Proximity Warning System Interfaces for Mining Vehicles: Can the Minerals Industry Learn from the Automotive Domain?

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Abstract. In the global mining industry, proximity warning systems are being increasingly deployed in mobile equipment such as haul trucks, partly due to the risk of collisions. This research first reviewed best practice interface design for new technologies in the automotive domain: for example, the European Statement of Principles on Human Machine Interfaces. Thereafter it reviewed the different types of proximity warning interfaces available in mining. Analysis then compared the identified best practice in automotive with current proximity warning interfaces in mining. Gaps found are discussed, and recommendations to improve the interface design of proximity systems in mining are proposed.

Keywords. Mining, Haul Trucks, Interface Design, Proximity Warnings

1. Introduction

In the minerals industry, collision detection and proximity warning systems for mobile mining equipment are becoming increasingly important (Horberry, Burgess-Limerick and Steiner, 2011). This is partly because of the high percentage of incidents that involve collisions, especially between mobile equipment, or between mobile equipment and operators on foot. In turn, this is partly because there are more mobile mining vehicles, especially larger equipment with significant blind spots (Bell, 2009). Visibility restrictions inherent in the design of haul trucks can lead to drivers being unaware of the position and movement of other vehicles.

Some original equipment manufacturers and after-market suppliers have responded to this challenge by developing a range of technologies which provide information to a haul truck driver about the states of other vehicles and other mine site hazards (Horberry and Lynas, 2012). The design of the visual and auditory interfaces which sit between these technologies and the human operator is still rapidly evolving and may be sub-optimal, leading to a relatively high probability of failure on demand of this control measure (Orchansky, 2009). In the minerals industry, few standards or guidelines for such interfaces exist to assist manufacturers or purchasers of proximity detection systems.

In contrast, in road transport, systems such as forward collision warning systems, reversing warning systems, land departure warnings and following distance monitor interfaces are now fairly common in the vehicle fleet in many countries. Such systems are designed to reduce either the occurrence or severity of an accident. The mandating of such systems in new road vehicles is being actively discussed in North America and Europe (Stevens and Burnett, 2014).

Guidelines and best practice for in-vehicle technologies do exist in the automotive domain. Leading documents are reviewed here, to gain an understanding of best practice in road transport. Whilst these are not necessarily a 'gold standard' for other domains to aspire to, they do build on a research base that is far more established than in the mineral industry (Horberry et al, 2011).

Thereafter, current proximity warning systems for mining haul trucks are evaluated against this identified best practice.

2. Automotive Guideline Review

Six guidelines/principles from the global automotive domain are summarised below. From these, general human factors design rules are identified.

2.1 European Statement of Principles (2008)

The European Statement of Principles (ESoP) provide the European Commission's recommendations for safe and efficient in-vehicle information and communication systems (European Commission, 2008). The ESoP was most recently revised in May 2008 to acknowledge the increase in the use of portable devices. The current version outlines several general design principles together with 35 specific principles focused on device installation, information presentation, user interactions with displays and controls, system behaviour and documentation information.

While the ESoP is applicable to both passenger vehicles and heavy vehicles up to and exceeding 12 tonnes, the principles are intended to apply specifically and exclusively to In-vehicle Information and Communication Systems (IVICS) devices used by the driver while driving. These include mobile phones, navigations systems and traffic and travel information systems. The principles are not intended to be applied to vehicle stabilisation systems (e.g. ABS), systems that use voice activation/recognition, or to Advanced Driver Assistance Systems (ADAS), although it is noted that some of the principles may assist in ADAS design.

ESoP principles cover built-in Original Equipment Manufacture devices, as well as aftermarket and portable devices. The ESoP principles are deliberately broad, since the relevant European stakeholders did not believe at the time that there was sufficient scientific evidence to generate prescriptive and inflexible design principles.

2.2 Alliance of Automotive Manufacturers' Statement of Principles (2006)

In North America, the Alliance of Automobile Manufacturers' (AAM) "Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems" was based largely on the ESoP and was last revised in 2006 (Alliance of Automobile Manufacturers, 2006).

Like the ESoP, the AAM guidelines are concerned with safety aspects of IVICS design and installation. The principles do not apply to conventional entertainment systems (radio, cassette), ADAS, HVAC, speedometers, fuel gauges or vehicle information centres. Unlike EsoP, they apply to light vehicles only. The AAM guidelines contain 24 principles divided into five categories: installation; information presentation; interaction with displays and controls; system behaviour; and information about the systems. The latest version of the AAM does not address voice-activated controls or inputs.

