Abstract

Tram driving is a complex task, requiring high levels of workload, route knowledge, and divided attention. Although similar to train driving, tram driving has its own unique skills requirements as well as higher demands on divided attention and decision-making in relation to operating in an environment with multiple road users. Due to the significant differences between the two tasks, research findings relating to train driving may not necessarily be applicable to tram driving. Despite this, very little research has been conducted on the tram-driving task in general and even less so relating to accidents and near misses. Australia has experienced a high incidence of tram collisions over the past decade and with new networks being planned for several cities and expansion of existing networks there is a potential for an increase in accidents. It is therefore timely to examine the tram-driving task and consider the human factors implications of tram collisions. This study incorporated reviews of accident reports, on-site observations, focus group exercises, and individual driver discussions. Results of the analysis revealed three major themes relating to causes of accidents: situation awareness, time pressure, and organizational behaviour. Interaction between these three themes was noted. This preliminary identified cultural issues and hinted at problems associated with normalization of deviance. Further analysis and research is needed to explore and unpack the themes with a view to determining effective strategies for tram organisations to implement to improve safety and minimize the risk of collisions.

Keywords: Trams; Safety; Accident analysis; Situation awareness

1. Introduction

Tram driving is a complex task, requiring high levels of workload, route knowledge, and divided attention. Metropolitan tram systems involve numerous routes that share roads with other road users as well as their own rail corridors, resulting in demands similar to those of motor vehicle drivers and train drivers combined. Generally
speaking, there are three types of environment in which trams operate: a light rail system where the track is separated from the road (i.e. with its own corridor); a segregated track where the tram is separated from the road by a track running through a central reservation but still travels through shared intersections; and an entirely shared road system in which the track runs on the road in mixed traffic without dedicated lanes. The areas in which potential for collisions is highest include intersections used by trams, motor vehicles, and pedestrians, and suburban areas where the track runs along the road without any form of segregation. Consequently, when collisions do occur, they can cause serious injury and be extremely disruptive [e.g., 1].

Tram driving shares clear similarities with train driving; both are limited by the tribological constraints of driving steel wheels over steel rails (e.g. low adhesion, slippage), and require similar throttle manipulation characteristics (e.g. momentum-based driving, compensating for gradients). However, there are enough differences to argue that tram driving ostensibly requires a range of different skills in the driver. Trams are lighter and slower than trains, include more stop-start functions, and while the handling characteristics may overlap, a mixed-traffic environment presents completely different demands for collision avoidance. In some situations, the mixed traffic environment requires a higher demand on situation awareness, with constantly high perceptual demands and the constant need to make predictions [2] being vital elements of safe tram driving. Due to the nature of the tram-driving task and its relationship with the road environment, distributed situation awareness [3] would also be different to train driving, especially in relation to the interaction between tram drivers and other road users.

The joint-cognitive systems theory suggests that drivers have a very unique dynamic with their vehicles, and operate with it as a single system [4]. Based on this notion, any differences in the features and characteristics of the two environments are likely to create subtle yet significant differences in task dynamics. In terms of safety for example, tram driving requires more awareness of activity in the passenger saloon (e.g. opening and closing of doors, monitoring passengers to ensure they get on and off safely). In terms of productivity goals, the performance regime is given to penalizing excessive punctuality (i.e. arriving at scheduled tram stops ahead of time) over lateness, largely in order to maintain effective separation between vehicles. Research in the rail domain on station dwell suggests that this may easily engender “hurry up and wait” scenarios [5], and in doing so, increase the experience of time pressure. This is of particular concern, given that time pressure on roads has been associated with negative emotions, stress, and an increased propensity for risk-taking behaviour [6].

In the absence of dedicated rail corridors, risk mitigation strategies in tram networks have a tendency to focus on engineering controls to improve safety, such as upgrading and/or relocating tram stops, and granting traffic light priority to trams. For tram drivers, the focus has been on defensive driving practices, development of skills that improve resilience, and training models that monitor on-road driving behaviour. Despite the abundance of light rail networks, very little research appears to have investigated tram-driving from a systems perspective and although accident investigations are carried out by the organization and/or third-party consultants, even less research has been conducted on the potential causes of collisions and near misses. This is of particular concern in Australia which has over 270km of tramway, the biggest and oldest light-rail network in the world [7], and currently undergoing a renaissance; new light rail projects are being planned, under construction, or operational in Melbourne, Adelaide, Canberra, Perth, Newcastle, Sydney, and the Gold Coast [8].

