COLLISION DETECTION AND PROXIMITY WARNING SYSTEMS FOR MOBILE MINING EQUIPMENT: A HUMAN FACTORS EXPLORATION

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ABSTRACT: The relatively high number of collisions between mining vehicles is the primary reason why collision detection and proximity warning systems are being increasingly introduced in this domain. This work presents a series of studies undertaken in underground mining where a prototype proximity warning system has recently been introduced. These studies encompassed a review of the system constraints (detection distances), an ergonomic audit of the system interface, Cognitive Tasks Analyses and other structured interview methods, a naturalistic field study, and a human factors risk assessment. All combined, the studies reviewed, from a user-centred perspective, the effectiveness of a system being trialled. Preliminarily results emerging to date and provisional recommendations for future system development or additional research are briefly outlined in this paper.

1   INTRODUCTION

1.1   *Background*

Collision detection and proximity warning systems are being ever more deployed in mobile mining equipment such as haul trucks, trains and light vehicles [1]. This is primarily due to the high percentage of incidents that are due to equipment collisions. For example, recent Australian data suggests that approximately 35% of mining fatalities are due to vehicle interactions and 53% involved pedestrians and vehicles [2]. Collisions are not only potentially fatal to mine workers, but also have significant financial costs due to repairs to equipment and lost production.

In this domain, collision detection and proximity warning systems cover a wide variety of technologies. Each differs in where, when and how they can be used. Their uses include [1]:

1.   Surface mining operations.

Surface mining equipment involved can include haul trucks, water trucks, graders, diggers and bulldozers. Collision technology sensors developed for road transport can often be adapted, using radar, Wi-Fi, camera, Radio Frequency Identification (RFID), GPS or Ultrasonic, as can aspects of the human machine interface (despite huge differences in the equipment design, the operating environment and the tasks it is used for, compared to road transport).

2.   Underground Mining Operations

Underground mining equipment involved includes load-haul-dump trucks, roof bolters, shovels/excavators and remotely controlled continuous miners. Many sensor types used in road transport will not work underground. However, low frequency magnetic field markers and RFID can be used.

Whatever the precise mining application, the general aim of these technologies is ultimately to prevent collisions between vehicles, vehicles and persons and vehicles and infrastructure. Many systems are currently subject to intensive research and development work by major equipment manufacturers, smaller enterprises, research institutes and mining companies. This research has focused heavily on ensuring the technology has appropriately sensitivity, accuracy and reliability to work in this environment. Largely this has been from a technology-centred perspective, and often with little thought to human element considerations such as integration strategies with existing work practices.

Similarly, relatively little systematic work has been done on the human machine interface, which is very likely to be important in the eventual effectiveness of the systems in preventing accidents [3]. As with road vehicles, 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. No single interface type fits all application areas in mining, so a careful understanding of the differing user requirements, analysis of the different tasks and user-centred evaluation of prototype technologies are required [4].

1.2   Description of the mine site and proximity/detection system

The work was undertaken at an underground gold mine in Queensland, Australia. A variety of mobile mining equipment work underground, including loaders/shovels (to load the ore onto a vehicle for removal), haul trucks (to remove the ore to the surface) and light vehicles (for a variety of maintenance and technical purposes, including setting charges for rock blasting). Figure 1 shows some of these vehicles and Figure 2 shows an example of the underground environment.

Figure 1: Examples of mobile Equipment

Figure 2: The underground environement

The mine involved in this research installed a RFID system primarily to improve the monitoring of production. Tablet PCs attached to tag readers were installed in haul truck and loaders at the mine. The tablets automatically read a number

of tags around the mine to assist in tracking production including cycle times, delays, dump position and load weight constancy. However, though the tracking of production was the primary driver for the installation of the system, the mine management saw the opportunity to add a proximity detection system to hopefully reduce the risk of collision between vehicles. The following are some of the notable features of the proximity detection system:

- When another vehicle is detected, the code for that vehicle is displayed on the screen. Part of the code indicates a type of vehicle (eg. LV403. TORO141). Codes are displayed in a list with most recent unacknowledged vehicles at the top.

