (1997) risk management framework were used to evaluate whether the NTSB investigation process adequately describes all aspects of road freight transportation system performance. That is, the representation of contributing factors and associated relationships identified in the data were matched to the theoretical propositions identified in the risk management framework. The Accimap was used to highlight patterns in the data related to the seven predictions (see Figure 2).

Results

Descriptive analysis

There were 27 investigations conducted into crashes involving road freight transportation from 1996 to 2013. An average of 2.07 investigations were conducted per year, with the highest number of incidents investigated in 2004 (n=5). In total, 89 fatalities and 264 minor to severe injuries were reported. Across the years of investigation, these figures represent an alarming average of 6.85 fatalities/year and 20.31 minor to severe injuries/year. Multi-vehicle collisions were identified in the investigation reports as being the most common crash type (n=15), with truck tractor–semitrailer combination units representing the most common type of heavy vehicle (n=19). The majority of the crashes described in the reports involved passenger vehicles (n=18), including sedans, sports utility vehicles or vans.

Accimap description

The median number of themes and relationships identified per investigation report was 12 (range = 3 to 21) and 4 (range = 0 to 8), respectively. Across all reports, the themes most frequently identified were Heavy Vehicle Driver: Sleepiness or fatigue (n=14), Road furniture: lights, bollards, barriers, static signs (n=12) and Heavy Vehicle Driver: Decision making (n=12).

A summary of the findings is presented as an aggregate Accimap in Fig. 2. In the following sections, the contributing factors and relationships underpinning each of the themes represented on the Accimap are described in more detail, and presented according to each level of the framework.

