Case study

Driver satisfaction with a modified proximity detection system in mine haul trucks following an accident investigation

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Abstract

Background: Collisions involving heavy vehicles at mines continue to be common, often with serious consequences. An emerging technology to prevent collisions is in-cab proximity detection systems. This paper builds on previous work where a proximity detection system at an underground gold mine was analysed using a number of human factors methods. After this work was completed, but before any changes were made to the interface, a collision occurred at the mine. **Aims:** The initial aim of the research was to determine if the predicted issues with the interface and collision prevention strategies were present in the accident. The secondary aim was to test driver acceptance of the interface changes made in response. **Method and results:** The incident was analysed by direct interviews using a modified form of the Critical Decision Method. The accident site was then viewed with the recreated vehicle positions. Twelve failings in collision prevention risk controls, including proximity detection systems, were found. All of these failings were predicted by the human factors methods. Some of the recommended changes were then made to the interface. Driver acceptance of these changes was measured using a scale accepted and validated for on-road in-vehicle systems. **Conclusions:** The analysis of the accident provides evidence that human factors methods can accurately predict issues with in-cab proximity detection systems for mining equipment. Furthermore, it appears that these methods lead to design changes that are accepted by drivers. More research is required to test if the changes are also *effective*.

Background

Reasons for deployment of proximity detection system in mining

Recent Australian data suggests that approximately 35% of mining fatalities are due to vehicle interactions and 53% involved pedestrians and vehicles [1]. In an attempt to prevent collisions involving vehicles, proximity detection systems are being ever more deployed in mobile mining equipment, such as haul trucks, excavators and light vehicles [2]. The aim of these technologies is ultimately to prevent vehicles colliding with other vehicles, persons and/or infrastructure.

Reasons for human factors analysis of proximity detection systems in mining

Many systems are currently subject to intensive research and development work by various parties. This research has mainly focused on ensuring the technology has appropriate sensitivity, accuracy and reliability to work in this environment – *the detection of proximity*. There has been relatively little systematic work conducted on how the human machine interface aids operational decision making and action – *that the detection of a vehicle in proximity can be effectively conducted.* Consideration of operator decision making is a major factor in the effectiveness of the systems employed in preventing accidents, especially for technologically complex systems [3].

A variety of interface types are possible for this technology, including warning lights/alarms through to automatic machine shut down when a likely collision is detected. A graphical representation of this technology, adapted from Van der Laan et al. [4] is shown in Figure 1. No single interface type fits all application areas in mining. Therefore, each context demands a careful, user-centred understanding in order to effectively implement the technology [5].

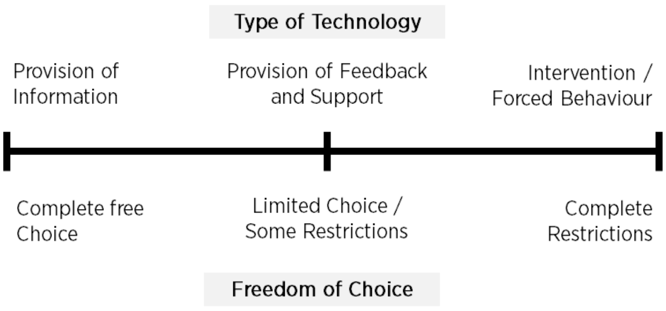

Figure 1. *Spectrum of in-vehicle systems*

The mine site

This paper describes the analysis of a proximity detection system interface at an underground gold mine in Australia. The mobile mining equipment can be considered in two categories:

1. **Heavy Equipment** including loaders/shovels, to load the ore onto a vehicle for removal and haul trucks to transport the ore to the surface; and
2. **Light vehicles** for a variety of maintenance and technical purposes, including setting charges for rock blasting.