2.3 Japanese Automobile Manufacturers Association Guidelines for In-Vehicle Display Systems (2004)

The Japanese Automobile Manufacturers Association (JAMA) "Guidelines for In-Vehicle Display Systems", Version 3 (JAMA, 2004), offer recommendations regarding the safe and ergonomic positioning of in-vehicle visual displays and the type of information presented on them. The guidelines pertain exclusively to the display characteristics, rather than the device as a whole, but are intended to cover systems that store and communicate information and that are used to display diagrams, letters, numbers, and images, as well as auditory information. The JAMA guidelines are primarily aimed at minimising driver distraction resulting from IVIS displays. While the JAMA guidelines state they are intended for vehicles, it does not explicitly state if this includes heavy vehicles.

2.4 University of Michigan Transportation Research Institute Human Factors Design Guidelines for Driver Information Systems (1993)

The University of Michigan Transportation Research Institute (UMTRI) published the first comprehensive set of human factors design guidelines for the design of safe and easy to use in-vehicle information systems (IVIS) and retrofitted devices in 1993 (Green et al, 1993). These guidelines are intended for use by system designers. The scope of the guidelines is restricted to private (i.e., non-commercial) use of OEM and aftermarket IVIS devices, not ADAS. The UMTRI Design Guidelines were developed for the US driving context but the authors suggest that the guidelines could be modified for international use. The guidelines apply specifically to passenger cars, although they may also be applied to light trucks, minivans and vans.

2.5 Battelle Crash Warning System Interfaces: Human Factors Insights and Lessons Learned (2007)

The Battelle guidelines present human factors design principles for collision warning systems, including those specific to heavy vehicles (truck and bus) (Campbell et al, 2007). The Battelle guidelines are one of the most detailed set of automotive guidelines available, in many cases providing exact display specifications (e.g. font sizes or colour values). Broadly, the Battelle guidelines provide design advice that covers aspects of collision warning design including visual and auditory warnings, visual display and control design, level, timing and prioritisation of warnings, and a whole chapter devoted to applying the guidelines to heavy vehicles (positioning of warning signal visual displays, auditory enunciators, and haptic display mechanisms within heavy vehicles).

2.6 HARDIE Design Guidelines Handbook: Human Factors Guidelines for Information Presentation by Advanced Telematic Transport (ATT) Systems (1996) The HARDIE Handbook (Ross et al, 1996) was produced as part of the Commission of European Communities DRIVE II collaborative project known as Harmonisation of ATT Roadside and Driver Information in Europe (HARDIE). The aim was to provide in-vehicle system designers with human factors knowledge to support the design of safe and user-friendly driver information systems. The handbook provides guidelines for the five ATT applications: traffic and road information; route guidance and navigation; collision avoidance; autonomous intelligent cruise control; and variable message signs. Only design issues that are deemed safety-critical, of high priority for designers and vital to the function of the application are covered. The HARDIE Handbook is limited to issues relating to the presentation of information to drivers only, not driver input. The guidelines are applicable to road vehicles, they do not specify if this includes all vehicles, or only light vehicles.

2.7 Conclusions from Automotive Guidelines

A range of automotive human factors guidelines have been developed by different global agencies to guide the safe design and assessment of in-vehicle systems. The guidelines reviewed are primarily focused on design and performance issues and largely present broad, general principles (e.g. ESoP, AAM, JAMA), although some do contained more detailed, prescriptive specifications (UMTRI and Battelle). A couple of the guidelines specifically state that they are applicable to heavy vehicle (e.g. ESoP and Battelle), although most pertain to light vehicles only or do not specify this information.

Finally, only two of the guidelines reviewed (Battelle and HARDIE) cover issues that are specific to collision warning design and timing.

3. Analysis

Using the 'Constant Comparative Method', a preliminary set of human factors rules was

created from an initial review of the guideline documents and then refined through additional reviews of the documents. This process produced a draft set of 17 general human factors rules.

Thereafter, a further review of the automotive guidelines was undertaken by comparing each one against the set of 17 general human factors design rules and assessing the extent to which each addresses the specific rules. The outcome of this analysis is presented in Table 1. As displayed, a number of the less commonly-used guidelines, particularly the HARDIE guidelines, cover the general design rules well, including those relating to warning design.

It is argued that the 17 general rules created by the authors have been demonstrated to be a constructive approach for summarising the key human factors issues in this field. Most of the 17 rules are present in most of the source documents: for example, all source documents agreed with the rule that '*System should be placed so that eye and hand movements are minimised*'.

