Background: In train driving, a signal passed at danger (SPAD) event is a significant mode of safe working failure that has implications for network safety, rail service delivery, and train driver welfare. Human-error related SPAD outcomes are frequently attributed to driver distraction, but very little rail research has sought to explore distractors that not only divert attention, but also subvert the regulation of safety-performance goals. Aim: The aim of this paper was to provide a better understanding of SPAD-risk factors from the perspective of task-related distraction in passenger train drivers operating in Australia and New Zealand. Method: Data were collected using a qualitative methodology that combined focus groups with a novel and generative technique designed to stimulate situational insight. In total, twenty-eight train drivers participated from 8 different passenger rail organisations. Data were analysed in a combined deductive and inductive thematic framework. Results: The data revealed several common risk factors to train driver distraction consistent with misprioritised attention. The experience of time-keeping pressure and station dwelling created tensions between safety and performance. These issues interacted with sighting restrictions to disconnect the driver from their route knowledge. Conclusion: The findings implicated significant SPAD-risk from task-related distraction, and suggested the experience of distraction was intensified when time-keeping pressure, station dwelling and sighting restrictions converged.

Abstract

Background: A signal passed at danger (SPAD) is a rail industry term for a train that has gone past a stop signal and encroached into a section of unauthorised track. The circumstance of a train moving where it has no authority is a significant safe working failure mode. In 2009, the Australian Transport Safety Bureau reported 407 ‘driver-error’ related SPAD events [1]. Whilst a single SPAD carries catastrophic potential [2], one that results in no injury can still send shockwaves through the organisation. Each SPAD has a lengthy recovery process that degrades service delivery, but may also be detrimental to welfare of the train driver.

Sustaining attention for long periods increases the drivers’ vulnerability to various task-related disturbances and risks, which impact the way route knowledge is internally mediated. A loss of information in working memory for example, may occur from the length of time that is spent on the task, or from displacement by new and competing information [11]. Given the route knowledge load needed to maintain the task efficiently, both of these factors (i.e. time on task and information loss) can impact the way a task is carried out. SPAD errors are frequently attributed to preoccupation on competing tasks, inattention, and distraction [3]. The impact of distraction, defined as the ‘diversion of attention away from activities critical for safe driving toward a competing activity’ [12], has been the source of much research, though most has been in non-rail domains, and focused on multi-tasking [e.g., 13] or in-vehicle technologies [e.g., 14, 15].

Broadly speaking, distraction manifests from internal or external sources that can be task-related or unrelated [16]. While rail research has explored the influence of cognitive distractions and shifts in workload [17, 18], very little research has sought to explore the nature of task-related distraction in terms of risk factors that divert attention and impact how safety-performance goals are regulated. In current driver distraction taxonomies, this category is typically referenced as Driver-Misprioritised Attention. This is where the requisite levels of attention for critical and safe driving are focused on one aspect of the task to the exclusion of another invariably more critical for safety [16]. The pressure to perform for example, is an example of a task-related distraction that may allocate attention to one aspect of the task whilst attracting attention away from another of greater concern [19].

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The nature of safety and performance regulation in train driving is paradoxical - conceptually, keeping time and driving safely is conflicting, and it can be difficult for the train driver to define how they should distribute their attention to maintain these twin-goals. Research on task-related distraction in the rail industry is needed to examine the key factors in the natural passenger train driving environment that impact SPAD-risk, particularly those that facilitate misprioritisation, and explore the nature of their relationships, if this risk is to be effectively reduced.

**Aim**

This paper aims to explore perceptions of risk in challenging SPAD scenarios invented by train drivers working in Australia and New Zealand. The aim of the study is to provide a better understanding of the key factors for SPAD-risk from the perspective of task-related distraction.

**Method**

**Study design**

The study methodology included interviews and observations. Interviews were semi-structured and framed within a focus group. The protocol explored SPADs from multiple perspectives and gradually focused the group dynamic, including thoughts on key contributors to a SPAD incident (e.g., awareness, distraction, fatigue, time pressure), and the type of strategies being exercised in effort to mitigate risk.