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Figure 2. *Haul Trucks*

The proximity detection system

The mine installed a Radio Frequency Identification (RFID) system to track vehicle movement. A RFID is commonly used for tracking objects such as cars on toll roads, public transport patrons and library books. RFID systems involve 'tags' which send out a vehicle identification (ID) in the form of electromagnetic waves that are interpreted by 'readers' showing the presence of an object. The system was primarily installed at the mine to improve the monitoring of production. However, there was an opportunity to add a proximity warning system to, hopefully, reduce the risk of collision between vehicles. 'Tags' were mounted on all vehicles. 'Readers' were mounted on heavy vehicles with large blind spots; haul trucks (Figure 2) and the loaders.

A visual display is provided to the drivers via a touch screen tablet computer. This is mounted on the right of the driver for both haul trucks and loaders. The system detects the presence of any vehicles in range, not just those that are determined dangerous or require action. The driver must still interpret the necessary course of action. The screen shows a text list of the vehicles currently being detected (Figure 3). Part of the text indicates the type of vehicle. A sound of alterable volume occurs on detection and the line with the vehicle ID flashes. Both continue until the screen is physically touched. When the vehicle is no longer detected, it is removed from the screen, regardless of whether the driver has acknowledged its presence by touching the screen.

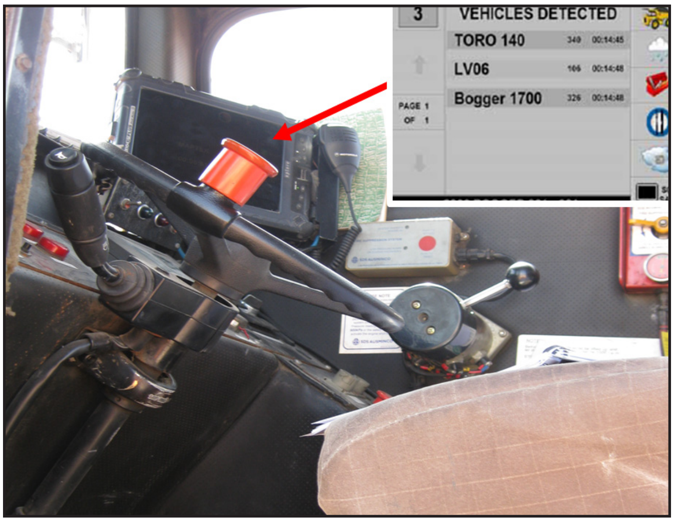


Figure 3. *Screen position in haul truck cab*

Previous work and research aim

Previous work has used a variety of human factors methods to investigate the proximity detection system [6]. This research was conducted to understand the proximity detection system within the system, including other collision prevention controls. There were nine distinct risk controls, including radio contact, direct vision of the vehicle and headlights. Failure modes were determined for each, including the proximity detection system. Generally, proximity detection was found to be the control of last resort. Following the previous research, an accident occurred at the mine. The aim of this research was to determine if the issues with the proximity detection system and other controls were accurately predicted. Following the accident, a number of changes were made to the proximity detection system interface. The secondary aim of the research was to test driver acceptance of these changes.

Method

Accident investigation method

A load-haul-dump (LHD) was waiting in the underground workshop for a service vehicle to arrive for refuelling. When the service vehicle arrived, upon seeing the loader in the service bay, it backed up the main decline to allow the loader to exit. Upon exiting the workshop, the LHD struck a light vehicle (LV) ascending the main decline. The loader bucket struck the bonnet of the vehicle causing equipment damage. No persons were injured, but there was the potential for fatal injury. All vehicle operators involved in the incident were interviewed using the Critical Decision Method (CDM) [7]. CDM is a semi-structured interview process. The positions and movements of the vehicles were reconstructed to assist in reviewing the incident. This involved placing a LV in the decline at approximately the impact point and approaching it with a LHD.

Acceptance

Following the accident investigation, a number of changes were made to the proximity detection system (see results). In order to gauge the success of the interface changes that were made, the equipment operators were surveyed. Eighteen drivers completed the survey of the 20 drivers who worked at the mine. The survey was conducted primarily to determine how accepting the drivers were of the initial system and, in comparison, the altered system. Drivers were also asked to rate the effectiveness of the system(s), the importance of other controls, and their opinion on further proposed changes.

