Loud and clear? Train horn practice at railway level crossings in Australia

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Abstract

The road environment has changed markedly over the years. Train horns are ostensibly used to alert road users and typically mandatory on approach to railway level crossings but has increasingly been seen as a nuisance. Beyond their negative aspects, a study has yet to comprehensively evaluate train horn effectiveness and understand if they remain beneficial and relevant in the contemporary environment. This study aimed to provide evidence on the actual use of train horns. Field observations were conducted at 54 railway crossings across four Australian States. The effects of level crossing type, location, and environmental conditions were investigated in relation to train horn loudness as objectively measured at the crossing. Results revealed that train horns were not always used, presenting an issue for passive level crossings, however, when sounded, train horn use carried redundancy and was insufficiently loud at level crossings equipped with bells. Taken together, current train horn practice was found to be highly variable and depended on crossing type, remoteness, and individual train drivers, resulting in inconsistent warnings, raising important implications for standardisation.

Keywords

Rail; Road; Safety; Noise; Loudness; Crossing; Standards

1. Introduction

1.1 Rules and guidelines for train horn use

Trains have an extremely limited and delayed ability to react to sudden intrusions on the rail tracks, and train drivers can only apply train brakes, reduce speed, and blow the train horn to warn those in danger of collision. The use of train horns is detailed in the Codes of Practice (e.g. Australian Rail Track Corporation, 2015; Brookfield Rail, 2016). These instruct train drivers on the scenarios requiring train horn use, including the intensity, length and repetition necessary based on the circumstances and distances over which warnings need to be heard. The train horn is a mandated safety device at known high-risk locations, such as railway crossings, bridges and tunnels, and when a train moves from a stationary position (e.g. on station departure) or when approaching track workers. Horn use is also mandated when train drivers foresee a dangerous situation (Queensland Rail, 2020). High-risk locations are often marked with whistle boards, indicating to train drivers when to use their horn and guidelines also stipulate train horns should not be sounded without a valid reason. Similar guidelines are used in the United Kingdom (Hardy & Jones, 2006).

In Australian standards, train horn decibel readings are set for urban and non-urban locations (Rail Industry Safety and Standards Board, 2016). An acceptable range for a warning device being sounded in urban locations is 96 – 101 dBA, with the minimum decibel limit in non-urban locations at 106 dBA (measured 30 meters away from the locomotive). Often, trains are equipped with two horns with different volumes: the main horn, and a low (or city) horn with a lower volume. Before 2016, train horn volumes were set in the National Railway Code of Practice, and train horns were set at a maximum of 130 dBA for the main horn when measured 1m from the locomotive, and a minimum of 88 dBA 200m from the locomotive. The low horn has a set range of 85 – 90 dBA 100m from the locomotive (Blutstein, 2015). Similar operating requirements exists for Australian freight locomotives and they have been documented by providers in the CRN Engineering Standard – Rolling Stock (John Holland Rail, 2011), and in the United States (Meister & Saurenman, 2000).

To balance excessive noise in surrounding residential areas and safety considerations, the use of train horns is regulated. Several jurisdictions have quiet sections/times, where train horn use is prohibited except in emergencies. For instance, train horn can be banned in Canada between 10pm – 6am, subject to a safety audit and installation of automatic gates (Blutstein, 2015). The United States implement train horn bans on track sections rather than time-based), and the United Kingdom have permitted in 2007 quiet times (11pm – 7am) or zones and train drivers can only use the low horn at whistle boards (Blutstein, 2015). In Australia, TasRail (Tasmania) have not implemented a quiet time, but have instructed train drivers in 2014 to only use their lower volume horn during the hours of 10pm and 6am (Blutstein, 2015).

1.2 Train horn negative impacts

The literature has primarily focused on the negative impacts of train horns. Such research identified two significant effects: residential noise and land value.

Traffic noise and other transport-related noise negatively impact residents' wellbeing (Hardy & Jones, 2006). Noises associated with railway operations have been found to increase sleep fragmentation and cardiovascular arousal and distress (Micheli & Farné, 2016). Residents surveyed in Brazil documented symptoms of irritability, headaches, poor concentration and insomnia associated with excessive train noise, with train horns being the loudest (Zannin & Bunn, 2014). Night-time disturbances from train noise, including horns, were considered most distressing.

Noise mapping models have been developed to quantify the spread of train noise at and around railway crossings on surrounding residential areas (Huang & Warner, 2010). Bunn and Zannin (2016) showed that the sounding train horns resulted in noise levels of 80-90 dB at residences close to the railway tracks whilst not sounding them reduced noise levels by 10-30 dB.

Somewhat unsurprising, train horn noise was also found to reduce property value. Bellinger (2006) study showed that train horns decreased property value by 4.1% for each 10 dB increment in a small US town.

1.3 Train horn safety benefits

While level crossing safety research has examined the effects of warning devices on different road user groups' behaviour, limited information exists on train horn uses, road-user audibility of train horns, and impacts on behaviour. Recently, Yeh, Multer, and Raslear (2016) examined the effects of a range of factors in driver behaviour at level crossings using the Signal Detection Theory. This theory considered how drivers took their decisions considering the detectability of the train – including cues leading to the detectability of trains – and attitudinal factors. Train horns were included in the cues leading to the trains' detectability, but their specific effects were not evaluated. However, the study revealed that the recent safety improvements at level crossings are largely due to driver attitudes toward stopping at the crossing and improvements in the cues leading to train detection. This suggests that the effects of train horn should be investigated specifically.

Research on the effectiveness of train horns has currently focused on the loudness required to ensure detection by road users. Their aim is to use the minimum loudness necessary to reduce the negative effects on nearby communities. Train horns were found effective at warning drivers of an approaching train when they can be heard above ambient noise (Landry, Jeon, & Lautala, 2016). Rapoza and Fleming (2002) evaluated the train horn sound level required for a driver with normal hearing to detect this warning with a 95% likelihood when detection must occur to avoid a collision. This research was conducted for an average motor vehicle and an average maximum locomotive speed. It suggests that the optimal range for train horn sound levels ranges from 106 dB to 112 dB, depending on the train speed.