<table>
<thead>
<tr>
<th>Class of question</th>
<th>Example question</th>
</tr>
</thead>
<tbody>
<tr>
<td>General experience</td>
<td>How does your organisation react to a SPAD?</td>
</tr>
<tr>
<td>Impressions of SPAD</td>
<td>What are your views on the different categories of SPAD?</td>
</tr>
<tr>
<td>categorisation</td>
<td></td>
</tr>
<tr>
<td>Prospective SPAD causation</td>
<td>What sort of things would you consider to be distracting during driving?</td>
</tr>
<tr>
<td>Task Influence</td>
<td>How much do you think fatigue contributes to the risk of a SPAD?</td>
</tr>
<tr>
<td>Impact of equipment design</td>
<td>Does your train have any special equipment designed to help you stop at signals?</td>
</tr>
<tr>
<td>SPAD Mitigation</td>
<td>What strategies have you developed or used to help you stop at red signals?</td>
</tr>
<tr>
<td>SPAD-Scenario invention task</td>
<td>Invent a scenario and driving conditions that may result in a SPAD for even the most experienced of drivers.</td>
</tr>
<tr>
<td>Broader issues</td>
<td>Do you think management could do anything to better prepare a train driver for a SPAD event?</td>
</tr>
</tbody>
</table>

The questions in the focus groups were coordinated around a SPAD-scenario ‘invention task.’ This was a generative approach designed to probe knowledge, stimulate situational insight, and extended similar techniques used in qualitative rail research. The invention task required each participant to invent a challenging SPAD event and record any significant decision points, shifts in situation assessment, anomalies, violated expectations, and so on. Participants were also asked to detail the strategies or changes they would adopt to mitigate the SPAD from reoccurring. The type of drawings employed in the invention task have been used to elicit expert knowledge. In particular, the rich picture soft systems approach has formalised elements such as pictorial symbols and sketches, in order to assemble relevant information and encapsulate the connections, influences, relationships, and cause-and-effect of the situation [22, 23]. Integrating an approach that escaped the bounds of conventional discourse addressed the difficulty of extracting tacit knowledge, often attributed to train driving [24].

**Participants**

Focus group participants were comprised of train drivers, and some effort was made to obtain a representative cross-section from each organisation. Variables included experience (i.e., novices and experts), unique insight (i.e., position on signal sighting committee), and SPAD history. In most cases, prior observational cab-rides were also undertaken at participating organisations. These familiarised the researcher with signalling conventions, enabled first-hand insight into the (technical) safety measures being used to mitigate SPAD-risk, and also provided an opportunity to contextualise the content in the focus groups.

Focus groups were undertaken at eight urban passenger rail organisations, six of which were in Australia and two in New Zealand. Twenty-eight drivers, two females and twenty-six males aged 24 to 58 years of age, gave informed written consent to participate in this study. The average age of these participants was 45.67 (SD = 8.52), with a median of 48, and a mode of 53 (four separate individuals). A focus group typically included a new train driver (less than one year’s experience), three experienced drivers (more than 10 years experience). The majority of participants (n = 22) possessed more than 10 years of train driving experience.

**Process**

The focus groups lasted 120 minutes and incorporated 3-to-4 train drivers. The invention task was introduced halfway through the focus group. Once the invention task was complete, each participant was asked to provide a detailed walkthrough of their scenario with the rest of the group. This was used to clarify the scenario and verify the timeline of events. Each scenario was then repeated back to the participant by the researcher, in order to clarify the nature of the scenario and understand all aspects of the driving situation. Each of the scenarios was then reviewed as part of the group, involving discussion of causal factors, driving challenges, and the operational disturbances.
Ethical considerations

Industry contacts within the organisation assisted with recruitment. This involved advertising and distributing information articles [e.g., 4] so that participation could be scheduled around working rosters. Data were de-identified and comments that could be traced back to an individual were not reported. Personal details (e.g., work history) were sought but participants were not (intentionally) compelled to provide them. Discussion of sensitive topics (e.g., fatalities), were avoided. Cab rides were approved and cleared by attending authorities (e.g., Driver Safety Managers). The study met the requirement of the human ethics committee of Central Queensland University (Ethics approval no: H12/03-033).