Human Factors Design Rules	Guideline					
	ES	AA	JA	UMT	Batte	HAR
	oP	М	MA	RI	lle	DIE
1. System should conform to user expectations/standard practice	\checkmark	\checkmark	×	\checkmark	\checkmark	\checkmark
2. System should be configurable to individual needs/requirements	\checkmark	×	\checkmark	×	\checkmark	\checkmark
3. System design should be as simple as possible	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark
4. Only essential information should be provided	\checkmark	\checkmark	\checkmark	\checkmark	×	√
5. System should be designed to avoid overloading or distracting the user	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	✓
6. System design and operation should be consistent throughout	\checkmark	×	×	\checkmark	\checkmark	\checkmark
7. Different functions/alerts should be easily discriminated	×	×	\checkmark	\checkmark	\checkmark	\checkmark
8. The most critical/important elements should be the most salient	×	×	×	\checkmark	\checkmark	\checkmark
9. The most critical/important information should be given highest priority	\checkmark	√	×	\checkmark	✓	\checkmark
10. Non-urgent or frequent information should be displayed in the visual modality	×	×	×	\checkmark	~	✓
11. Urgent warnings should be presented in both visual and auditory modality	×	×	×	\checkmark	~	✓
12. Warnings should provide directional information	×	×	×	\checkmark	\checkmark	✓
13. Expected/accepted colour conventions for warnings (e.g. red is danger) should be used	×	×	×	\checkmark	~	✓
14. Timely and informative feedback should be provided to user to inform of system status or errors.	√	~	√	\checkmark	~	\checkmark

Table 1. Assessment of guidelines against general human factors design rules

15. Labelling should be clear and familiar with minimal use of abbreviations	✓	✓	✓	✓	✓	✓
16. System should provide predictable/ expected response to user actions (stimulus-response compatibility)	✓	✓	×	✓	✓	✓
17. System should be placed so that eye and hand movements are minimised	✓	√	√	\checkmark	\checkmark	\checkmark

4. Mining Proximity Warning Interfaces

4.1 Systems available

Building on a review of over 60 new technologies available for mobile mining equipment by Horberry and Lynas (2012) and subject matter expert input (mining personnel with experience of the different systems), a set of nine leading proximity warning systems that are currently in use at mine sites in Australia was developed. For reasons of commercial confidentiality and space, these are de-identified in this paper. However, all systems presented visual alerts and most also supplemented this with auditory warnings. The visual and auditory alerts were generally progressive and were often prioritised based on the location of the other vehicle(s). Visual information displayed may include the other vehicle's identity (and type, such as a light vehicle), its position, its speed and its relative direction on a visual map.

4.2 Comparison of proximity warning technologies against the human factors design rules

As part of a desktop review, each of the nine systems was evaluated against each of the 17 created rules by two human factors specialists. The output of this review was then independently evaluated by a third human factors researcher. Example results are shown in Table 2 below for four of the de-identified systems and the first four human factors design rules. A tick indicated that the system meets the rule, a cross indicates that it does not meet the rule and a question mark signifies that further work is needed to assess if the rule is met after the system has been installed in the vehicle.

Human Factors Design Rules System		stem		
	Α	В	С	D
1. System should conform to user expectations/standard practice	√ ?	?	×	?
2. System should be configurable to individual needs/requirements	\checkmark	✓	?	?
3. System design should be as simple as possible	\checkmark	\checkmark	×	×
4. Only essential information should be provided	?	\checkmark	×	×

Table 2. Example comparison systems against the human factors design rules

One key outcome was that no single system met all of the 17 human factors rules. This suggests that general improvement in the mining interface designs would be possible.

5. Discussion and conclusions

This research has shown that is it possible to identify best practice in automotive interface design by means of general 'human factors design rules'. Furthermore, it is also possible to apply such rules to proximity warning systems in mining. Although such best practice is not necessarily a gold standard for proximity warnings, human factors in the automotive industry is generally more established than in the mining

industry (Horberry et al, 2011).

The results with the nine mining vehicle proximity detection systems have shown that no single system met all the human factors rules; however, two of the nine systems met most of them. One rule that was not met by many systems was '*System should be designed to avoid overloading or distracting the user*', hence further work to limit overloading or distraction is recommended.

Using the human factors design rules, a recommendation for additional research would be to test the systems in mine site operational conditions by mining personnel who have hands-on experience with the nine systems. Additionally, further work with the manufacturers of leading mining proximity warning systems will shortly be undertaken with the aim to further integrate human factors best practice into the interface designs of their systems. This research will utilise a haul truck simulator to undertake an evaluation of currently available interface types. It is likely that the outcome of this forthcoming project will be performance specifications for interfaces designed for use as part of proximity detection systems, whether stand-alone or (ideally) integrated with other incab technology interfaces.

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