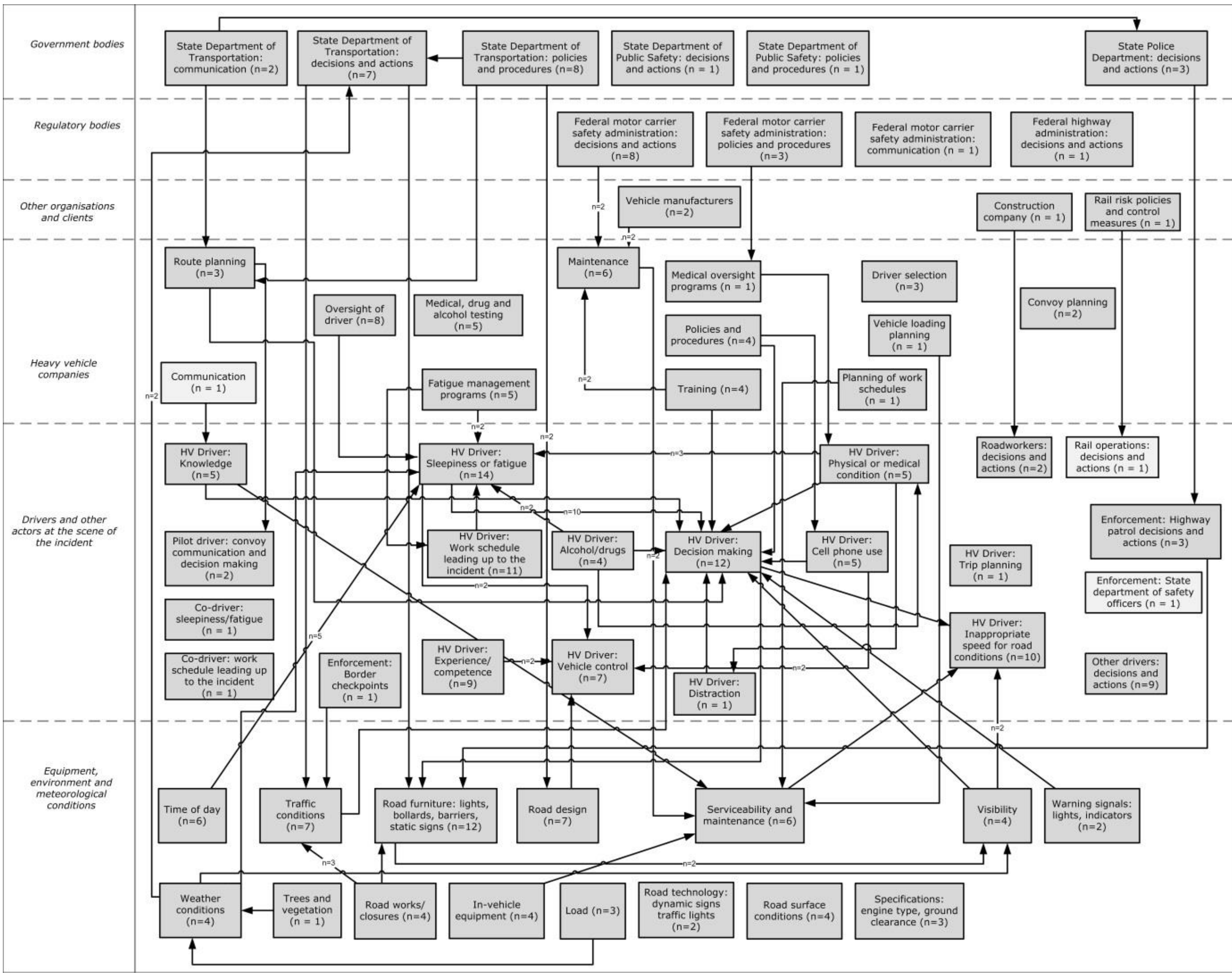

Figure 2: Aggregate Accimap of the contributing factor themes, and the relationships between them involved in road freight transportation crashes identified from the NTSB investigation reports.

1. Government bodies

Twelve reports identified factors at the "government bodies" level. Table 1 shows the contributing factors identified from the NTSB reports underpinning each theme represented at this level on the Accimap.

The NTSB reports identified only a few relationships between this level and the lower levels; however, they illustrate the key role that government bodies play in maintaining safety at all other levels within the system. First, DoT's policies state that it is carrier's responsibility to identify low overhead clearances along proposed routes. They also allow carrier's to self-issue permits online for transporting over-sized loads, without any review of the route. The NTSB concluded that this does not motivate carriers to conduct route surveys prior to transporting oversized loads. Second, the NTSB highlighted limitations with DoT's guidelines for the selection and installation of median barriers for high volume traffic roadways, which impacted on road design. Thirdly, one report highlighted how the DoT failed to include the State Police Department in planning meetings for construction works, even though they were responsible for implementing traffic control plans around the work zone. This led to confusion regarding how responsibilities for traffic control was shared between the highway patrol and the construction company and, subsequently, a poorly controlled work zone.

Table 1 Frequency of contributing factors identified by the NTSB underpinning each theme represented on the Accimap at the government bodies level.

Contributing factors identified by NTSB	**N**
DoT's decisions and actions	
Provision of inappropriate warning signs or the failure to provide warning signs	5
Inadequate traffic control plans	2
Closures of interstate lanes	1
Poor separation between road workers and road users	1
Inadequate treatment of the roads in snow and ice conditions	1
Inadequate roadside inspections	1
DoT's policies and procedures	
Inadequate policies and procedures - warning signs	2
Inadequate policies and procedures - inspections	2
Inadequate policies and procedures - incident management	1

Inadequate policies and procedures - traffic control	1
Inadequate policies and procedures - snow and ice	1
Inadequate policies and procedures - repairs to infrastructure	1
Inadequate policies and procedures - issuing of permits	1
Inadequate policies and procedures - transportation of hazardous materials	1
DoT's communication	
Inadequate information about bridge clearances	1
Poor planning and co-ordination between the department, highway patrol and construction contractors	1
State Police Department: policies and procedures	
Deficiencies in training programs for escorting oversized and super loads	1
Deficiencies in training programs for incident management procedures	1
Deficiencies in training programs for work zone traffic control	1
Department of Public Safety's policies and procedures	
Lack of alignment with state police guidelines on traffic control	1
Department of Public Safety's decisions and actions	
Poor incident control	1

2. Regulatory bodies

Nine reports identified factors at the "regulatory bodies" level. Table 2 shows the contributing factors identified by the NTSB underpinning each theme represented at this level on the Accimap.

Again, the NTSB identified only a few relationships between the "regulatory bodies" level and the lower levels; however they illustrate the direct impact that regulatory bodies have on road freight operational management. Specifically, two reports highlighted how

FMCSA inspections failed to detect deficiencies in heavy vehicle companies' maintenance procedures, which in turn meant that vehicles with poorly adjusted and non-functional brakes were allowed on the road. One report highlighted how FMCSA medical condition guidelines did not provide sufficient guidance on sleep-related disorders; this impacted on the comprehensiveness of the heavy vehicle operators' medical oversight program, which meant that a driver with a significant sleep-related to disorder was allowed on the road.