Despite the complexity of the task, tram accidents are relatively infrequent. However, statistics still show significant increase in tram-related trauma, for example injuries associated with passengers falling in the saloon are among the most common safety issue[9] and have been linked with concerns for jerky tram driving[10]. While some of these issues may be related to human performance and training, it is worth questioning the extent to which systems-related issues may be influencing them. While this may simply reflect increased likelihood of accidents from increasing in growth and rates of exposure, the environment may possess a range of contributing technical and non-technical factors that create complexity and if unidentified may further elevate risk in unpredictable ways.

Recently, complexity theory has emerged to present a view of systems where complexity is becoming the defining characteristic [11, 12], and describes how failures may emerge from the very systems that are put in place to prevent them. This draws links with normalisation-of-deviance theory [13] which describes the effect of people in organizations growing so accustomed to deviant behaviours, that they do not consider them as such even when exceeding their own rules for elementary safety. The Practices Migration model adds to these ideas [14, 15] and suggests that a system can be easily stressed by a rapid pace of technological change, through increasingly aggressive, competitive environments, and from changing regulatory practices and public pressures. All of these
elements feature pervasively in the light rail domain. Given the increase in operations, introduction of new trams and technologies, research in this area is needed.

1.1. Aim

The purpose of the study reported in this paper was to undertake an exploratory and qualitative investigation of the potential causes of tram collisions in an Australian metropolitan setting. The study focused on the human factors elements, including but not limited to situation awareness, with the aim to identify key themes.

2. Method

2.1. Design and data collection process

Data was collected in an Australian tram organization. The methodology involved multiple stages, and two researchers (the authors) took part in each of the stages. The first was to review the organization’s existing accident reports pertaining to tram collisions.

In the next stage, researchers conducted on-site observations at two locations in the tram network, identified from accident reports as high-risk locations, evidenced by a high rate of previous accidents. One of these was a busy and large intersection in a multi-laned road on the edge of the city’s centre. The other was a tram junction in the suburb separated from the road but with trams entering from multi-laned roads. Tram activity (direction and flow) and potentially conflicting situations (scenarios giving rise to collisions) were recorded at both locations during peak and non-peak periods. Observations were also made of pedestrian activity in and around the intersections, the activity and behaviour of other road users including motor vehicles, cyclists, and horse-drawn carriages, and passenger behaviour including those travelling on the tram, boarding or alighting, and waiting at stations. During this stage, researchers boarded trams and observed the trams and drivers travelling through the two intersections from all possible directions and entry/exit points.

Fig. 1. Sample drawing from the scenario invention task. Note: handwriting has been replaced with typescript to improve legibility of the drawing and road names / locations have been de-identified.
Stage three involved discussions held with individual drivers at three different depots. For logistical reasons related to design of work rosters, drivers were recruited upon arrival at the depot with the assistance of an organizational contact. Before commencing the discussions, participants were advised of the purpose of the investigation, given a copy of the participant information sheet, and then signed a consent form. Discussions were semi-structured and focused on the challenges that drivers faced at the two intersections and the strategies they use when negotiating those intersections, and then the wider network as a whole.

The final stage involved a generative scenario simulation exercise known in the literature as a “scenario invention task” which has been applied in the rail industry previously[5, 16]. This was conducted with six drivers in a focus group at one depot (at which a total of three depots were represented) and three drivers in a focus group at another depot. Again, participants were recruited with the assistance of a contact at the organization. Participants were advised of the purpose of the focus group, provided with an information sheet and provided signed consent. Participants were provided with sheets of A3-sized paper and coloured marker pens and instructed to draw the intersections and then add a scenario that could result in a collision, noting significant decision points, shifts in situation assessment, violated expectations, and so on. Figure 1 illustrates an example of a drawing obtained during the study.