The method for measuring driver acceptance used in this research was developed by Van der Laan et al. [4]. This technique was selected because it had been applied in several different studies of measuring the acceptance of in-vehicle systems, including collision avoidance systems with auditory feedback in a variety of environments [8-10]. In these studies, it was found to be a good measure of both absolute acceptance and was sensitive enough to determine relative/comparative acceptance amongst groups or technology options. Using this technique, a five point rating scale was used for nine questions rating acceptance of the initial and altered interface of the proximity detection system . Drivers selected between five boxes placed between two opposing qualitative words. The position of the positive and negative words is sometimes reversed. The positive words are shown in bold below:

1. **Useful** ☐ ☐ ☐ ☐ ☐ Useless
2. **Pleasant** ☐ ☐ ☐ ☐ ☐ Unpleasant
3. Bad ☐ ☐ ☐ ☐ ☐ **Good**
4. **Nice** ☐ ☐ ☐ ☐ ☐ Annoying
5. **Effective** ☐ ☐ ☐ ☐ ☐ Superfluous
6. Irritating ☐ ☐ ☐ ☐ ☐ **Likeable**
7. **Assisting** ☐ ☐ ☐ ☐ ☐ Worthless
8. Undesirable ☐ ☐ ☐ ☐ ☐ **Desirable**
9. **Raising Alertness** ☐ ☐ ☐ ☐ ☐ Sleep Inducing

The sum of all questions makeup a score for 'acceptance'. Additionally, the odd numbered questions (i.e. 1, 3, 5, 9) are a rating of 'usefulness' and the even numbered questions (i.e. 2, 4, 6, 8) are a rating of 'satisfaction'. Drivers were all initially asked to make a rating of the current proximity detection system. Those drivers who were working at the mine with the previous system were also requested to make a rating of the previous system. In the scoring system for the scales determined by the Van der Laan, the middle box represented a score of 0, the boxes either side represented -1 to +1 and the outer boxes +2 or -2. However, in this case, Van der Laan's scoring system was adapted by the authors to be positive numbers only (1- 5) to allow shape plotting on a radar graph. By joining up each of the ratings, an irregular polygon is formed and these types of radar graphs are particularly useful for visually communicating the overall change. This change does not alter the analysis in any other way. The original and adapted scoring can be seen below:

Veer deer Laan's Score	-1	-2	0	+1	+2
	☐	☐	☐	☐	☐
Adapted Score	+1	+2	+3	+4	+5

Results

Investigation

Many of the predicted issues identified by the failure modes analysis of the controls were incidentally validated following a collision at the mine between a LHD and a LV. However, the controls failed in a way that was predicted and no unpredicted failure modes occurred. The failure modes that occurred in this incident are italicised in the Table 1. Notably, 8 controls needed to fail with 12 distinct failure modes.

Additional controls other than proximity detection

The investigation made a number of recommendations which related to strengthen the risk control of direct vision. This is because with the loader bucket raised, the driver of the LHD could only see the LV just before it crashed into the vehicle (see box in Figure 4). To assist direct vision in the future, LVs operating underground were fitted with light beacons and flags.