Table 2 Frequency of contributing factors identified by the NTSB underpinning each theme represented on the Accimap at the regulatory bodies level.

Contributing factors identified by NTSB	N
Federal Motor Carrier Safety Administration decisions and actions	
Failures to conduct hours of service compliance reviews	4
Failures to conduct safety audits	1
Failures to reduce operator safety ratings in response to poor performance in hours-of-service compliance reviews	2
Poor quality compliance reviews	1
Federal motor carrier safety administration policies and procedures	
Failure to account for repeated hours-of service and vehicle-related violations in motor carrier safety fitness ratings	1
Inadequacies in the hours-of-service compliance review procedures for identifying consistent violators	1
Lack of requirement to use tamperproof driver's logs	1
Pre-trip inspection procedure guidelines did not include procedures for determining brake adjustment	1
Lack of guidance in medical condition guidelines regarding the impact of	1

hypothyroidism on fitness to drive	
Federal Highway Administration decision and actions	
Decision to accept the installation of a barrier system on a slope that did not comply with the design specifications	1

1. Other organisations and clients

Four reports identified factors at the “other organisations and clients” level. Table 3 shows the contributing factors identified by the NTSB underpinning each theme represented at this level on the Accimap.

Four NTSB reports described accidents where the decisions and actions of actors at this level impacted on those at the two lower levels. First, two reports identified flaws in vehicle manufacturers’ maintenance documentation. The poor documentation was directly linked to heavy vehicle company’s brake maintenance practices, which in turn meant that vehicles with poorly adjusted and non-functional brakes were allowed on the road. Second, one report described how a rail company’s poor risk control policies and measures directly contributed to the ignition and spread of the fire next to an interstate highway. Third, another report found that a construction company had failed to establish traffic control plans for a road works operation; this had a direct impact on the traffic control and safety aspects of the work zone operation.

Table 3 Frequency of contributing factors identified by the NTSB underpinning each theme represented on the Accimap at the “other organisations and clients” level.

Contributing factor identified by NTSB	N
Vehicle manufacturers	
Flaws in maintenance documentation	2

Construction company	
Road works operation lacked traffic control plans and a clear establishment of responsibilities across the parties involved	1
Rail risk policies and control measures	
Contributed to ignition of grassfire	1

2. Road freight transportation company

Eighteen reports identified factors at the "road freight transportation company" level. Table 4 shows the contributing factors identified by the NTSB underpinning themes relating to company management, while Table 5 shows themes relating to the direct supervision of drivers and driving operations.

The majority of links identified from factors at this level describe how the management of the road freight transportation company directly contributes to the decisions, actions and condition of the heavy vehicle driver and the vehicle. First, two accidents involving driver sleepiness or fatigue were partially attributed to poorly executed fatigue management programs. Second, one report found that the driver was using his cell phone to communicate with his supervisor at the time of the accident; using cell phones to communicate with drivers throughout the day was normal practice. Third, one report found that training programs lacked information about the hazards associated with railway crossings and oversize/overweight vehicles; this led to a driver becoming trapped on a level crossing. Finally, two reports found that company training programs did not contain information about how to correctly service brakes, which in turn led to inappropriate brake adjustment.

Table 4 Frequency of contributing factors identified by the NTSB underpinning themes related to company management, which are represented on the Accimap at the "road freight transportation company" level.

Contributing factor identified by NTSB	**N**
Fatigue management programs	
Poor design and ineffective implementation of the programs (e.g. materials not widely disseminated)	5
Policies and procedures	
Allowing the use of cell phones to communicate with drivers	2
Inappropriate lead distances specified for pilot vehicles	1
No system for monitoring drivers' hours-of-service in secondary jobs	1
Training	
Lack of formal driver training programs	1
A lack of driver task-specific training (e.g. heavy/wide loads, driving conditions, inspections)	3
Failing to ensure drivers attend refresher training	1
Lack of mechanic training	1
Ineffective driver training	1
Medical oversight programs	
Failure to test for sleep-related disorders	1

Table 5 Frequency of contributing factors identified by the NTSB underpinning themes related to the direct supervision of drivers and driving operations, which are represented on the Accimap at the "road freight transportation company" level.