Once the scenarios were constructed, participants were instructed to simulate driving over their route and describe the sort of strategies they would apply to change or prevent it from happening. This involved listing strategies in a different coloured pen. Upon completion of the drawings, each participant provided a walkthrough of their scenario and a general discussion was held between all participants and the researchers regarding that scenario. Drivers were then asked to note any technical and non-technical solutions that they believed could minimize the risk of collision.

2.2. Participants

A total of 23 participants were involved in the study (22 Male, 1 Female). Nine of these participated in the focus groups, and 14 took part in individual driver discussions. There was a widerange of multiple work roles and responsibilities in the participants, some of which were supplementary to driving. Thirteen were tram drivers, eight were Driver Trainer/Tutors, seven were team managers, one was a traffic officer, one was an OH&S Coordinator, and one was a Manager of Lines. Most of the Driver Trainers/Tutors also performed regular driving duties. The age of the participants ranged from 25 to 67 years, with an average age of 50 (SD = 8.89 y). Years of tram-driving experience ranged from 1.5 to 21 years, with an average of 10 (SD= 6.47 y). More than half of the participants (n = 13) possessed over 10 years driving experience.

2.3. Data analysis

This study adopted multiple methods, including document review, focus groups, interviews, and observations. Data was captured via voice recordings and written notes for the focus group, individual interviews, on-site observations, and observations aboard trams, and photographs taken from numerous perspectives around the two locations. Two researchers read the reports independently and coded potential contributing factors for each accident. These were then cross-referenced and combined into a table of technical and non-technical human factors contributions to produce a dataset. All interviews were audio recorded and transcribed orthographically. Data analysis was inductive with text coded from focus groups (including scenario drawings) and driver discussions, without determining categories in advance. Thematic analysis was used to classify data into repeated concepts and phrases [17], and compared with codes from the report coding process [18].

2.4. Ethics

The study met the approval of Central Queensland University Human Research Ethics Committee: Approval number: H14-10-209. Participants were provided with an information sheet about the study and informed consent was obtained before beginning each stage of data collection.
3. Results and discussion

Preliminary analysis of the data collected identified a number of categories within three major themes. These were: situation awareness; on-time running pressure; and organizational behaviour. These are discussed below with excerpts from the data to illustrate and support the points being made.

3.1. Situation awareness

Data collected from observations, individual discussions, and focus groups, showed that tram driving was a highly cognitively demanding task incorporating a vast number of elements in the environment that require attention:

Yes well you’ve got the stops coming up, you’ve got pedestrian crossings at both ends of the stop, you’ve got the crossovers happening ... you could have a number of trams in that area ... and then you’ve got to contend with all the cars, bike riders, you’ve got the horse and carts that come along there as well ... there’s a lot to think about ... pedestrians running across the tracks...

An ability to compile all those elements into a solid understanding of the broader picture was considered essential. Perhaps more importantly than many other dynamic tasks, safe tram driving required the ability to make predictions, including the behaviour of other tram drivers, other road users, pedestrians, and passengers. It was this ability to predict that often mitigated accidents:

It's thanks to the skill of the tram drivers [...] a lot of these guys have learned to predict things in advance. When you’re driving along you just sort of know that something is about to happen.

This ability developed and improve with experience but the high level of concentration and the need to be alert at all times was considered to be very demanding and even the most experienced drivers said it was easy to lose concentration:

... it’s a frightful scenario because sometimes [...] I’ve gone right up to [location] and I think to myself, hang on how did I get to [location]? [...] It’s a frightening scenario because you’re in that second sense, it is your second sense that is detecting what you’re doing.

Consolidated findings from the accident reports revealed that deficiencies in situation awareness played a major role in many collisions and near misses. In some instances, the lack of situation awareness related to technical human factors such as not being able to see a signal due to another tram blocking the driver’s view. In other cases, comprehension may have been the cause, such as seeing a stationary tram in front but not understanding that the tram was not moving off. However the most common element was issues with predicting and planning ahead. For example, it was common for drivers to assume that a tram that was stationary at a stop with no passengers waiting to board would move off from the stop before the next tram arrived. This expectation bias developed with expertise and habituation on the task; that is; trams with no passengers waiting almost always move off before the next tram arrives. However, in this instance, experience also led drivers to make poor decisions regarding stopping and it was common practice to aim to stop where a tram is currently sitting rather than aiming to stop behind it.