Train horn bans and hours of limited train horn use tend to support train horns' safety benefits. A review of crashes at railway crossings in the United States found that collisions increased when horn bans were implemented but decreased when rescinded (Rapoza, Raslear, & Rickley, 1999). Train horns were found to lead to a 38-69% reduction in train-vehicle collisions, depending on railway crossing type (active or passive) and location (city or rural) (Rapoza et al., 1999). Coleman and Stewart (1990) examined the effect of train horns on reducing collisions at active crossings in Florida, United States. Train horn bans were found to be associated with a tripling of level crossing collision rates at gated crossings, despite the presence of bells, flashing lights and barriers. However, the studies that have evaluated the effects of train horns are not only limited, but dated and focus on US practice, which is substantially different from other countries and settings, where train horns are used for longer and louder.

Pedestrians and cyclists are more likely to rely on auditory information (primarily bells, followed by hearing the train) than visual information (flashing lights and behaviour of other road users). On the other hand, drivers are more influenced by visual information such as booms or flashing lights (Beanland, Lenné, Salmon, & Stanton, 2016). This suggests that train horns may be more beneficial to pedestrians and cyclists' safety than other road users. The increasing prevalence of auditory distractions by pedestrians (talking on a mobile phone or listening to music) (Goodman, 2018; Larue, Watling, Black, Wood, & Khakzar, 2020; Mwakalonge, Siuhi, & White, 2015) may diminish the effectiveness of auditory railway crossing signals for the road users depending most on these. This is particularly concerning given that pedestrians and cyclists are more likely to access information outside the warning systems – such as the position of the train (Mulvihill et al., 2016) – and that pedestrians have the highest rate of non-compliance, whether self-reported (Mulvihill et al., 2016) or observed (Larue, Naweed, & Rodwell, 2018).

Cushing-Daniels and Murray (2005) examined the trade-off between house values and safety of crossing users. Their cost-benefit analysis suggests that the costs associated with requiring the use of train horns outweigh the safety benefits (measured as lives saved), raising questions of the relevance of train horns as a necessary warning in the current environment.

However, such outcomes may result from a poor evaluation of the safety benefits of train horns, given the lack of research that attempted to quantify such benefits.

1.4 Train horn use in practice

Rules and guidelines for the use of train horn provide are not restrictive and allow train drivers to exercise their judgement to a great extent on how to use their horn. Rail being a regulated environment where collisions result in severe consequences to drivers and occupants of trains and road users, the vast majority of train drivers have a focus on safety and compliance, as supported by the rarity of occurrences of Signals Passed At Danger (SPAD) in the rail environment, as shown by the 260 and 190 SPADs reported for passenger and freight trains respectively (corresponding to 1.87 and 2.22 SPADs per million train kilometres respectively) in Australia between July 2019 and June 2020 (Office of the National Rail Safety Regulator, 2020).

However, driving a train requires a significant workload (e.g., continuous visual monitoring of the environment). Train drivers develop and rely on mental models to reduce their workload as their driving skills increase (Moray, Groeger, & Stanton, 2017). As part of these mental models, they develop long-term expectations which become part of their route knowledge. Still, such expectations can sometimes result in strong-but-wrong assumptions about the environment they are driving in and potentially in human errors (Moray, 1990).

In the absence of evidence on train horns specifically, it is likely that train drivers likely comply with the use of train horns, particularly since the locomotive records the use of the horn (as a binary record). However, it is unknown how and when they use their horn when approaching crossings (how many times, how long, how loud), as no research has investigated how train horns are used in practice in the field, nor the mental models used by train drivers when they decide to use their horn.

1.5 Study aim

Despite continuous safety improvements of rail networks (Fraszczyk, Lamb, & Marinov, 2016; Office of the National Rail Safety Regulator, 2019), the number of vehicle-train collisions at level crossings have become stagnant (Operation Lifesaver, 2020). The road environment's social-technical properties have changed markedly since the last studies on train horns were undertaken (Keller & Rickley, 1993; Multer & Rapoza, 1997; Rapoza et al., 1999). In the current more noisy environments (Bunn & Zannin, 2016), with the emergence of better soundproofing of vehicles (Brach, 2009), the distraction of pedestrians with headsets and mobile devices, and expansion of rail networks and traffic (Love, Zhou, Edwards, Irani, & Sing, 2017) resulting in bells ringing at level crossings for extended periods (Larue & Naweed, 2018; Zannin & Bunn, 2014), a contemporary evidence-based study is required to understand whether train horns remain beneficial and indeed, relevant, for safety at level crossings.

There is currently a lack of research on how train horns are used in practice and whether they are beneficial to road users' safety. This research, therefore, aimed to provide evidence on the actual use of train horns in Australia in a variety of contexts (level crossing protection, location) and how loud they are where road users depend on them. Such research is a stepping stone towards understanding the relevance of train horns for safety.

2. Method

2.1 Study design

Field-based observations were conducted at Australian level crossings with various characteristics to record the practice of train horn use and contextualised by taking considering the: (1) protection at the crossing; and (2) the geographical location. The type of protection at the level crossing was sampled to represent a large variety of possible configurations, including passive crossings (with a stop sign), active crossings with flashing lights, active crossings with flashing lights and boom gates, active crossings with boom gates and bells, and pedestrian-only level crossing (Table 1). The geographical location considered the crossing's remoteness (major city, regional and remote) following the Australian Standard Geographical Classification (Australian Bureau of Statistics, 2011).