Table 1. *Failure modes of controls that prevent collisions*

Control	Failure modes
Radio	*A driver has radio on a different channel.*
	Radio 'dead spots'.
	Radio electrically fails.
	Radio calls heavy, spaced out or blocked.
	Radio is not or infrequently used.
	Radio volume is turned very low or off.
Location Signage/ Naming	Location name hard to interpret
	Location can be easily confused with another location (e.g. Similar name).
	Location is not named at all.
	Location name is large, making exact location non-specific.
	Location has multiple names, or colloquial name that could be confused or not known.
Drivers Mental Model of Mine	Inexperienced drivers lack mental model.
	Driver over interprets a location to usual route, when unusual route is being taken.
	Complexity and frequency of calls makes it difficult to remember locations of vehicles.
Direct Vision	*Blind spots, particularly from heavy vehicle.*
	Driver is looking in a direction other than vehicle approaching
	Mud/Dust on windscreen.
	Vehicle is hidden from direct sight by obstruction (e.g. around corner.)
Headlights	Headlights are not on.
	Headlights on approaching vehicle are obscured by headlights of driver's vehicle.
	Backlit area prevents headlight being seen.
	Interaction is on surface in the daylight, where headlights do not assist.
Roadway Design	*Roadway not wide enough for two vehicles.*
	Roadway does not physically separate vehicles, either by signs/markings or physically.
Horns	Horn cannot be heard (e.g. engine noise.)
	Horn misinterpreted (e.g. source, meaning).
	Horn is used too late.
	Horn is not used
Evasive Action	Driver cannot take action in time.
	Driver does not have the available room to take action (e.g. backed into stockpile).
	Driver takes evasive action, but then becomes blocked (e.g. wall/ ditch/ embankment/ vehicle).
Proximity Detection	Driver not aware of detection and is not alerted by sound (e.g. looking other direction)
	Driver wrongly assumed direction of a vehicle when there are no other vehicles in the area (e.g. a vehicle is detected in front but interprets it to the rear.)
	Driver misinterprets detection of a vehicle for an alternative vehicle in a different direction that is also known to be in the area.
	Too many detections to interpret
	Detection is on subsequent screen (only 6 on home screen, and new ones added at rear).
	Detection does not occur in time.

Figure 4. *Vision from the loader and extra controls*

Changes to the proximity detection system

From the previous research and accident investigation results, a number of changes to the touch screen computer interface were suggested. The following changes were made to the system:

1. Making the audio alarm a short sharp sound, rather than continuing until the computer interface was touched.
2. The detected vehicle flashes on the computer screen for a short period of time and then stops flashing, rather than ongoing flashing until the computer interface is touched.
3. Adding new vehicles to the top of the list on the computer screen, rather than to the bottom of the screen, where they were added previously.

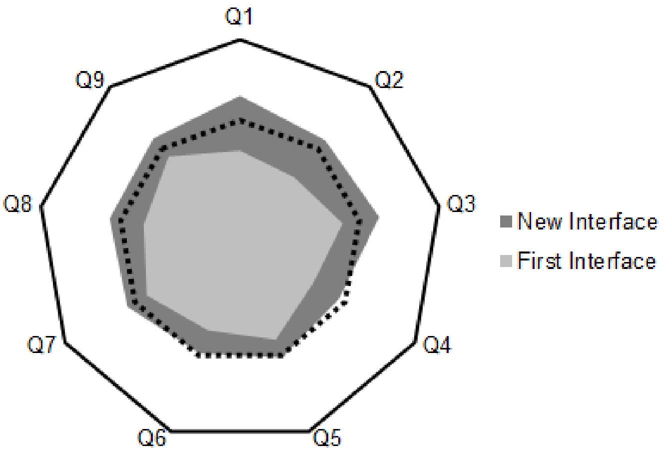
The following changes have been recommended and are planned to be included in full proximity detection system upgrade:

4. Turning off the proximity detection system when vehicles are on the surface, due to reports of too many tag readings being registered on the computer interface to make the system useful.
5. Indicating if a vehicle is detected from the front or rear of the existing vehicle.
6. Showing the proximity of vehicles at all times, even during loading cycles.
7. Moving to an icon based system, rather than the lettered codes of vehicles.
8. Removing the 'time detected' of each vehicle from the computer screen.

Acceptance of changes made

Driver acceptance of the changes made to the proximity detection system was examined. Two polygons were plotted and layered to reveal acceptance of the drivers with the initial and revised proximity detection systems. The 1 to 9 around the polygon represents the questions asked of the drivers.

A 'maximum', shown with a solid line, represents a score of 5 by all drivers on all measures. This shows how far the system is from the 'theoretical' maximum, though the capacity of the technology may well be lower. A 'positive negative line', shown with a dotted line, represents the average score of 3 on all measures. The acceptance of the first interface is shown in the lighter grey. The acceptance of the altered (new) interface is shown in darker grey. Parts of the interface polygons below the 'positive negative line' represent a negative view of the interface.