- Six vehicles can be displayed on the screen. If the number of vehicles detected is greater than six these will be displayed on subsequent screens, which can be accessed by a scrolling feature.

- A timer starts next to the code after initial detection indicating how long a vehicle has been continually detected. The timer will continue until the vehicle is no longer detected.

- A sound is emitted from the PC and the code flashes on initial detection (the colour varies on the colour scheme used). The sound tone is alterable, and can be significantly turned down. It was reported by an operator that with hearing protection and the volume low the sound could no longer be heard.

- When the presence of the vehicle is acknowledged, by the operator touching the code on the screen, the sound ceases and the vehicle code changes colour and stops flashing. When the vehicle is no longer detected it is removed from the screen whether or not the driver has acknowledged its presence by touching the screen.

- The following are some of the acknowledged limitations of the proximity detection system:

- No direction of the detected vehicles is given to the operator. In an underground environment it is unlikely that directional capacity will work with an RFID system other than 'forwards' or 'rear' with the use of two antennas.

- There is no set distance when a vehicle will enter and exit detection. For example, the detection distance was thought to be much greater when on high ground on the surface than when underground. This was reported to be many hundreds of meters on the surface, down to less than 20 metres, or even missed detection, underground.

- The system only acknowledges the presence of a vehicle but not that it is necessarily dangerous or requires action. The driver must still interpret the necessary course of action based on this information and other features of the environment.

Figure 3 shows an example of proximity detection screen in a vehicle cab (the screen is shown in upper left hand side) and figure 4 shows an example of the system interface.
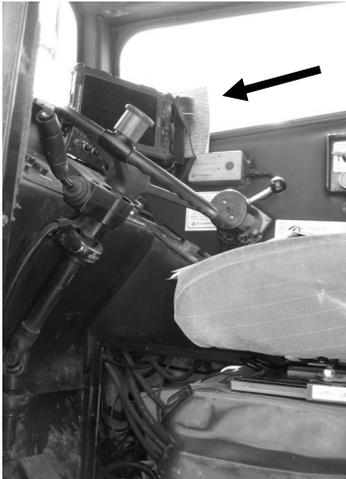
Figure 3: Screen position in cab

Figure 4: The system interface

1.3   Research Objective

The overall objective of the work was to identify and explore the human factors issues associated with collision detection and proximity warning systems in mobile mining equipment. This was achieved through undertaking a series of studies at an underground mine site which has recently installed a prototype system. The purpose was to review, from a user-centred perspective, the effectiveness of a system being trialled and provide recommendations for future system development or additional research.

2   METHODS

The research approached the issue from both a problem and a user-centred perspective, rather than from a technology-centred one. Therefore, a variety of methods were used to explore this issue. These are described below.

2.1   Exploration of System Constraints

At the onset of the research it was evident that the mine site was aware that detection distance may vary considerably depending on the scenario. However, it was unknown how much distance varied; equally, it was unknown what were the effects of different variables such as underground road position. Therefore, a logical starting point was an exploration of the constraints and detection reliability of the system. Without this, it was difficult to determine if the system could effectively assist operator decision making regarding other vehicles.

Therefore, detection distances at different locations at the mine (surface and underground) were analysed. Whilst underground, the truck was approached with a hand held RFID tag attached to an antenna (like those installed in light vehicles working underground), from different locations. The truck was also placed facing towards (forwards) the tag or away from the tag (backwards). The measurements were recorded three times for each scenario, to determine