Contributing factor identified by NTSB	**N**

Oversight of drivers	
Lack of monitoring or disregard for compliance with hours of service regulations	4
Poor record keeping	4
Vehicle maintenance	
Poor quality maintenance practices	7
Lack of reflective sheeting as required by FMCSA	1
Poor quality maintenance records	1
Medical, drug and alcohol testing	
Assigning a driver without performing the appropriate tests	4
Failure of the medical certification process to detect and remove a medically unfit driver	1
Driver selection	
Failure to conduct on-road driving tests	1
Employing drivers with no prior experience with the vehicle type	1
Failure to review driver history	2
Convoy planning	2
Poor planning and coordination between the parties involved in moving oversized loads	
Route planning and communication	3
Selection of inappropriate routes for the transportation of oversized loads	
Work scheduling	1
Failure to ensure the vehicle was available for maintenance work	
Vehicle load planning	1
Poor load planning impacted on serviceability of the vehicle	

3. Drivers and other actors at the scene of the accident

All reports identified factors at the “drivers and other actors at the scene of the accident” level. Table 6 shows the contributing factors identified by the NTSB that concerned actors that were directly involved in the road freight operation (e.g. driver of the heavy vehicle, co-drivers, pilot drivers). Table 7 shows the contributing factors identified by the NTSB related to other drivers in the road environment, and Table 8 shows those relating to roadside operations.

In the NSTB reports, the majority of factors identified at this level link to factors at this same level, specifically describing the immediate conditions that contributed to the driver error involved in the crash. For example, “poor decision-making” is frequently identified as a contributing factor. A number of reports attribute “poor decision-making” to driver fatigue or sleepiness. In turn, driver fatigue or sleepiness is linked to the use of alcohol and drugs, and sleep-related disorders. Another example of driver error that is frequently described in NTSB reports is loss of control of the vehicle. Two reports attribute loss of control to distraction due to cell phone use, and two reports attribute it to a lack of driver experience with the driving conditions.

Table 6 Frequency of contributing factors identified by the NTSB underpinning themes related to actors directly involved in the road freight operation, which are represented on the Accimap at the “Drivers and other actors at the scene of the accident” level.

Contributing factor identified by NTSB	**N**
HV driver: Sleepiness or fatigue	
While driving	14
HV driver: Decision-making	
Driving into areas of reduced visibility	1

Failure to slow in response to traffic	5
Loading arm positioning	1
Decision not to leave when dispatched	1
Inappropriate decision to cross railway crossing	2
Following distance to pilot vehicle	1
HV driver: Work schedule leading up to the incident	
Schedules that violated hours-of-service regulations	5
Insufficient breaks or sleep	6
HV driver: Driver experience/competence	
Vehicle control skills	7
Limited experience in operating the heavy vehicle	3
HV driver: Physical or medical condition	
Sleep-related disorders	3
Heart conditions	1
Use of prescription medications that induce fatigue	1
Pain due to a physical injury	1
HV driver: Alcohol or drug use	
While driving	4
HV driver: Driver knowledge	
Poor route knowledge	3
Pre-trip inspection knowledge	1
Vehicle maintenance knowledge	1
HV driver: Distraction due to cell phone use	
Use of cell phone while driving	5
Co-drivers : Sleepiness or fatigue	

While driving	1
Co-drivers: Work schedule	
Insufficient breaks or sleep	1
Pilot driver: convoy communication and decision-making	
Routing errors – leading to low bridges	2
Poor communication with the convoy about the route	1
Use of cell phone to communicate with convoy causing distraction	1

Table 7 Frequency of contributing factors identified by the NTSB underpinning the theme "other drivers in the road environment", which is represented on the Accimap at the "drivers and other actors at the scene of the accident" level.

Contributing factor identified by NTSB	N
Other drivers in the road environment	
Poor decision-making	4
Medical conditions	2
Sleepiness or fatigue	1
Distraction caused by passengers	1
Distraction caused by lack of route familiarity	1
Distraction caused by cell phone use	1

Table 8 Frequency of contributing factors identified by the NTSB underpinning themes related to roadside operations, which are represented on the Accimap at the "drivers and other actors at the scene of the accident" level.

Contributing factor identified by NTSB	N
Enforcement: State department of safety officers	

Poorly controlled incident response	1
Border checkpoints lack of warnings	1
Enforcement: highway patrol decisions and actions	
Use of conflicting warning signs	1
Incomplete heavy vehicle inspections	1
Lane closures	1
Maintenance work crews	
Insufficient fire control measures implemented by a rail work crew	1
Poor traffic control operations during a road work	1

4. Vehicle and environmental conditions

Twenty-six reports identified factors at the “vehicle and environmental conditions” level. Table 9 shows the contributing factors identified by the NTSB that relate to the condition of the heavy vehicle, while Table 10 shows those related to environmental conditions.