Observations occurred in four different Australian states and provided a wide variety of crossing contexts rather than a representative sample. Data collection lasted approximately a week for three states, namely Queensland (6 days), Victoria (4 days) and Western Australia (4 days). Differences in durations reflect travel times required to reach the various states and the more remote crossings. Data was collected at the border between Victoria and New South Wales to increase the variety of crossings (flashing lights without boom gates and passive crossings). As a result, some observations also occurred in New South Wales (1 day). Level crossings in urban areas are closer to each other, easier to reach, and frequent train services, resulting in more crossings and train being observed in such areas. To mitigate this, observations lasted longer at regional and remote crossings, and scheduling of observations was informed by online passenger train timetables and other available information for freight movements to maximise the number of trains observed at crossings with limited train traffic.

Observations and measurements were made at the level crossings when a train approached. Contextualisation of the train horn use was investigated by also recording and analysing the environmental (background) noise. Background noise measurements were collected at the level crossing when no train approached and when bells were activated.

The selection of level crossings was informed by the data provided by the Australian Level Crossing Assessment Model (ALCAM) Technical Committee (2016), which provided level crossing protection, road and rail traffic volumes, variety of rolling stock passing the crossing, and level crossing risk rating. ALCAM is similar to the All Level Crossing Risk Model used in the United Kingdom, and such models are the standard for evaluating level crossing risks (Network Rail, 2019). The research team also considered timetable availability, safety while collecting data, and discussions with rail organisations.

A total of 54 level crossings were observed (Figure 1). Each was observed for at least one hour, and up to 4.5 hours when train traffic was low. On average, observations were 1 hour 40 minutes (*SD* = 50 minutes). An average of 3.5 crossings was observed per day (*SD* = 1.1; range: 2-6), and observation occurred on average between 9 am (range: 6 am – 11:45 am) and 3 pm (range: 1:30 pm – 5:45 pm).

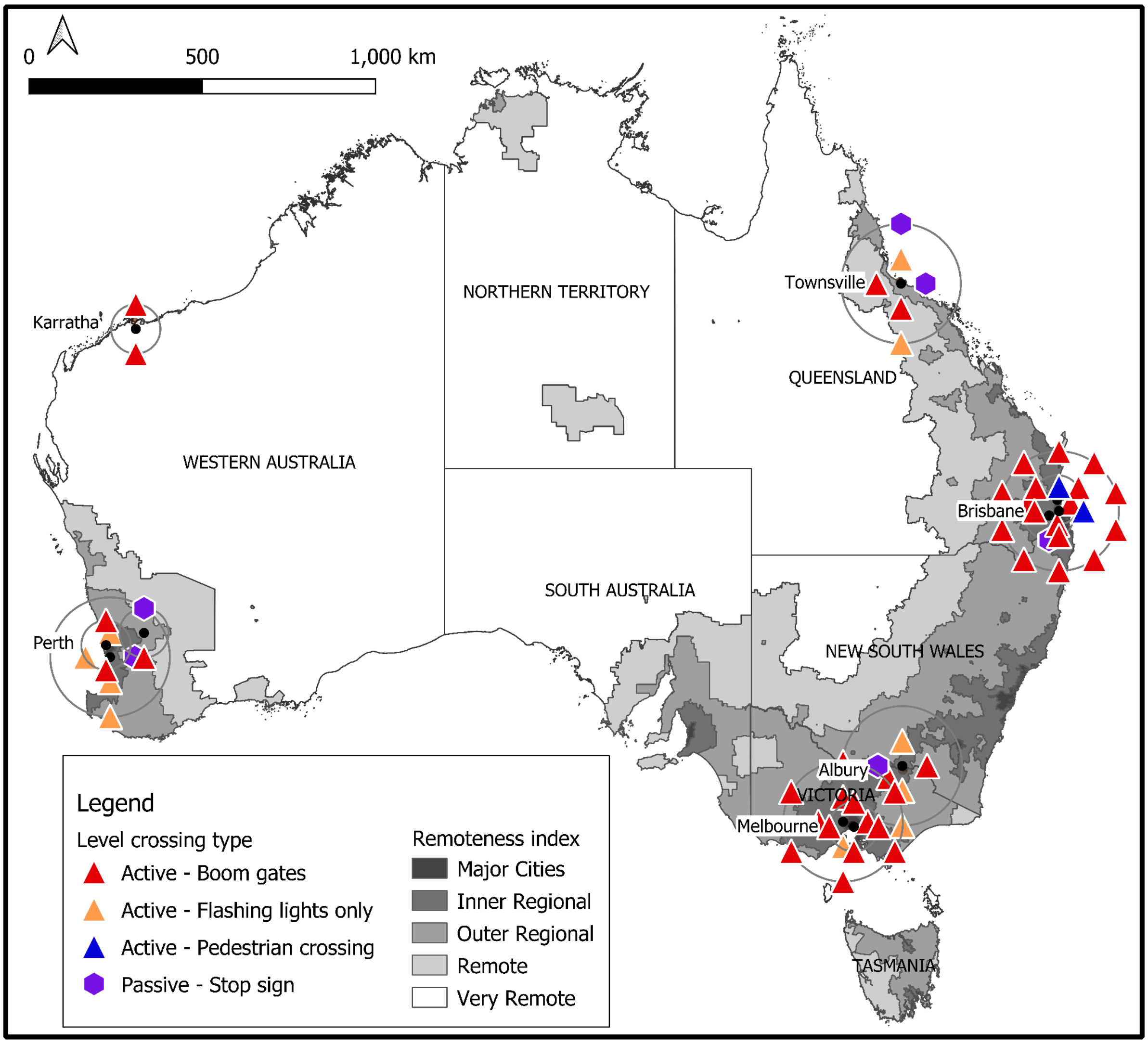

Figure 1: Map of the sites (including level crossing protection) selected for observations. The remoteness of the site is overlayed on the map following the Australian Standard Geographical Classification (Australian Bureau of Statistics, 2011)

Table 1: Characteristics and number of the observed level crossings (Number of observed trains in brackets)