variability and accuracy of the measurements. As the system used RFID, there were sections where the radio waves would need to bounce around corners, but on a long straight section of the mine line of sight was possible.   The different types of corners examined are depicted in Figure 5 below.
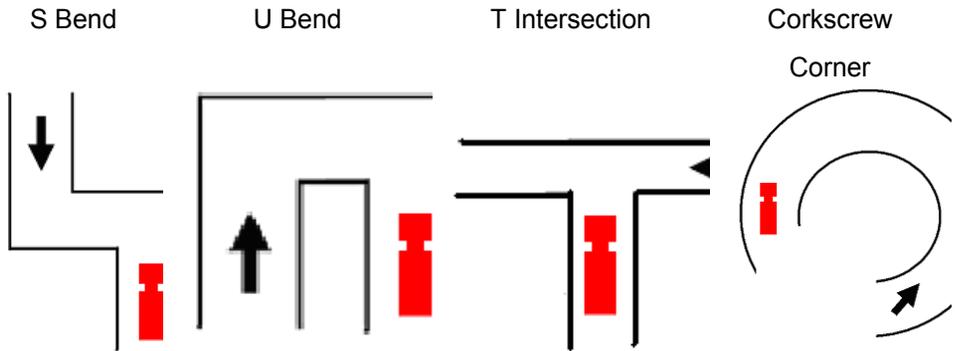

Figure 5: Different types of underground corners investigated

2.2   Ergonomic audit of the collision/proximity system interface

Two experimenters, who both had postgraduate qualifications in Ergonomics/Human factors, reviewed the interface. The primary tool they used (after suitable adaptation to the exact context of this research) was the TRL Safety Checklist for the Assessment of In-Vehicle Information Systems [5]. Both experimenters separately viewed the interface in a haul truck at the mine and later compared their assessments to determine significant usability defects.

2.3   Cognitive Tasks Analyses and Structured Interview Methods

Knowledge and experiences were elicited from operators involved in previous mobile equipment collisions or who used the current proximity detection system. This allowed a detailed user-centred perspective of equipment operation tasks and the current controls in place. Initially, it was planned to use the Critical Decision Method (CDM) to elicit knowledge about vehicle incidents and near misses, on the basis that these represented 'tough cases' which has previously been found to be an efficient way of eliciting knowledge from experts [6, 7]. However, the interviewees were unable or unwilling to recall real incidents to analyse (partly because of the newness of the system).

Instead, the operators were asked to consider where they felt the more complex areas of road and vehicle interaction were in a mine and construct a fictional, but possible, scenario of a collision occurring. This included the position of the vehicles in the mine and the other barriers that would need to fail in order to for proximity detection to be useful. Though not real scenarios, it did show a logical path to failure, and helped determine what features a proximity detection

would need for it to be effective. These features could then be compared to the current prototype RFID proximity detection system in place. Eight operators were interviewed by two experimenters. In every interview the operator was able to construct plausible, though admittedly unlikely, scenarios where a collision could occur and a proximity detection system could be useful should other controls fail. This included scenarios in the underground, on surface haul roads and around workshop areas.

2.4   Naturalistic field study

The Naturalistic field study recorded operator behaviour whilst using the collision/proximity detection system in a large mobile mining vehicle. In particular, two measures were recorded: filming the operator and proximity data collected by the system (included other vehicles detected and operator responses to acknowledge these vehicles). Video data were obtained from 20 x 2-4 hour sections; these involved 10 different equipment operators. Approximately half the videos were taken on day shift, and half on night shift.

2.5   A   Human   Factors   risk   assessment   of   the collision/proximity system

The final technique used to investigate the system will be the application of a risk assessment technique, developed by the authors, that is part way between a risk assessment and a tasks analysis [8]. The technique will be applied in a workshop format on the key operational scenarios encountered at a mine. Importantly, this technique will draw on the information gained in the other techniques and, therefore, will not be undertaken until analyses of the other techniques are finalised. The outcomes of the workshop will not only be analysis of the effectiveness of the current system, but recommendations on future improvements.

3   RESULTS

At the time of writing, all the data except the risk assessment have been collected and are currently being analysed. As such, only summary results will be presented below.