Data analysis

Data from the focus groups were analysed thematically, following the Grounded Theory approach by Glaser and Strauss [25]. This involved inductive coding of orthographic focus group transcriptions, that is, categories and themes for the SPAD pathway in each of the collected scenarios emerged as a function of the analysis. In all, thirty challenging scenarios were collected (two of the twenty-eight participants elected to provide an extra scenario). The overall process was iterative where each theme was subjected to multiple reviews and gradually refined. The data analysis approach broadly adopted the four-step incident categorisation scheme illustrated in Figure 1.

The scheme was guided by inductively derived codes, descriptors, and keywords associated with SPAD-risk and train driving (note: the codes shown in categorisation scheme contextualise the scenario in Figure 2). This was so that the relationships between different SPAD risk factors could be better understood. The first and second steps of the analysis were to define the driving challenges and operational disturbances from a human factors perspective. The third step was to elicit the main causes for the SPAD including any events that exacerbated the risk. The final step was to classify the scenario. Although this analytical framework was derived specifically for the SPAD-scenario invention task, qualitative path analysis methods are commonly used to analyse rail incidents [e.g., 11, 20]. The data reported in this study were systematically collected and analysed by a single individual (the author). The findings were then presented to a reference group comprised of a variety of subject matter experts (e.g., risk, safety and SPAD program managers) at the participating organisations, as a means of verifying and validating the findings against existing SPAD trends.

Results

The results will present three key factors for SPAD-risk that emerged from the findings. The most common were (1) time pressure, which features in 60% of collected scenarios, (2) station dwells, in 50% of scenarios, and (3) sighting restrictions in 80% of scenarios. The results section will use excerpts from the data to expand on the points. Example drawings from the SPAD-scenarios will be given to illustrate the type of data that came out of the invention task; and evidence the depth, individuality, and nuances of the scenarios identified by participants in the study. A walkthrough of each of the illustrated scenarios are provided to support the legibility of the drawings. The discussion section will extend these themes to consider their impact for SPAD-risk management, before concluding with a projection of future research.

Time-keeping pressure

Time keeping in train driving was considered to be of the upmost importance: “Well, that’s your job. That’s your job. As a train driver your job is to get the train in on time.” Although participants contextualised time keeping as a goal-directed activity, time-keeping pressure was described as a distraction. The drawing in Figure 2 shows a short section of track with a train about to enter a caution zone. The next signal is set at danger and located on a blind corner. While this signal is restricted from view, the driver would know about its location from route knowledge, and based on the aspect of the immediate signal, that it would be set to danger. In this scenario, the driver experiences a “loss of focus” from a radio call as they enter the caution zone, to result in a SPAD outcome. Aside from the train, track, and two signals, there is little infrastructure, though the duration of the conversation is marked, and a meticulously drawn vignette of the driver in the act of losing focus is given. On the drawing notes, the participant wrote a “focus on quick turn around of train due to timetable running late.” Given the propensity for acquiring and maintaining route knowledge, there is no reason why a SPAD would occur from line of sight restrictions alone.

Figure 2. A SPAD-scenario involving a combination of time pressure and sighting restrictions.
The main risk factor for a SPAD outcome in Figure 2 was time pressure, an internal distraction that rendered route knowledge less dependable. While the drawing highlighted a radio call to explain the loss of focus, this came back to the pressure to perform, as a strong motivator for violating safe working to answer the call. The driver was running late, and a call from the controller to seek an explanation for the delay increased the pressure to perform. This disconnected the driver from their route knowledge (i.e., there is a signal around bend), their awareness of the signal (i.e., the next signal is at danger), and attracted ineffective regulation of safety and performance. Along with the blind corner, the emphasis on maintaining focus expands the nature of route knowledge. Half of all SPAD-scenarios collected were blind-corner type scenarios, indicating the importance of route knowledge for overcoming sighting restrictions yet also how brittle it was under certain conditions of service delivery. Participants also indicated that inexperienced train drivers were very fastidious in their time keeping: "there are guys that really try to keep up time and...they will do anything to try and make up time. They will, you know, bend the boundaries..." The less experienced drivers in the focus groups exhibited some taciturnity when discussing how distraction influenced time keeping.