All of a sudden he’s gone off there and he’s started to brake because he’s realized the tram has stopped at the stop and he expected the tram to start moving off. The tram has stopped at the stop and he’s braked, he’s gone for his emergency brakes, he’s slipped and hit the tram in front.

There are several factors that negatively affected situation awareness over and above the obvious ones such as the high demand for divided attention, fatigue, and high workload. Two less common issues that have a negative effect on situation awareness and performance in general are the pressure felt by drivers regarding running on time, and organizational factors as noted below.

3.2. On-time running

On time running was felt to create a great deal of pressure on drivers and impact many areas of their task, particularly decision-making. As with most public transport systems, trams have scheduled stops and drivers are expected to arrive at nominated locations at specific times. They are required to be no later than ~6minutes late or ~1min early at those specified locations. The tram drivers at the organization for which this research was conducted
have a display in their cab that indicates whether they are on time, running late, or running early. During observations, it was noted that drivers continually glanced down to the right of their cab where the display was mounted. This behaviour was observed during dwells (e.g. waiting for lights to change) and during driving. Data from focus groups and individual driver discussions verified that drivers did indeed pay considerable attention to their timekeeping and constantly referred to the display. The implication here was that the +/- time window was used to regulate speed (i.e. as an indicator for train state) instead of the speedometer. Although managers stated that safety was the organization’s first priority, most drivers reported feeling considerable pressure to meet the expectations of the management for on-time running, and this perceived pressure could lead to poor decisions and acceptance of greater risks that they might otherwise avoid:

I feel the pressure every day because what I try to do is I try to run on zero.

Well yes because they’re under pressure. They get spoken to by their manager asking why they get late all the time […] which makes them feel pressured so they try and take shortcuts.

Due to this perceived pressure, they are more likely to bend or break rules, especially when they are running behind time. For example, some drivers will enter an intersection immediately behind another tram on a short ‘T’ light (i.e. a movement authority indication solely for trams). The rule for trams on a short ‘T’ light was that only one tram could enter the intersection because there was not enough time for two trams to cross the intersection before the motor vehicle traffic was given authority (i.e. a green light). When running late, drivers were also more likely to delay braking when approaching a stationary tram in the expectation that it will move off. It was clear from driver discussions that on-time running was a major element of a driver’s mindset and thought about constantly throughout every route. Even common everyday occurrences were thought about by drivers in terms of how they will impact on their timetable:

... the timing of the light system there because if you lost one sequence, it takes you roughly about three minutes to come back on. So a lot of drivers try not to lose time there so there’s a bit of a rush. So three minutes is a lot of time for OPR.  

Yes, on-time running. Because the times are so tight and if the equipment’s not working properly it creates that problem ... it’s often an issue of cars. Cars build up, they run the red light at the last minute and then you can’t get around the corner and that again contributes towards stress.

It is not difficult to see how this constant sense of pressure and focus on maintaining on-time running can impact decision-making and motivate risk-taking such as taking the chance that a tram in front will move off in time, or entering an intersection knowing that they may not be able to clear the intersection and therefore create the risk of a collision with another tram or other road user.

The pressure of on-time running directly affects performance and therefore safety. It impacts upon a drivers’ situation awareness, and on a larger note, draws attention to the system itself and questions the awareness that is being lost there.

3.3. Organizational behaviour

Many behaviours that play a role in tram collisions appear to be manifestations of an overarching organizational culture. A large category of organizational behaviours theme was inter-depot rivalry. This was rife and caused an ‘us and them’ attitude amongst drivers that appeared to affect the way they perceived and related to other drivers:

There’s very little consideration given to, well, to courtesy and to teamwork.

You’ll be lucky to find, out of 200 people here, I reckon I’m good friends with five.

