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Using virtual computer analysis to evaluate the potential use of a camera intervention on industrial machines with line-of-sight impairments

Alison Godwin*, Tammy Eger

School of Human Kinetics, Laurentian University, 935 Ramsey Lake Road, Sudbury, Ontario, Canada, P3E 2C6

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ABSTRACT

A medium-sized Load-Haul-Dump (LHD) mining vehicle was evaluated using visibility tools in a computer simulation environment. The line-of-sight (LOS) available to the operator of a medium-sized LHD was calculated and displayed in a boxplot. Severe LOS restrictions were observed to several areas around the vehicle. A modified LHD design, aimed at improving LOS resulted in a marginal improvement in driver LOS (20–36%). Secondary viewing systems have not been widely accepted in the mining industry but several potential locations can be easily evaluated using computer simulation. This paper tested three camera locations for their ability to increase LOS to areas around the LHD vehicle that were very difficult to see from the operator's position. All camera locations were able to significantly improve LOS to 60% or greater while combinations of forward-facing and rear-facing cameras could improve LOS by as much as 80%.

Relevance to industry: Several industries have successfully added closed-circuit camera systems as a driving aid for vehicles with poor LOS from the operator's compartment. The mining industry has yet to adopt a widespread camera intervention on all vehicles. This paper demonstrates the potential utility of using computer simulation to evaluate camera locations on a vehicle and discusses some outstanding issues behind the ergonomics of implementing and using camera views on industrial vehicles.

1. Introduction

Operating an underground mining machine known as a Load-Haul-Dump (LHD) is a dynamic task that requires simultaneous operation of hand and foot controls, monitoring of the roadway and the ability to detect hazards in less than optimal conditions (Tyson, 1997; Marx, 1987). Tyson (1997) identified operator visibility as the primary causative factor in 50% of LHD accidents occurring between 1986 and 1996. Since beginning visibility and line-of-sight (LOS) investigations in 1997, the number of accidents and injuries linked to LHD operation in Ontario (Canada) mines has seen a decrease compared to earlier statistics (MASHA, 2003). However, the Mines and Aggregates Safety and Health Association (MASHA) reported two fatalities and 29 lost-time incidents that occurred from 1997 to 2002 indicating that there is still work to be completed in order to enhance LOS for the operator. For instance, 15.4% of all LHD accidents were related to visibility issues such as the LHD striking other vehicles, walls and pedestrians while accidents due to unforeseen ground hazards accounted for a further 8.2% of accidents (MASHA, 2003).

Simple retrofit modifications may not be sufficient to improve LOS for the operator in the areas that are required for safe operation of the machine (Rushworth, 1996; Godwin et al., 2008). In particular, LOS to the wall, between ground and 2 m height, on the far-side of the vehicle when driving forward and backward was still severely limited (Godwin et al., 2008). Pedestrians walking on the opposite side of the tunnel would not be visible to the operator driving the LHD (Godwin et al., 2008). A swivelling seat intervention was tested in a virtual computer model and as much as 45° of seat swivel improved the number of Visual Attention Locations (VALs) viewed by the operator (Godwin et al., 2007). However, nearly twenty VALs identified as being critical for safe operation of an underground machine were still not visible to the operator (Godwin et al., 2007). Many mines in Ontario (Canada) have only the minimal required clearance between the machine and the wall, leaving very little side or overhead clearance and little room for error if an obstacle has not been detected by the LHD operator.

Previous LOS evaluations occurred in the field and required substantial time and resources with little versatility in the plots that were produced (Hella et al., 1991; Eger et al., 2004). A new laser-scanning method introduced by Bhattacherya et al. (2007) demonstrated good correspondence to the light filament method (range of error from 1.7% to 5.2%) used by Eger et al. (2004) and had the added advantage of being a significantly faster method of

* Corresponding author. Tel.: +1 705 675 1151; fax: +1 705 675 4845.
E-mail address: agodwin@laurentian.ca (A. Godwin).

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evaluation. Computer simulation has also proven itself as a more time-efficient and meaningful method of assessing visibility (Eger et al., 2005; Jeffkins, et al., 2004; West et al., 2007). Several specific tools provided in Classic Jack software or a ruler LOS function in computer-aided analysis can be used to generate a LOS boxplot (Eger et al., 2005; West et al., 2007). The LOS boxplot provides a visual representation of visible (green if displayed in colour or grey if displayed in black & white) and a non-visible (red if displayed in colour or black if displayed in black & white) area as well as a quantified percentage of area that is visible to the operator. LOS boxplots can be scaled in size according to individual machine dimensions. In terms of accuracy with a real-world assessment, West et al. (2007) found the total difference between LOS boxplots generated with a laser-scanning method and LOS boxplots generated with a computer simulation method to be 15.5%. The error was attributed to slight differences in orientation of the vehicle and estimated operator eye-position in both virtual and real-world environments (West et al., 2007). The benefit of using the computer simulation environment is that the program allows accurate positioning of the virtual human in order to model different operator movement strategies or posture tendencies (Godwin et al., 2007). Many established methods of visibility assessment use a standard eyepoint position and assume a 360 degree radius of viewing whereas computer simulation has allowed researchers to perform assessments using more realistic operator postures.