Remoteness	Level crossing protection	Bells	New South Wales	Queensland	Victoria	Western Australia	Total
Major cities	boom gates	yes		11 (123)	8 (68)	2 (13)	21 (204)
	flashing lights	yes				1 (0)	1 (0)
	pedestrian	yes		2 (13)			2 (13)
Regional	boom gates	no		2 (9)			2 (9)
		yes	1 (0)	2 (13)	4 (13)	1 (3)	8 (29)
	flashing lights	no		2 (1)		5 (11)	7 (12)
		yes	1 (1)		4 (6)		5 (7)
	stop sign	no	1 (9)	3 (9)		2 (5)	6 (23)
Remote	boom gates	yes				2 (8)	2 (8)

2.2 Materials

The Siemens LMS SCADAS XS Handheld Data Acquisition System was used to record sounds at level crossings (Figure 2). This system is a portable acquisition module designed for full-day field data collection. The Siemens LMS SCADAS 3D binaural headset was connected to this data acquisition system. This headset uses an omnidirectional microphone installed on each side of the headset, recording sound at the position of human ears. The measuring bandwidth of the equipment was 20 Hz-20 kHz (audibility range for humans), with a maximum level above 130 dB, a typical noise floor of 27 dBA, and a sensitivity of 31.7 mV/Pa, which is factory aligned. The audio signal was collected at 51,200 Hz. The Sound Calibrator for LMS SCADAS 3D Binaural Headset was used to ensure that sound levels were measured with high accuracy (± 0.2 dB at 250Hz) and consistency across the different locations.

An app was developed for observers to record when the train horn was used. One observer also recorded information to contextualise train horn use with respect to the train arrival at the crossing. This app was developed using AndroidStudio (ver. 3.5) and was used on a Samsung S6 smartphone and a Samsung Tab S5e tablet.

A GoPro Fusion camera was used to record videos with a 360-degree field of view. Video recordings were used where data was not recorded within the app (e.g. the observer did not have time to press a button) or when sequence timings were outside of expected values.

Figure 2: Siemens LMS SCADAS 3D binaural headset and the LMS SCADAS XS Handheld Data Acquisition System as used during observations.

2.3 Procedure

Before collecting data in each state, the appropriate rail organisations were contacted and informed of the selected level crossings planned for observation on a given week. The study methodology and position of researchers were provided to rail companies to ensure they met their safety requirements.

Two researchers were present for all field observations and wore high visibility vest for their safety when working on the roadside. The first was responsible for collecting audio recordings using the binaural headset and the sound acquisition module (Figure 2) and was positioned at a similar place for all crossings. Observers were located at the road users' entrance of the crossing (next to the entry of the maze, the pedestrian gates or on the pathway next to the stop line for road vehicles, depending on the crossing configuration). The observer recording sound was facing the railway crossing, as a road user approaching the crossing would. This observer also recorded when they heard a train horn (via the smartphone). The second researcher was responsible for placing the camera for video recording and collection of data (via the tablet). To ensure the accuracy of audio data, the Scadas measurement unit was calibrated at the start of each day in a quiet place (indoor). The timings of the smartphone, tablet, Scadas system and cameras were also synchronised at that time. Once at the observed site, the equipment was placed at a location where the optimal view of the crossing could be safely recorded. After placing the equipment, the second observer went next to the other observer.

Measurements took place both with and without the presence of a train. Without a train, the ambient background noise levels were measured. Sounds and video measurements were primarily taken from the pedestrian area of the level crossing, and thus, represented the perspective of vulnerable road users.

When a train approached, the two observers clicked on a button displayed on their phone or tablet every time they heard a train horn as soon as they heard it. Each click was recorded with a timestamp. The second observer also clicked on a second button when the train was observed to enter the level crossing. This click was also recorded with a timestamp. After each train traversal, the sound acquisition module and video recordings were stopped and restarted immediately, allowing data files to be created for each train.

Ethical clearance was obtained from the university's Human Research Ethics Committee through a full-committee review.

2.4 Measures

2.4.1 Verification of train horn sounding

The number of horn blasts per train approach was obtained from subjective measures of both observers. In cases where the two observers did not report the same number of horn blasts, the recorded videos were used to determine how many times the horn was used. The agreement between the two coders on the number of train horns was 88.2%.

2.4.2 Train horn durations

The subjective timing of the train horn was used to identify the time in the audio signal record when it was used. A researcher listened to the audio record using Audacity (ver. 2.3.3) to confirm train horn occurrence. The researcher identified the start and end of the train horn through listening and by visual inspection of the audio signal (Figure 3). The start was identified as the moment when the Sound Pressure Level (SPL) signal started to rise, while the end was identified as the time when the signal reached a background level (which might be different to the one before the horn). The software also allowed extraction of the indices of the start and end of the signal, which were then converted into time (by dividing with the signal frequency). Train horn duration was then recorded as the difference between the end and start time.

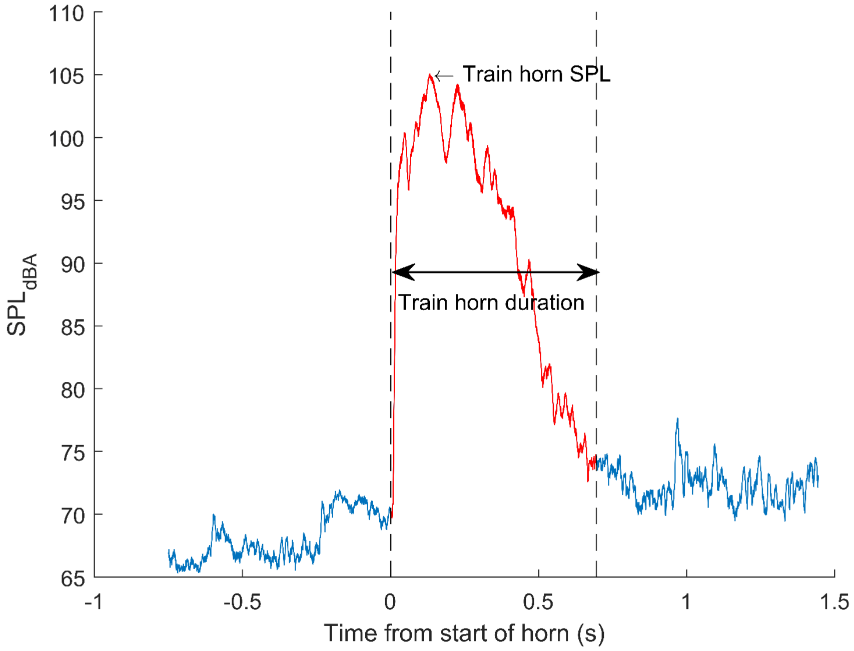

Figure 3: Scadas signal SPL when the horn in used (red) showing the train horn SPL (maximum) and duration.