3.1   Exploration of the System Constraints

Illustrative results regarding detection are shown in Figure 6. They show, for example, that backwards detection was less that forwards detection, and was non-existent around S or U bends backwards underground.
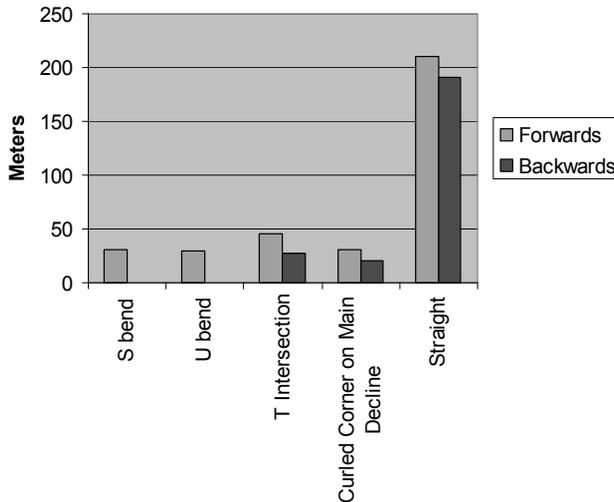
Figure 6: Sample of the detection distances at the gold mine site.

Additionally, it was found that different equipment (eg different model RFID tags and longer connecting leads) significantly influenced detection distances. Finally, as hypothesised, detection distances were longer on the surface compared with underground.

3.2 Ergonomic interface audit: Safety Checklist for the Assessment of In-vehicle Information Systems

The researchers independently applied a checklist developed by the Transport Research Laboratory to serve as a structured aid to assist the experts in the evaluation of In-vehicle information and communication systems. The checklist primarily looks at simple usability issues, such as menu structure, glare, reach and distraction. No significant usability issues were identified, but some of the more minor issues were the potential to distract from driving when acknowledging multiple vehicle detections, auditory feedback being able to be reduced to where is can no longer be heard and the possibility of glare making the screen difficult to read. Of course, the audit was not detailed enough to conclude if the information given by interface would aid driver decision making, reducing the risk of collisions. However, some issues for further investigation were noted, such as the lack of distance and direction of vehicles, the variability in detection distances and the possibility of large numbers of detections at one time.

3.3 Cognitive Tasks Analyses using the Critical Decision Method and other structured interview methods.

Overall, the findings are broadly similar to many of the 'classic' human factors issues with automation and new technologies identified in other domains [1,3,9]. These include shorter term issues such as non-optimal interface/warning design, plus longer terms challenges such as technology acceptance, trust and

skills fade. Additionally there might be unanticipated side effects related to over-reliance on the technology and risk compensation.