This inter-depot rivalry was associated with the need to meet the timetable. Each depot had a number of tram routes travelling to, from and through the city centre, with routes merging at various locations in the network. For example, the junctions observed in this investigation were used by trams on multiple routes from one depot and multiple routes from another depot arriving from different directions, converging at the junction and then proceeding towards the city along the same section of track. Further along this same section of track, routes from a

1“OPR” is a standard industry abbreviation for Operational Performance Regime.
third depot also converged at the road intersection. At these observed locations, drivers from different depots endeavoured to move onto the city-bound track in front of trams from other depots. The reason for this depended upon the depot. For example, trams from one depot travelled through the city centre and beyond whereas trams from the other two depots turned around at a location on the other side of the city. The trams that went beyond the city generally carried more passengers because they not only pick up passengers wanting to go to the city but also those wanting to go beyond. Thus drivers from the other two depots expressed frustration at being held up due to the frequency of stopping and the time it took for passengers to board the trains from the first depot.

Some drivers are afraid to get in front of these trams ... Right up to the [Location] you could be following the trams.

Frustration with other drivers is understandable considering the need to meet the timetable and the delays that other trams can cause due to other drivers’ goals:

A prime example is I had a tram from another depot in front of me [...] he was obviously wasting time to get what we call a short shunt [...] that was then holding me up. So I ended up arriving here back at the depot 15 minutes late and at the very most I should have been only two or three minutes late given the traffic and that.

Added to the pressure of on-time running, inter-depot rivalry appeared to lead to dangerous decisions, even to the extent of breaking rules such as stopping at a red signal:

Now they’ll even run the red light there. We have what’s called a [specific manoeuvre] and that, the exit to that is supposedly determined by lights but often if they see you they’ll just come straight out there without waiting for the arrow.

Inter-depot rivalry was also influenced by an incentive scheme that was considered to create negative feelings between drivers within depots. The best performing drivers were rewarded with a variety of incentives, based on criteria that included on-time running, no accidents, and minimal sick leave. Drivers indicated that the criteria were unfair because some routes were much more difficult than others and in peak hour it was simply impossible to keep to the timetable. Some shifts were also easier than others, e.g. it would be easy to maintain on-time running and avoid accidents during a night shift with minimal road traffic.

Although it varied between depots, relationships with managers and attitudes of drivers towards the organization were generally negative. Several drivers commented that the organization cared more about money than safety or the wellbeing of their employees:

...managers are telling drivers now that it’s you know here’s a note saying “Here’s how much you cost us this week”.

The managers who participated in the individual discussions and focus groups felt that they had a good relationship with drivers and were generally respected and trusted. However, several drivers expressed negative feelings towards the way managers dealt with drivers, especially when there was an issue that needed discussing such as a customer complaint:

This is another thing too like, we get letters in our letterbox saying that the manager wants to see us and before you even start the job you think “What have I done wrong?” The stress factor’s already kicked in.

Overall organizational culture appeared to play a role in the morale of drivers and their willingness to perform at a high level. This was exacerbated by the constant perceived pressure of on-time running and negative effects of inter-depot rivalry.

4. Conclusions

This study used a mixed methodology to collect data from an Australian tram organisation, and provide an account of potential human factors that contribute to tram collision risk. Preliminary analysis reveals that while the train- and tram-driving tasks are analogous, there are marked differences in the manner in which trams are driven, in addition to the operating environment. The demand for situation awareness placed on the participants was considered to be very high, and at the person-level, hinted at problems with planning. Time pressure was also identified as a core category of on-time performance. Whilst time-keeping was ostensibly a requirement, time pressure was considered to be an organisational norm, and attracted rule breaking. This was linked with a key category of inter-depot rivalry in the theme of organisational behaviour and hinted at normalisation of deviance. All
the data pointed to task-related distractors of tram driving. Further analysis of the data will provide a more in-depth understanding of how these three elements impact on the decision-making and performance of tram drivers, and safety across tram networks in general. This will then lead to the development of effective strategies to minimize risk of collisions.

Acknowledgements

The authors thank Matthew Allan for his support in the project. The authors would also like to thank the organization and individuals for their participation in the study.

References