**Station dwelling**

Over half of the scenarios featured a SPAD outcome on station platforms. The vast majority of these occurred on departure and involved other risk factors, such as time pressure: “drivers accelerate away from platforms, trying to maintain a schedule.” The drawing in Figure 3 depicts a suburban train waiting to depart the platform. In this scenario, the driver closes the doors and departs when station staff announces that the train is ready to leave instead of departing at the signal’s authority (i.e., when the signal clears to a proceed aspect). The gravity of this error has been emphasised by a near-collision with an express passenger train on a parallel line, and the proximity of a rail level crossing. Additionally, the train stop mechanism, which would detect the false start and automatically trigger the brakes of the departing train, has been located near the crossover, allowing the train to attain a faster speed before the speed would be arrested. Again, this SPAD outcome is unintentional, yet there is more than time pressure that has contributed to the scenario.

Ordinarily, the driver would complete platform work (assisted by the Train Guard if present), and then depart when the signal is clear to proceed. In this scenario, the driver missed the last step altogether, and departed without consulting the signal. The inattention was rooted in the disengagement from driving, and distraction from the station dwell. Participants also indicated that time pressure, or alternatively, the motivation to avoid time pressure, played a part in premature departure. Station dwelling was described as an anxious state to be in. On the one hand, participants were relieved to not be driving, but also experienced unrest from the need to keep driving. Behaviour at stations was highly ritualistic and most participants reportedly undertook a series of physical tasks and/or internal dialogue whilst waiting to depart. This ranged from standing/pacing with a reminder object (e.g., keys) through to very specific train control interventions that also acted as reminders (e.g., reverse in neutral, full brake on, park brake on). Internal dialogue included repetition of current system state, for example, “I'm departing on a yellow stick, I'm departing on a yellow stick…”

**Sighting restrictions**

A large number of invented scenarios converged time pressure with station dwelling and sighting restrictions. For example, the drawing in Figure 4 depicts the scenario of a train waiting to depart a station. In this scenario, the driver arrives on the caution signal, which means that their next signal (identified in the drawing as ‘B’, located on a blind corner) is set to danger. The driver misreads signal ‘D’ as their own, which is set to a proceed aspect for the other line, and departs with a SPAD outcome. Originally, the drawing highlighted the tree as the main contributor to the SPAD, and proposed a mitigation strategy to “cut it down.” During the walkthrough, the other focus group participants indicated the tree was not the issue, and the driver should know from route knowledge that the signal visible from that side of the platform is not their own. As a consequence, the participant added the notation that they were “distracted at station.” Additionally, the temptation to misread the signal and power away from the station instead of pulling away at caution was attributed to time pressure.

**Figure 3. A SPAD-scenario involving distraction from station dwelling and time pressure.**

A key risk factor for the SPAD outcome in Figure 3 was station dwelling, defined here as the subjective experience of staying longer at a station than deemed to be necessary. The station dwell comprises a mixture of factors, including feelings, anxieties and perceptions of workload, that transcend the confines of usual scenario pathways.
Discussion

Time keeping pressure, station dwelling, and sighting restrictions were key factors that impacted SPAD-risk in train driving. These were associated with service delivery and the driver-signal dynamic, and had the effect of disconnecting and/or dislocating the participant from their route knowledge. Given the rail networks did not provide in-cab signaling or preview the route for drivers, their route knowledge was required to carry out the task and overcome sighting restrictions. Thus, the relationship between the risk factors was convergent and very dynamic. Figure 5 conceptualises the relationships between the three factors uncovered in this study. Designed using a basic 3-dimensional form that transcends the conventions of Venn-type diagramming, the figure models the dynamism, and temporal depth between the risk factors. It also illustrates how porous the factors are, and how simultaneity and convergence of these elevated SPAD-risk in the reported scenarios. It is worth noting that the three themes presented do not eliminate the existence of others. The analysis was cognisant of this issue and it has been reflected in Figure 5 in the empty layers bearing question marks.