2.4.3 Train horn and environment sound levels

The audio signals recorded with the Scadas equipment were first pre-processed using a set of temporal and frequency analysis tools commonly applied to acoustic signals to estimate the sound level perceived by humans were used. The first step was to filter the measurements using human ear sensitivity, as the human ear is less sensitive to low frequencies; an A-Weighted frequency filter was used for this purpose, following the IEC 61672-1:2013 (2013) Standard.

The sound pressure level was then computed from the A-weighted sound level. SPL is considered as the benchmark measurement for noise and has been used to quantify the harmfulness level of the noise for human and public health (World Health Organization, 2018).

The final pre-processing step was to use a moving average filter to reduce the additive noise caused by microphones and electroacoustic equipment. The time window of the filter was tuned with pre-recorded sound level from the calibration device and was set to 500 samples. Using the calibration signal ensured that use of a moving average filter did not eliminate important information from the original signal (IEC 61672-1:2013).

Since train horns are usually characterised by short exposure time (at least in Australia), the train horn signal resembles an impulse signal. The characteristic of the signal can therefore be captured by the maximum SPL_{dBA} value (Rapoza et al., 1999; State of NSW and Environment Protection Authority, 2013). The train horn loudness was extracted as the maximum SPL during the identified peak.

The background sound level before the train approached was extracted as the mean of five seconds of SPL data two minutes before the train's first use of the horn. The signal was visually inspected by a researcher and any other train horn or bells during that time (from another train for example) were filtered out.

The presence of bell sounds in the audio records were identified using the timestamps recorded with the tablet (i.e. the times when lights were activated and deactivated). The SPL data of the first 20 seconds of the bells were extracted for each closure when a train horn was sounded. The bell sound level was extracted as the maximum SPL recoded from five seconds after the activation of the bells to ten seconds after. The bell signal is very specific and allowed researchers to visually inspect it to ensure no other sounds were included in the selected signal (e.g. road traffic). When the interval included other sounds, the researcher identified a different time interval for extracting the bell SPL value. When it was not possible to find a signal without other noise, the bell SPL was not extracted (this occurred for 29 records out of 216).

2.4.4 Time when the train horn is used

Train horn use timing was considered with respect to the time the train reached the crossing. It was obtained from the timestamps recorded with the tablet by one of the observers. The time was the difference between the time the train entered the crossing and the time the train horn was used. In cases when the observer did not record the time the train entered the crossing, or for values outside the range of value broadly observed, the time duration was verified using video records.

2.5 Data Analysis

Analysis of data collected aimed to show the core similarities and differences between train horn and noise levels. Statistical tests were run using Generalised Linear Models (GLMs) on R (ver. 3.6.2). These tests focused on assessing the effects of the type of the level crossing, the geographical location and the environmental conditions on the number of horn uses, their duration and timing, and their loudness compared to the surrounding environment. The level of significance chosen for the study was set at α=0.05.

3. Results

3.1 Number of train horn sounding per approach

A total of 305 travelling trains were observed (Table 1). Out of these level crossing traversals, 459 train horn blasts were recorded. Train horns were observed to be used during the approach of level crossings between 0 and 5 times. Most trains used it either once (133 times; 44%) or twice (109 times; 36%). A total of 27 traversals were observed without any train horn use (9%).

Statistical analyses showed that train horns were significantly less likely to be used at level crossings with a stop sign (73.9%; *z*=-2.81, *p*=0.005) compared with active (boom gates or flashing lights) or pedestrian crossings (92.6%). No effects were found for the location type or the presence of bells at the crossing.

Further statistical analyses with GLM showed that when used, the train horn was more likely to be used more than once at pedestrian crossings (91.7%; *z*=2.31, *p*=0.021) compared with other crossings (49.2%). At other crossings and when used, the train horn was blasted once half of the time, and more than once the rest of the time. No statistical effects were found for location type or the presence of bells at the crossing.

3.2 Horn blast duration

Horn blasts lasted on average 0.96 s (*SD*=1.18) and ranged between 0.08 to 8.41 s. Statistical analyses revealed that train horn duration was significantly different between level crossing location types. The duration of the train horn was found on average to be 0.75 s (*SD*=0.51) for the observed level crossings in urban and regional locations. Values ranged from 0.08 to 3.77 s, with 90% of the values within the 0.25 to 1.75 s range. The duration was found to be longer in the remote location observed (Pilbara, Western Australia), with horn blasts lasting on average 5.18 s (*SD*=2.47) in that region (*t*=24.81, *p*<0.001) and 90% of the blasts lasted between 1.39 and 8.41 s. No other factors were found to have a statistically significant effect on the duration of train horn blasts.

3.3 Time when horn used before entering the crossing

Initial use of the train horn during level crossing approach was on average 26.4 s (*SD*=24.4) before the train entered the crossing. This timeframe corresponded with the horn being used a few seconds before lights were activated at active crossings. However, given the variability of the number of uses of the train horn per crossing approach, it was also important to consider whether the horn was used once or multiple times. When blasted once, the first time the train horn was used was on average 13.7 s (*SD*=9.3) before the train entered the crossing. When blasted multiple times, this increased to an average of 38.3 s (*SD*=27.5). Large variability with the use of the horn was found, particularly for multiple uses of the horn.