Factors at this level were primarily linked directly to the level above, describing the impact of the road conditions on the heavy vehicle drivers’ capacity, decision-making and behaviour. For example, five reports described how late afternoon and early morning conditions contributed to driver sleepiness and fatigue. One report described how heavy vehicle drivers did not adjust their speed, despite limited visibility.

Table 9 Frequency of contributing factors identified by the NTSB underpinning themes related to the condition of the heavy vehicle, which are represented on the Accimap at the “vehicle and environmental conditions” level.

Contributing factor identified by NTSB	**N**

Serviceability and maintenance	
Poorly adjusted and non-functional brakes	6
In-vehicle equipment	
Lack of fatigue detection technologies	1
Lack of brake stroke monitoring systems	1
Lack of anti-lock brakes	1
Inappropriate use of cruise control	1
Specifications	
Vehicle height	1
Brake specifications	1
Vehicle instability	1
Load	
Inappropriate load size for the route	2
Unbalanced loads	1
Warning signals	
Lack of lights or indicators	2

Table 10 Frequency of contributing factors identified by the NTSB underpinning themes related to environmental conditions, which are represented on the Accimap at the "vehicle and environmental conditions" level.

Contributing factor identified by NTSB	**N**
Road furniture	
Conflicting or confusing warning signs	3
Lack of warning signs	2

Signs impeding drivers' perception of other signs	1
Design and placement of barriers	3
Profile of rail crossings	1
Road posts lying on the road	1
Lack of overheard safety lighting	1
Road design	
Co-location of rail track and highway	1
Merging of lanes	1
Design of entrance ramps	2
Lack of traffic capacity	2
Intersections between road and rail	1
Traffic conditions	
Slowed due to heavy traffic	7
Road works or road closures	
Operations infringing on traffic	3
Road closures	2
Road surface conditions	
Snow and icy	2
Wet	2
Loose gravel	1
Time of day	
Early morning or late afternoon caused sleepiness	6
Weather conditions	
High winds	2
Snow and ice	1

Rain	1
Visibility	
Absence of natural or artificial light	3
Smoke	1
Vegetation	
Lack of surrounding vegetation causing high winds	1

Discussion

This study aimed to apply Rasmussen's (1997) risk management framework and Accimap technique to examine the contributory factors identified in twenty-seven road freight transport crash reports. With the exception of the case study that applied the Accimap to represent the causal factors of a crash at a rail level crossing (Salmon et al., 2013), this study is the first to apply the Accimap, and a systems-based framework, to the analysis of multiple road freight transportation crashes. To evaluate where the NTSB investigation process adequately described all aspects of road freight transportation system performance, the Accimap output was compared to a series of predictions which underpin Rasmussen's risk management framework. These predictions are presented in Table 1, along with supporting evidence from the Accimap analysis. As shown in Table 1, all six out of seven of Rasmussen's predictions were identified in the present analysis to a certain degree. This finding suggests that although it is reasonably comprehensive, the NTSB investigations process does not fully consider all aspects of system performance.

The analysis highlights two key aspects of system performance that the NTSB investigations fail to address. First, the reports did not explicitly identify economic pressures that influenced decisions and actions at the higher levels of the system (ie., regulatory and government bodies). However, it could be speculated that economic pressure on the Federal

Motor Carrier Safety Administration was likely the cause of insufficient maintenance inspections of road freight transportation companies. To illustrate this argument, in Australia in 2013, mechanical failure was attributed to a fuel tanker crash and explosion that resulted in two deaths and five serious injuries in Australia. Mechanical operations within the parent organisation were found to be running below accepted levels of safety and formal mechanical safety warnings were issued to over 40% of the fleet. The response to this intervention from a representative of the parent company was that company profits would be negatively affected as would up to 540 jobs (O'Sullivan, 2014). In response to situations such as this, worker representative bodies such as transport unions have advocated additional system regulation to ensure safety standards are met or maintained (Rumar, 1999; Transport Workers' Union of Australia, 2011). This example, in addition to the results of this study, well illustrates how actors at each level of the framework contribute to the systematic degeneration of work practices over time and how a combination of factors (eg., system regulation, economic pressure, HV driver decision making and environmental conditions) can impede safety operational practices. Second, no relationships were identified between driver decision-making and factors operating at the upper levels of the framework. The data suggests that driver decision making in these accidents was only influenced by factors occurring at all three lower levels of the framework.