Figure 5. Conceptual representation of the inter-dynamic relationship of the themes uncovered in this study.

Individually, distraction from time keeping and station dwelling pressures created risk, but the likelihood of a SPAD outcome reportedly increased when both of these elements converged (shown in Figure 5 as simultaneous converging pressures). In Figure 5, time keeping, station dwelling, and sighting restrictions are depicted as porous layers within a bidirectional cognitive framework. Each of these tasks elements gave rise to distraction by disconnecting and/or dislocating attention from key task components. The type of distraction revealed in this study was fundamentally task-related; time pressure and station dwells were proponents of performance that emphasised service delivery, and misprioritised the time keeping at the cost of safety, and under certain conditions, disengaged the driver. When asked about the type of pressure comprised in the themes of this study, one participant described it as “a hurry up and wait scenario.” Whilst the pattern of distraction was closely related to Driver Misprioritised Attention, there were also shades of intentional goal neglect and cursory attention, evidencing a poor ability to self-regulate in response to a competing activity, and implicating qualitative differences in the taxonomic profile [16].

Participants experienced distraction from time pressure and station dwelling on a regular basis. For example, temporal station dwelling tensions manifested on rail networks where Train Guards or Passenger Service Attendants were not employed to aid platform work (e.g., to assist wheelchair passengers). Resistance to the cumulative effects of distraction from time pressure and station dwelling were considered to come from experience, and participants described an internal condition or mental state of activation that enabled them to manage the pressures associated with keeping time and station dwelling: “Basically, you really have to just get into that one little zone;” “It’s about getting the zone;” “You need time to develop unconscious competency.” From the train driver’s perspective, these assertions say much about the way inattentiveness and disengagement from the task is perceived. The notion that drivers would miss an entire step in the process, as depicted in the station dwelling scenario (see Figure 3), also highlights a schema-based response to a generic message from train crew. Changing this dynamic may go some way to addressing this type scenario, particularly if the experience of station dwelling does not manifest.

The study illustrated a great deal about the ways of working for passenger train drivers. Train driving requires an intimate awareness of current and future states, and all participants alluded to a highly disciplined and cognitively conditioned baseline driving state. Departing stations on cautionary signals and generally engaging with cautionary zones required alertness and a heightened awareness of the evolving situation in order to manage disturbances. Much of the scenarios painted a picture of distraction by indirectly placing a strain on route knowledge, where managing an environment high in infrastructure density and event rate essentially augmented distraction in critical conditions, including distraction from ineffective performance regulation. In many of the given scenarios, SPAD-avoidance and risk mitigation may arguably come down to experience, reaction time, perfunctory response, and importantly, preemptive defensive driving strategies.

Future directions

The results of this study create some important directions for future research. The study identified relationships that emerged between key factors for SPAD-risk, however some consideration is needed of the potential solutions to the problems, and the hypothesised relationships associated with the three themes in Figure 5 need to be tested. This research should consider the extent to which the identified risk factors moderate other factors, such as anxiety and multi-tasking load. Research should continue to explore time pressure in the context of passenger train driving, identify how safety versus performance is regulated, and research how good self-regulation in response to a competing activity can be developed during training. Whilst this study employed an innovative data collection method, the participative ergonomics framework can also be extended to garner a wider representation from the whole-system perspective [e.g., 26]. Subsequent research should compile the strategies that train drivers use to reduce the impact of SPAD-risk and explore pragmatic pathways for adoption, particularly for new train drivers.

Conclusions

This paper has outlined a novel qualitative data collection methodology that was used to collect situational insight into SPAD events, and enrich the understanding of time pressure, station dwelling, and sighting restrictions, as key risk factors in passenger rail service delivery. These factors impacted the driver-signal dynamic and reduced the effectiveness of the route knowledge needed to overcome sighting constraints. Internal task-related distractions from performance
pressure emerged under certain conditions, and while distractions from
time keeping pressure and station dwelling disrupted performance in
their own right, their convergence with sighting restrictions intensified the
experience and increased the likelihood of a SPAD outcome.

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