Elsewhere in industry, several secondary viewing devices such as closed-circuit television systems, radar or radio-frequency tags, ultrasonic sensors, laser detection and Global Position System (GPS) technology have been implemented on industrial machines to aid the detection of objects in blind spots and to reduce driving hazards (Ruff, 2001). Each of these systems has challenges to overcome during implementation in underground mining applications. GPS technology cannot be used in an underground mine while ultrasonic and laser sensors have not yet been proven as reliable for underground use (Ruff, 2001). Radio-frequency identification systems with coloured light systems that illuminate based on the detected hazard have been implemented by some mining sites but radars are highly susceptible to false alarms. False alarms or nuisance alarms are unacceptable and may lead to high levels of annoyance, reduced productivity and a lack of compliance (Ruff, 2001; Boldt and Backer, 1999). Given the recent advances to closed-circuit television technology, this may become a viable option but the sensors and mountings of a camera system must be robust enough to operate in an environment prone to vibration and rock impact as well as wet, foggy and dusty conditions (Roberts and Corke, 2000; Ruff, 2001). The system as a whole must be intuitive to use while operating a large piece of machinery and must be accepted by the operators. In a review of all systems currently used, Ruff (2001) reported that regardless of sensor type (radar, radio-frequency tags, GPS, etc.), a video camera system would be beneficial for backup and confirmation of why the alarm was being triggered.

Due to their successful implementation in above-ground applications, the mining industry has started to look at using cameras on underground machinery. In 1998 the Mine Safety and Health Administration (MSHA) reported that adding video cameras as a visibility aid showed promising results. MSHA subsequently issued a Directorate of Technical Support Accident Reduction Program that aims to eliminate blind areas by providing guidelines for positioning and mounting cameras and monitors (MSHA, 2001). Roberts and Corke (2000) found that a LHD cab-mounted laser scanner solved the problem of not being able to mount on the front due to a loaded bucket but still allowed forward and rearward travel monitoring. However, several concerns exist for the safe implementation of cameras on industrial machines, including safe and consistent use. Computer simulation programs can be useful for determining ideal cameral location, or for testing a combination of locations. The main advantage to computer analysis is that several potential sites can be evaluated quickly and at a very low cost. This paper will demonstrate that the LOS boxplot method previously used to assess operator LOS can also be used to evaluate camera placement on industrial vehicles. Three potential camera locations were tested and compared to the view available from an operator's eyepoint. The potential LOS improvement from cameras was compared to only the LOS improvements due to retro-fit modifications.

2. Method

2.1. LOS boxplot

This research used the protocols already established by Jeffkins et al. (2004) and further refined by West et al. (2007). To review, accurate 3-D files of LHD machines were imported into a computer simulation environment (Classic Jack v4.1) and a virtual 50th percentile male (for height and weight) was positioned at the h-point of the cabin seat with the hands and feet positioned on the appropriate machine controls. Using a coverage plane tool, a boxed area of 10 m width by 20 m length by 4.5 m height was located in the environment and further divided into 11 key zones (Fig. 1). The nodal resolution in the program was set to 10 cm in order to generate a coverage zone that contained red/black zones that indicated no LOS available to the operator and green/grey zones that indicated a LOS was available to the operator. The percentage of visible area was also determined for all 11 zones of the LOS boxplot and for the total boxed area.

2.2. Operator posture changes

Eklund et al. (1994) found that sideways-seated operators, common to LHD machines, had frequent and long term head rotations at the extreme range of motion. In order to make the LOS boxplots representative of these observed postures, a series of progressive neck and trunk deviations were chosen based on observed motions of LHD operators underground (Eger et al., 2008). To view panels 1, 2, and 10, the virtual operator used 45 degrees of left neck rotation and 10 degrees of left trunk rotation. To view panel 3 and 4, the virtual operator used 25 degrees of left head rotation and 10 degrees of left trunk rotation. To view panel

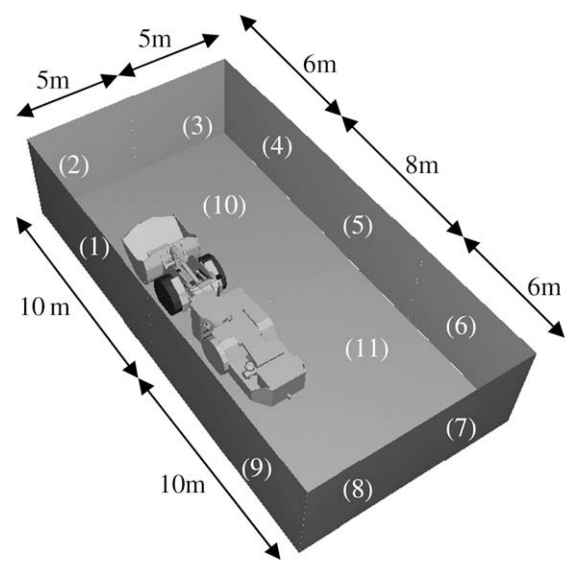

Fig. 1. A LOS boxplot of 10 m width and 20 m length and 4.5 m height divided into 11 separate panels of varying sizes as indicated.