Table 1: Test of Rasmussen's predictions in road freight transportation crashes.

Predictions	**Support for prediction**
1. Performance is an emergent property of a complex socio-technical system. It is impacted by the decisions of all of the actors—politicians, managers, safety	Factors that shaped the performance of the HV driver (and other actors involved in the incident eg., pilot/co-driver) were identified at all levels of the freight transport system.

officers and work planners—not just the front-line workers alone	Relationships between factors within and across all levels of the system were also identified. Performance was also identified as an emergent property, as it is characterised by uncertainty (Newnam & Watson, 2011). In uncertain contexts, performance is less predictable as individuals adapt to the changing demands and conditions. The basic requirements for driving a vehicle are arguably predictable. However, as evidence by the Accimap, performance is influenced by a combination of factors, which are not necessarily well managed. For example, the performance of other actors (eg., co-pilots) and environmental conditions.
2. Performance is usually caused by multiple contributing factors, not just a single catastrophic decision or action	The Accimap shows how multiple contributing factors across all levels of the freight transport system were involved in the crashes examined. Further, the crash reports identified between 3 and 21 contributory factors. Many of these factors are also influenced by other causal factors. For example, decision-making is influenced by multiple factors occurring at the scene of the incident, within road freight transportation

	organisations and environmental conditions. None of the factors were identified, in isolation, as being independently responsible for road freight transportation incidents.
3. Deficiencies in performance can result from a lack of vertical integration (ie., mismatches) across levels of a complex socio-technical system, not just from deficiencies at any one level alone	The Accimap identifies multiple examples of non-linear interactions across the different levels of this complex sociotechnical system. For example, there was a lack of coodination between the decisions and actions of the State Department of Transportation and their planning and design of road furniture.
4. The lack of vertical integration is caused, in part, by a lack of feedback across levels of a complex socio-technical system. Actors at each level cannot see how their decisions interact with those made by actors at other levels, so the threats to safety are far from obvious before an accident	The Accimap identifies several examples of poor feedback across the levels of the freight transport system. One example is the ineffective translation of policies and procedures of the State Department of Transport on route planning and road design. The impact of this lack of vertical integration meant that drivers were using unsafe routes and roads.
5. Work practices in a complex socio-technical system are not static. They will migrate over time under the influence of a cost gradient driven by financial pressures in an aggressive competitive environment	The Accimap does not explicitly identify economic pressures that influenced decisions and actions at the higher levels of the system (ie., regulatory and government bodies).

	and under the influence of an effort gradient driven by the psychological pressure to follow the path of least resistance	
6.	The migration of work practices can occur at multiple levels of a complex socio-technical system, not just one level alone.	The migration of work practices were identified at all six levels of the sociotechnical system. For example, organisations develop fatigue management programs. Over time, new drivers do not receive training in these programs. Another example relates to the maintenance practices. When vehicles are replaced, drivers are not informed that the manual adjustment of brakes is inappropriate. Over time, the manual adjustment leads to non-functional brakes.
7.	Migration of work practices causes the system's defences to degrade and erode gradually over time. Performance is induced by a combination of this systematically induced migration in work practices and a triggering event, not by an unusual action or an entirely new, one-time threat to safety.	The Accimap illustrates the mechanisms generating behaviour in this dynamic work context. Some factors affecting the system were clearly degenerating systematically over time. For example, it was clear there was ineffective policy translation and communication failure, which impacted the driving environment, which when combined with sub-optimal work practices and driver

	performance created inadequate responses to a triggered event (eg., collision) on the road.