However, the interviews were successful in determining scenarios where proximity detection, if effective, may prevent collisions. Each scenario was represented using Energy Trace and Barrier Analysis (ETBA) to qualitatively show how the scenario might develop. In all scenarios, additional controls that assist operator knowledge of the location of other vehicles were required to fail; most notably radio communication, where drivers are required to regularly 'call' their position and direction, and visual location of the vehicle, either directly or through a reverse angle camera mounted in the cab. Figure 7 below an example of where a proximity detection system may act as a control should other controls fail:
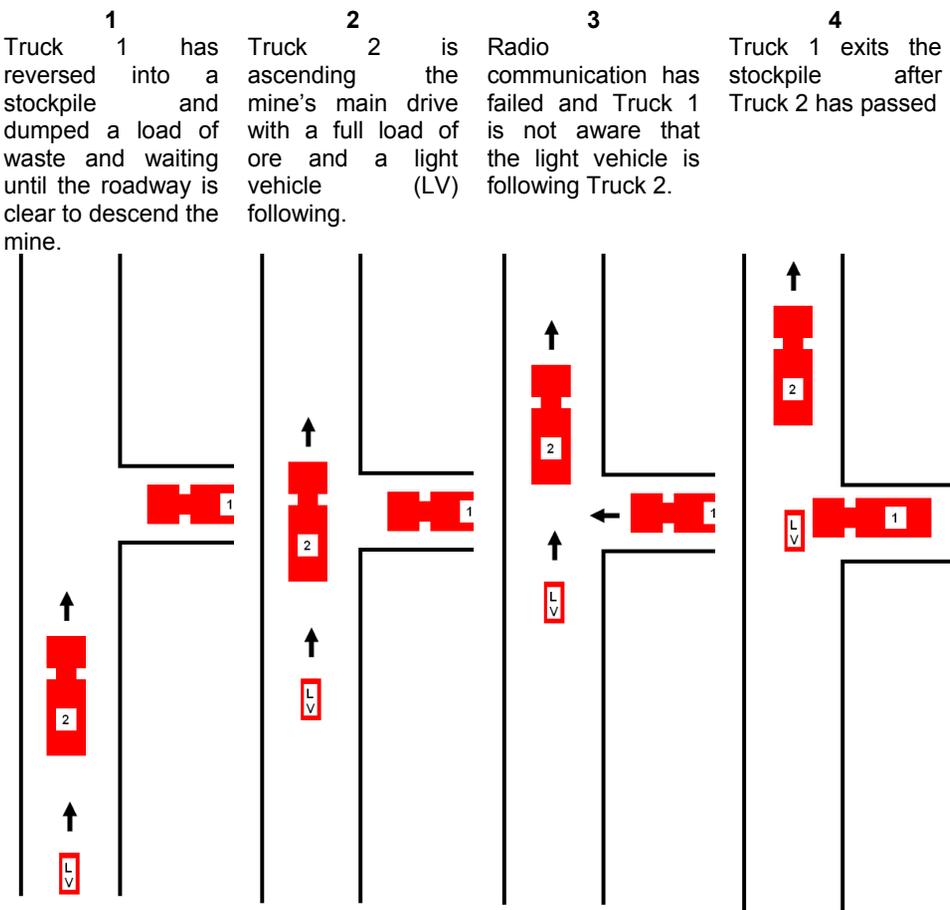
1	2	3	4
Truck 1 has reversed into a stockpile and dumped a load of waste and waiting until the roadway is clear to descend the mine.	Truck 2 is ascending the mine's main drive with a full load of ore and a light vehicle (LV) following.	Radio communication has failed and Truck 1 is not aware that the light vehicle is following Truck 2.	Truck 1 exits the stockpile after Truck 2 has passed

Figure 7: Example scenario where proximity detection system may act as the key control.

3.4   Naturalistic field study

The naturalistic field study collected a large amount of behavioural data regarding operator interaction with the system. At present these data is still being analysed. The issues to be analysed will include;

- If operators acknowledge the system when a vehicle has been detected,

- If the screen is looked at when a vehicle is detected

- Whether major changes in driving behaviour occur after another vehicle has been detected

Provisionally, it appears that drivers are often choosing not to acknowledge the detected vehicles by touching the interface, but are glancing at the screen indicating the have cognitively acknowledged the detection. Further analysis is required to determine how driver behaviour is altered.

3.5   A   Human   Factors   risk   assessment   of   the collision/proximity system

As noted above, the human factors risk assessment workshop is scheduled to occur following the completion of the analysis of other tools. This will include the prioritisation of the most critical collision scenarios, an analysis of the steps involved including the failure of controls up to and including proximity detection, analysis of the risk of control failure at each step and possible improvements to the controls. This will include possible changes to the proximity detection system and consideration that the proximity detection system might reduce the effectiveness of other controls, through unanticipated side-effects including compensatory behaviour.

4   CONCLUSIONS

New in-vehicle technologies, including collision/proximity detection, can help produce significant safety benefits in mining situations where off-road haulage is responsible for a significant number of fatalities [10]. Mining has the opportunity to learn from other domains such as road transport and aviation, and develop and implement technology from both a human-centred and an operational need perspective. Therefore, rather than being purely introduced because the technology is available, careful consideration must be given to how it will support the users' tasks, and how it will be integrated with other existing technologies & management systems. In this respect mining is no different from other ITS application areas. The multifaceted research approach described above, with significant involvement of system end-users, will not only assist in determining the effectiveness of the currently installed system but also limitations and future improvements. Furthermore, it is likely that many of the issues could have been identified prior to installation. This provides good evidence that the involvement of end-users and human factors engineers through all stages of the design lifecycle, from concept through to the deployment and evaluation, of a working system is the best way to achieve effective integration of such technologies in mining.

5   ACKNOWLEDGEMENTS

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