Statistical analyses confirmed that when blasted multiple times, the train horn was used on average 27.5 seconds earlier (*t*=11.6, *p*<0.001). No other factors were found to have a statistically significant effect on the first time the train horn was used before the train reached the crossing.

When the train horn is blasted multiple times, it is important to determine when the horn was used last. With multiple uses of the train horn, the last time train drivers warned road users of their approach was on average 9.9 s (*SD*=8.6) before the train reached the crossing. Statistical analyses revealed that in remote locations, the train horn was used last 3.8 s before reaching the crossing (*t*=-3.37, *p*<0.001). Analyses also found that the train horn tended to be used 2.7 s earlier in major cities, but the difference was only approaching statistical significance (*t*=-1.91, *p*=0.059). No other factors were found to have a statistically significant effect on the last time the train horn was used before the train reached the crossing.

3.3 Loudness

3.3.1 Overall context

On average, the environmental noise was 58.6 dBA (*SD*=8.1) and ranged between 35.1 and 85.6 dBA. 95 percent of the records had a loudness less than 71.7 dBA. At active crossings equipped with bells, the environmental sound increased to 77.1 dBA (*SD*=8.2) on average once the crossing is activated, with 90 percent of the records between 64.4 and 90.2 dBA.

3.3.2 Train horn

Train horns were on average 82.2 dBA (*SD*=11.0) loud. Loudness ranged between 51.3 dBA and 116.2 dBA. 90% of the train horns were between 61.5 and 106.3 dBA, showing significant variability. Given that sounds attenuate with distance, statistical analyses were conducted to evaluate how horn loudness varied depending on the type of horn in the arrival sequence. There was no statistically significant difference between a single horn or the first of multiple horns (*t*=-1.19, *p*=0.235), and they were on average 79.7 dBA loud. The last horn was found to be 9.2 dBA louder (*t*=7.10, *p*<0.001), reaching 88.9 dBA. The intermediate horn tended to be between the two previous values, being 3.7 dBA above the first horn. However, this difference was only approaching statistical significance (*t*=-1.94, *p*=0.053). No other factor was found to statistically influence the loudness of the horn at the crossing.

3.3.2 Train horn loudness above environmental noise

Train horns were on average 23.8 dBA (*SD*=12.8) louder than the environmental noise before the train approached the crossing. This difference ranged between -9.9 dBA and 67.0 dBA. 90% of the train horns were between 3.0 and 53.6 dBA above background noise, showing significant variability. Three quarters (76.0%) of the recorded horns were more than 15dBA above background noise, which is the recommended threshold for alerting road users.

Statistical analyses revealed that the difference in loudness between the train horn and environmental noise depended on the horn sequence. When the horn was used a single time, or when it was used first, no statistically significant difference was found (*t*=0.06, *p*=0.951), and the loudness difference was on average 20.4 dBA. The last horn was found to be 11.8 dBA louder (*t*=7.55, *p*<0.001), reaching 32.4 dBA above background noise. The intermediate horn was between the two previous values, the difference being 6.2 dBA above that of the first horn (*t*=2.79, *p*=0.006). As a consequence of this difference with horn sequence, horn loudness was found to be sufficiently louder than the environmental noise 70%, 82% and 91% of the time for first or single, intermediate and last horns respectively. No other factor was found to statistically influence the difference in loudness between the train horn and the environmental noise at the crossing.

3.3.2 Train horn loudness above level crossing bells

At active crossings equipped with bells, train horns were on average 6.1 dBA (*SD*=11.9) louder than the environmental noise before the train approached the crossing. This difference ranged between -31.6 dBA and 48.8 dBA. 90% of the train horns were between 12.1 dBA below and 31.0 dBA above background noise, showing significant variability. Several train horn blasts were not as loud as the environment when bells were ringing, and almost half (47.7%) did not reach the loudness of the bells for observers at the crossing. 36.8% of observed train horns at such crossings were at least 15 dBA above the bells' noise.

Statistical analyses revealed that the difference in loudness between the train horn and bells' noise depended on horn sequence. When the horn was used the first time in a sequence of uses (t=-1.55, p=0.121), or when it was not the last use of the horn (t=-0.02, p=0.983), no statistically significant difference was found when the horn was used a single time. In those cases, the loudness difference was on average 3.6 dBA. The last horn was found to be an additional 9.4 dBA louder (t=5.97, p<0.001), reaching 13.0 dBA above bells' noise. No other factor was found to statistically influence the difference in loudness between the train horn and the environmental noise at the crossing.

4. Discussion

4.1 Train horn practice

The methodology used in this research consisted of field observations covering major Australian States for rail network and a variety of crossings types and locations. As per guidelines and Standards for an Australian context (Blutstein, 2015; Rail Industry Safety and Standards Board, 2016), the train horn was widely used at level crossings at least once as an alerting signal (i.e. to inform others of the approach of the train). Often, it was sounded multiple times to reinforce the imminence of train arrival at the crossing, but some variation between crossing types was observed. Train horn use at active level crossings was somewhat more consistent and frequent than at passive crossings. It is unclear why train horn use was less frequent at passive crossings, given that users at these types of level crossings do not receive any information about trains approaching other than the horn and sighting of the train itself, and because train horn blasts would be more critical at these higher risk crossings (Haleem & Gan, 2015), where road users exhibit more risky behaviours (Yeh et al., 2016). It is hypothesised that train drivers may not only rely on whistle boards in their decision to use train horns and may also use the flashing lights and bells as cues when approaching crossings. Indeed, flashing lights are also designed to be visible to train drivers so that they can identify when a level crossing signal is malfunctioning when they approach. Such an explanation would be consistent with the significant focus train drivers spend on visually monitoring the rail environment, particularly signals (Naweed & Balakrishnan, 2014). Such finding may also be related to the limited road traffic at passive crossings, which may affect train drivers' risk perception and mental models, and the often longer sighting distances at such crossings, which may provide higher perceptions of control on the environment they operate in and a use of the train horn only when train drivers deem it necessary.