Q1 Useless - **Useful**

Q2 Unpleasant - **Pleasant**

Q3 Bad - **Good**

Q4 Annoying - **Nice**

Q5 Superfluous - **Effective**

Q6 Irritating - **Likeable**

Q7 Worthless - **Assisting**

Q8 Undesirable - **Desirable**

Q9 Sleep Inducing - **Raising Alertness**

Figure 5. *Vision from the loader and extra controls*

The results show that before the small numbers of changes to the system were made drivers, on average, were not accepting the system, finding it useful or satisfying. After the system changes, all measures saw an increase. On all of the measures, except Q4 and Q6, the drivers gave overall positive ratings of the revised system. Both these measures are in the 'satisfying' portion of the survey. This indicates that, on average, the drivers have mildly positive 'acceptance' of the system, are mildly positive about its 'usefulness' and neither positive not negative about 'satisfaction' with the system.

Discussion

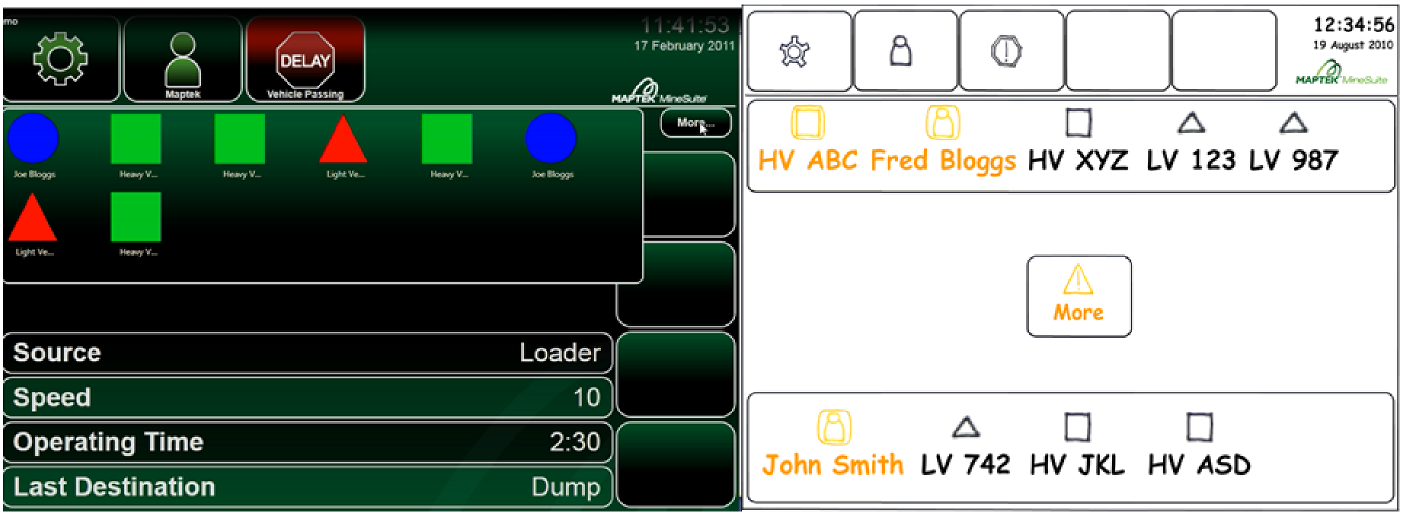
Validation and future changes

The measures of acceptance show some validation for the use of human factors methods to predict issues related to proximity detection systems. This provides evidence that human factors professionals could increase the effectiveness of proximity detection systems in mines, if they are consulted during their design and deployment. A number of changes were recommended to be made to the computer interface and this research goes some way to providing evidence that the recommended changes should be implemented. In fact, the mining technology company has already created prototypes for the computer interface (Figure 6). Furthermore, the human factors identified other issues related to collision prevention with actionable design outcomes. Therefore, involving human factors engineers in accessing the entire system of collision prevention has support.