Despite these gaps in the NTSB investigation process, the results of this study suggest that systems accident analysis methods are required to adequately describe all aspects of road freight transportation system performance. Based on this conclusion, a reductionist view to crash causation is unlikely to inform effective intervention or policy development. The results of this study suggest several intervention opportunities, such as implementing policy and procedures to ban the use of cell phones (hands-free and hands-held), and developing fatigue management programs to reduce sleepiness and fatigue while driving. Consistent with the tenets of Rasmussen's risk management framework, the findings suggest that these strategies will fail unless actors across the all levels of the system support their implementation. For example, hours-of-service regulation needs to be supported by fatigue management programs, which require consistent management commitment and support to ensure implementation by drivers. One intervention could be focused on the development of policy to prevent driving in high risk hours, which has been suggested to be between midnight and 5:59am (Connor et al., 2002; Stevenson et al., 2013). Given that a high proportion (n=8) of the crash reports identified incidents occurring between these hours, it is highly likely that this intervention would directly improve the decision making capabilities of drivers and ultimately reduce crash involvement. Systems thinking suggests that interventions that target higher level system factors, and their interactions, will be more appropriate than the treatment of local factors at the sharp end of system operation (e.g., Rasmussen, 1997; Reason et al., 1990; Salmon et al., 2014). Implementation of intervention should also be considered from a systems perspective. Facilitating links between the employers (organisations), employees (drivers) as well as regulatory policy-makers and researchers is important for enhancing the interface between research and policy and practice in this safety critical domain.

A further contribution of this research is that it has provided, for the first time, a systems thinking framework that supports the analysis of road freight transportation crashes. It is the opinion of these authors that the development of a road freight transport specific incident investigation process is required. In the NTSB reports, the role of government departments and regulatory bodies in crashes was typically only considered if they directly impacted on the conditions at the immediate scene of the incident. Only a few reports considered how these agencies impacted on the management of road freight transportation companies. Moreover, the identification of interactions between factors in reports was limited. As discussed above, this information is critical for the development of effective countermeasures.

Although some system-based accident investigation processes have been developed in other safety critical domains (Katsakiori et al., 2009), none have been translated for the road freight transportation industry. Existing accident investigation processes also do not consider the impact of regulatory and legislative requirements on operations, as required for systems incident analysis methods, such as Accimap. As evidenced in this paper and the broader literature (e.g. Thompson & Stevenson, 2014; Williamson et al., 1996), this information is a critical consideration in the road freight transportation industry.

To guide crash prevention efforts in the road freight transportation industry, a research agenda is proposed for the development of a domain-specific accident investigation and analysis method underpinned by systems thinking. Ideally, this would involve the development of interview schedules, questionnaires, audit checklists etc. to support the collection of appropriate data. In addition, a domain-specific taxonomy would be developed to populate the adapted Accimap framework developed in the current study. This could be used to guide investigations and for classifying the contributing factors and relationships identified. The development of a taxonomy would help ensure that the proposed accident analysis method is reliable, which is crucial if trend analysis is to be performed (Underwood & Waterson, 2013). The methods should then be piloted with key stakeholders within the road freight transportation industry, and refined, to establish usability, reliability and validity. A final stage would involve the implementation of the proposed accident investigation and analysis method. Implementation would potentially generate critical data on the complex system of factors that contribute to road freight transportation crashes, and truly test whether systems thinking can provide new insights into crash prevention efforts in this domain.

Limitations

As a first of its kind study, there were some limitations worthy of discussion. First, the factors identified by the NTSB investigations are likely to be limited in scope because they are not underpinned by a systems model of incident causation. As a corollary, it is likely there were other factors involved in the crashes analysed, particularly at the upper levels of the freight transportation system not identified in the reports. Investigations based on systems thinking may have revealed a more complex system of factors. Second, the results may have been biased due to the selection of interviewees. It was apparent in the investigation reports that interviews were voluntary, which suggests that some personal perspectives may not have been captured (or underestimated) in the Accimap. Further, the retrospective nature of the data collected suggests that the account of events presented from various parties, including drivers, passengers, witnesses, and family members may have been impacted by recall or a tendency to avoid blame. However, given the causal factors have been supported by the literature (eg., fatigue, cell phone use) bias was unlikely to impact the veracity of the results.

Conclusion

This paper applied Rasmussen's (1997) risk management framework and associated Accimap technique tonestablish its applicability for enhancing analysis in the road freight transportation industry. This is the first study that actively 'moves road traffic crash analysis from a hunt for the broken component to a hunt for the interacting system components mentality" (Salmon et al., 2012). Moreover, a practical contribution is made through the examination of existing investigation methods for their ability to support systems analyses of road freight transportation crashes and in the identification of interventions designed to prevent future crashes. The output from the Accimap demonstrates how a systems approach can increase knowledge in this safety critical domain, while the findings can be used to guide prevention efforts and the development of system-based investigation processes for the heavy vehicle industry. The results of this study will be used to develop a theory based accident investigation process for Australian organisations in the road transport industry.

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