Train horn were used much longer in the remote area included in this study (Pilbara, Western Australia) compared to urban (major cities) and regional areas. The trains in the Pilbara had the particularity to be very long and slower than the trains observed at other level crossings, leading to increased distances required for trains to slow down to a complete stop. They also share the crossing with very long road vehicles (Naweed, Balakrishnan, & Larue, 2018; Naweed, Gale, & Larue, 2016). Such use may therefore represent the ideal use of train horn as a safety device when no other constraints are considered, such as noise pollution/complaints. However, use of the train horn in such a way and in such an area represents a small part of the rail network and may not be transferable to other locations.

In urban and regional areas, the duration was rather short but was highly variable. These short durations may be explained in urban areas by the number of adjacent residential areas and their likely noise complaints from residents (Zannin & Bunn, 2014), which may influence how train drivers use their horn. Indeed, they are required to use their horn at least once before reaching the crossing, but the number, duration and loudness of horns are left to their discretion. Our observations show that some train drivers use their horn as short as possible and as low as possible, suggesting that they may use the horn so that it is recorded rather than as a message for road users in some situations (e.g. to reduce noise complaints). However, it is not clear why durations are shorter in regional areas, particularly when the crossings were either passive or without boom gates, and far from residential areas.

4.2 Effectiveness of train horn as a warning

The train horn was found to be often used long before the train entered the crossing when used multiple times, suggesting that such horn use is more informative for road users than a critical warning. This is likely to be the consequence of the location of whistle boards, which are placed to ensure that the approach of the crossing is conveyed to road users for the worst case scenario, that is for the fastest train when the heaviest and longest vehicle is at the entrance of the crossing. When used once only, it was used much closer to the crossing, providing a more critical warning to road users, that the train is about to enter the crossing. The informative use is likely to be too early to provide road users with a useful warning. It is also important to note that using multiple warnings may not be necessary for eliciting road users' reaction. It has been found that when an alarm is heard, there is no benefit in having multiple alarms for eliciting road users' reaction, as reaction times are similar in single versus multiple warning approaches (Cummings, Kilgore, Wang, Tijerina, & Kochhar, 2007; Ho & Cummings, 2005). Our findings suggest that not all train horns may be beneficial to the safety of road users, providing opportunities for reductions of the use of train horns.

The effectiveness of train horn as a warning depends largely on how loud it is compared to the environmental noise. Almost all of the measured horn loudness values were within the 65 to 118 dBA range recommended for warning the public of danger in the *Ergonomics — Danger signals for public and work areas — Auditory danger signals* International Standard (ISO 7731:2003(R2015)), which also applies for road users (Burgess & McCarty, 2009). Our measurements also aligned with previous research by Bunn and Zannin (2016) on noise levels close to the railway tracks and the minimum expected loudness 200 meters away from the locomotive (John Holland Rail, 2011), suggesting that train horn was used as recommended.

The loudness of the horn as perceived at the crossing was deemed sufficient when considering human hearing dynamics. For more critical warnings (i.e. close to the crossing), the large majority of train horns were above the desired threshold of 15 dB above environment noise recommended by ISO 7731:2003(R2015) (2015). However, for the more informative train horn uses, a significant proportion was below that threshold. Further, most train horns were not as loud as the optimal sound levels recommended by Rapoza and Fleming (2002) to ensure detection by road users at railway crossings. These observations are consistent with other research that has shown that in certain environments, train horns exceed environmental noise only when the train is 30 meters away from the crossing (Landry et al., 2016). This raises questions about their effectiveness as a warning for a significant proportion of uses. Such issues become even more acute at active level crossings equipped with bells, where environmental noise is dominated by the bells.

4.3 Implications for policy and practice

Large variability was found at every level of analysis for all the different factors considered. Train horn use and characteristics were highly variable within remoteness levels, within level crossing protection levels or even at the individual level crossing level. Variability was found on horn durations, the timing of the use of the horn and loudness. This variability is likely to be as a result of jurisdiction and rail organisations differences, unique crossing specificities, variability in train traffic at the crossing (passenger/freight; express) and train driver decision making processes. Similar conditions can lead to very different information provided to road users, who are therefore not provided with a consistent warning with the train horn. All this reflects a disconnect between the use of the train horn as stated in policies and the way it is performed in practice.

This variability could play a critical role in road users' assessments of the train distance and criticality of the warning provided and their decision making. This variability can also reduce the perception by road users that this warning is reliable, which can reduce drivers' inclination to stop at crossings (Yeh et al., 2016) and non compliance with level crossing rules (Larue, Blackman, & Freeman, 2020; Larue, Miska, et al., 2020). Standards and guidelines for train horns should be expanded to consider not only the conditions requiring blasting the train horn and the sound characteristics close to the locomotive, but also the actual sound levels where road users perceive such blasts and the way the train horn should be used to obtain a consistent warning at the crossing.

While it may sound counterintuitive, train horns may not always be adopted at the riskiest of locations: passive level crossings. It is hypothesised that this reduced use may be related to train drivers assuming the absence of traffic at passive crossings, drivers having better sighting distance (Larue, Filtness, et al., 2018; Standards Australia, 2016), and/or experience with the particular crossing to evaluate the current condition at the crossing, given that passive crossings were located in open areas. Additional training of train drivers may be required to increase the use of train horn at such crossing, given their risk characteristics, and the limited negative effects they may have at such crossings, which are often located far from residential areas.

Train horns tend, however, to be used more at pedestrian crossings. This may reflect knowledge from train drivers on the higher dependence of vulnerable road users on audible warnings and the higher chance that a pedestrian may enter the crossing despite its active state (Larue, Naweed, et al., 2018; Mulvihill et al., 2016), and suggest that train horns may be used more toward such road users than road vehicles, particularly when crossings are equipped with flashing lights and bells.