Importance of acceptance

In mining, acceptance of technology is extremely important in technology utilisation. In isolated environments, employees often have the opportunity to choose to avoid using new technologies. Therefore, if drivers do not accept proximity detection technology its potential to prevent accidents may never be realised. With the original interface, that showed overall negative measures of effectiveness, some drivers admitted to turning down the sound and brightness of the computer screen, in order to avoid the system as much as possible. With improved acceptance of the new interface, it is logical that the drivers are much less likely to try and avoid using the system.

It is also likely that acceptance of the technology is indicative of its effectiveness. The underlying assumption is that, because the operators are the experts, their acceptance is generally related to whether the technology aids them in driving. As accidents are extremely rare, testing the effectiveness of a proximity detection system is both difficult and, potentially, unethical. Therefore, though it must be used carefully, measures of acceptance of technology may be able to be used as a proxy for effectiveness as they are likely correlated.



Source Loader
Speed 10
Operating Time 2:30
Last Destination Dump

Figure 6. *Prototype proximity screens with and without directional elements*

Conclusion

New in-vehicle technologies, including proximity warning, could help produce significant safety improvements in mining situations where off-road haulage is responsible for a large number of fatalities [11]. Mining has the opportunity to learn from other domains, such as road transport and aviation, to develop and implement technology from both a human-centred and an operational needs perspective. Therefore, rather than being introduced purely because the technology is available, careful consideration must be given to how it will support the users' tasks and integrate with existing technologies.

It appears that including human factors knowledge will not only assist in determining the effectiveness of the system which is currently installed, but should lead to future improvements. When considering new systems, it is likely that, prior to installation, human factors investigation could help determine which technology is able to provide the information required by drivers. It could also help design the interface, so required information is effectively communicated. This provides good evidence that the involvement of end-users and human factors engineers through all stages of the lifecycle of a working system is the best way to achieve effective integration of such technologies in mining. Future research will hope to measure the effectiveness of any further changes to the interface and supporting technology.

References

1. Bell, S. *Collision Detection Technology Overview*. 2009 [cited 2009 17th of December]; Available from: http://www.dme.qld.gov.au/zone_files/mines_safety-health/deedi_2009_proximity_workshop_ppt_p1-18.pdf.
2. Horberry, T., R. Burgess-Limerick, and L. Steiner, *Human Factors and Mining Equipment*. 2010, USA.: CRC Press.
3. Sheridan, T.B., *Humans and automation: System design and research issues*. 2002: John Wiley & Sons, Inc. New York, NY, USA.
4. Van Der Laan, J.D., A. Heino, and D. De Waard, A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies*, 1997. 5(1): p. 1-10.
5. Horberry, T., Larsson, T., Johnston, I. and John Lambert, Forklift safety, traffic engineering and intelligent transport systems: a case study. *Applied Ergonomics*, 2004. 35(6): p. 575-581.
6. Cooke, T. and Horberry, T. (2011). The Operability and Maintainability Analysis Technique: Integrating Task and Risk Analysis in the Safe Design of Industrial Equipment. Book Chapter in *Contemporary Ergonomics and Human Factors 2011*. Edited by M. Anderson, CRC Press: UK
7. Horberry, T. & Cooke, T. (2010). Using the Critical Decision Method for Incident Analysis in Mining. *Journal of Health & Safety Research & Practice*, 2(2), pp10-23.
8. Hoedemaeker, M. and K.A. Brookhuis, Behavioural adaptation to driving with an adaptive cruise control (ACC). *Transportation Research Part F: Traffic Psychology and Behaviour*, 1998. 1(2): p. 95-106.
9. Brookhuis, K. and D. de Waard, Limiting speed, towards an intelligent speed adapter (ISA). *Transportation Research Part F: Traffic Psychology and Behaviour*, 1999. 2(2): p. 81-90.
10. Vlassenroot, S., et al., Driving with intelligent speed adaptation: Final results of the Belgian ISA-trial. *Transportation Research Part A: Policy and Practice*, 2007. 41(3): p. 267-279.
11. Groves, W.A., V.J. Kecojevic, and D. Komljenovic, Analysis of fatalities and injuries involving mining equipment. *Journal of Safety Research*, 2007. 38(4): p. 461-470.

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