The findings from this study also suggest that there could be opportunities to reduce train horn use without impacting safety. Given that it is more critical to warn road users at the appropriate time rather than multiple times, and that warning should be relevant to them, a number of train horn use provided while the train is far from the crossing may not be necessary. Policy and guidance could therefore be adapted to reduce unnecessary train horn blasts, particularly around residential areas. Such reductions may have significant benefits to communities. Indeed, while further train horn blasts were significantly less loud, this difference may primarily be due to sound attenuation with distance (Rail Industry Safety and Standards Board, 2016) rather than train drivers using their horn differently at the whistle board and just before the crossing. It is therefore likely that these horn blasts are much louder than measured at the crossing in the vicinity of the train, suggesting that train horn effects on communities may be wider than 60-meter radius around level crossings for negative impacts on the quality of life for those who live and work in the vicinity (Rapoza et al., 1999).

The use of wayside horns located at the crossing could also be an option to automate train horns for level crossings, reducing noise pollution from train horns and the variability of its usage. Such an approach has been trialled in the US. It directs the sound toward the road traffic, further reducing sound pollution in nearby communities. Research suggests that they may result in safer driver behaviour as the sound appears closer to the road user, leading to perceptions that the train is closer (Landry et al., 2016). However, limited research has currently evaluated these effects, particularly over the longer term.

The use in urban and regional location appears to be very different from the unconstraint use observed in remote areas, being shorter and not as loud within the environment. In particular, bells and train horn may not work well in conjunction with one another when warning road users, and it is not clear whether train horns provide additional benefits under such conditions, particularly for road users with reduced hearing ability, in soundproof vehicles, or wearing headsets. This also raises the question of whether train speeds may be an issue for warning road users, given that faster trains will warn road users from further, and their horns are likely to be less effective, being more attenuated by the longer distance, and road users being less likely to detect trains at such distances (Clark, Perrone, & Isler, 2013; Larue, Filtness, et al., 2018). Our observations at level crossings also highlight that road users are not only exposed to train horns that are directly relevant to them. It is especially the case when level crossings are in the vicinity of a train station. In such case, road users at the crossings may hear additional train horns, such as the ones when train depart a station. It adds further complexity to the message provided to road users. This raises questions about whether the current practice in most urban and regional areas is sufficient to provide the expected safety benefits.

4.4 Strengths, limitations, and future research directions

While level crossing safety remains a global issue which has been the focus of numerous studies, little attention has been put on one of the safety tool used for safe traversals of such crossings: train horns. Given their known adverse effects, it is critical to ensure that the use of train horns is beneficial to safety. This field study is the first to provide a broad understanding of the use of train horns at railway crossings in practice, having examined different types of level crossings and different types of locations. The findings from this study provide important insights into the need for further standardisation of the use of train horns, as well as the first step toward understanding whether train horns are beneficial to the safety of all road users.

While the research design employed in this study was comprehensive, there are invariably some demarcations that need to be drawn around the applicability of the findings, mainly because of limitations in the scope of the research.

While the findings from this study provide a cohesive understanding of train horn practices in Australia, the research team lacked access to information which may have been very useful during field observation planning and data analysis. Some of the observed crossings initially selected as passive had been upgraded to active crossings upon site arrivals, which reduced the number of passive crossings investigated and resulted in no crossings with a give-way sign included in the observations. An additional limitation is that the team was not aware of the presence and location of whistle boards, which reduced the ability to contextualise train horn counts as well as the locations where train horns were used. Additional research is necessary to understand whether the loudness difference in the sequence of train horns is only a result of attenuation due to distance, or whether the use by train drivers is different, the earlier uses being more informative and the later more a warning. This is important to understand the necessity of this practice and a potential avenue for reducing the number of train horn uses and their associated negative effects.

Logistical constraints, non-automated wide-scale observations, and train traffic volumes also led to a limited number of trains traversals at crossings which were passive and at crossings in regional or remote areas. While researchers spent a longer time at these crossings, it was nevertheless insufficient to gather train horn data to a similar scale as for level crossings close to major cities.

Observers stood next to the crossing and wore high visibility vests when collecting data. Rail organisations were also informed of the researchers' presence within some areas, information which may have been provided to train drivers. This may have affected the way train drivers used their horn at crossings. However, such an effect, if existing, would likely result in higher use of train horns and would not affect our finding that train horn was used less at passive crossings. Also, this effect is likely to be limited given that *(i)* the crossing may not always be visible to the train driver when they usually use their horn, (ii) train drivers were not aware of the exact location and time when data was collected, and *(iii)* the rail industry is highly regulated, with uses of train horns are recorded by the locomotive and accessible in case of incidents.

Further, data were only collected during daytime due to the limited train traffic at night. Given the relationship between noise complaints and usage of train horn during night conditions, it appears essential for future research to gather objective information on the use of train horns at night, to confirm whether train horn use is similar or different from what was observed during daytime. Automated data collection approaches are required to tackle the challenge of the limited train traffic at night.

This work is also a steppingstone, which informs required future work. Having established a rich understanding of what train horns sound like at rail levels crossing, further research should consider how train horns are perceived by road users. These insights are required to understand the future utility of train horns, relative to the safety benefits in the Australian context. This study also shows that practice is very variable, even at a given crossing. This suggests that train drivers are using their horn differently. With current guidelines and standards focusing on when to use the horn rather than how, train drivers have to interpret such guidelines when driving. It is therefore essential to understand their perspective, their interpretation of guidelines as well as their decision processes to ensure road users are provided with consistent and effective warning messages.

5. Conclusion

This observational field study has identified that train horns are not always used when a train approaches a crossing, particularly at passive crossings. Observations have also revealed that train horns are often used multiple times, resulting in train horns being provided to road users too early and at reduced loudness due to attenuation. Importantly, a significant proportion of train horns that are sounded at active level crossings are insufficiently loud to warn road users because of the increase in background noise created by the audible warnings (bells). Train horn practices were shown to be largely variable depending on protection type, location, and train drivers, suggesting the need for revised standards and guidelines, and further evaluation of their safety benefits for road users.

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