FACTORS AFFECTING LOAD-HAUL-DUMP OPERATOR VISIBILITY IN UNDERGROUND MINING

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Abstract

Visibility is restricted when operating load haul dump vehicles resulting in a number of serious accidents in the Ontario Mining Industry. One of the leading causes of these accidents is the inability of the equipment operator to see clearly people, objects or hazards around the machine. Line of sight tests were conducted on 12 different LHD models currently used in the Ontario mining industry. Results indicate blind spots are caused primarily by posts, the back of the operator's cab, and by lights and light brackets. Impaired visibility on some machines was caused by the wheel well covers, bucket lip extension, fire extinguisher, over-sized buckets, light posts, radiator back, booms, hoses on the booms, radio remote boxes, engine and the air intake cylinders. Results of this study have been used to conduct "visibility" awareness campaigns in the Ontario Mining Industry and computer simulation trials, with the co-operation of several LHD manufacturers are underway to evaluate design modifications to LHDs with the goal to improve visibility.

Introduction

Operating a vehicle in an underground mining environment presents many environmental and machine factors, which potentially can affect driver visibility. For example, the design of load-haul-dump (LHD) vehicles is adapted to the physical constraints of the mine rather than optimizing driver visibility. The driver sits transversely to the direction of travel on the left side of the machine and the cab is relatively low since there is often a restricted ceiling height (Figure 1). In addition, there is no naturally produced light which results in drivers operating their LHDs under conditions paralleling those of nighttime driving. It is therefore not surprising that “poor operator” visibility has been linked to many accidents in mining. For example, Boocock, Corlett, and Naylor (1994) reported that free steering vehicles were the primary cause of four fatalities and 38 major injuries in British coal mines over a five year span between 1986 and 1991. In a report for the Ontario Natural Resources Safety Association (this sector is now referred to as the Mining and Aggregates Safety and Health Association), Tyson (1997) summarized the accident statistics for LHD related injuries and accidents in Ontario mines spanning ten years from 1986 to 1996. During this time Lads were involved in 1559 reported incidents, including 7 fatalities. Half of these fatalities and 67 incidents could be directly related to poor operator visibility. A common incident involving poor visibility is the collision between an LHD and another vehicle unseen by the LHD operator. Often (22%) the LHD operator is injured when his/her vehicle strikes an unseen object on the ground in the drift causing the driver to bounce up and strike a body part on something in the cab. As reported by Tyson (1997), two different coroners reports during this time recommended that LHD visibility be studied. The present research is a direct result of these Ontario statistics and coroner's recommendations.

Figure 1: Example of a typical LHD vehicle.

The design of the LHD vehicle, particularly one with a protective cab, results in restricted line of sight and blind spots. Of note is vision over and around the bucket (Boocock, Corlett, & Naylor, 1994; Vergunst, 1992) and the significant blind spots produced by the cab roof supports/posts (Boocock, Corlett, & Naylor, 1994; Marx, 1987; Rushworth, 1996). Both drivers and researchers have noted that vehicle lights both restrict vision and are often not placed so that the roadway is adequately lit for proper operation (Boocock & Weyman, 1994; Rushworth, 1996). The other major complaint is that the seat position in the LHD does not allow the driver to adopt a posture to afford an adequate field of vision. As concluded by Marx (1987), "Ergonomically designed components are hard to find on machinery used in underground mining". For most models of LHDs, carrying capacity and fit within a confined environment have been the prime engineering design concerns.

The primary purpose of the present research was completed to systematically assess the design characteristics which lead to obstructed lines of sight of several different LHDs that are currently use in Ontario mining.

Methodology

<u>LHDs Tested</u>

In the fall of 1999 underground mine sites across Ontario were contacted by the members of the Underground Equipment Committee (a technical advisory committee supported by the Mines and Aggregates Safety and Health Association) and asked to provide a list of the total number as well as makes and models of LHDs in operation. A cross section of manufacturers and machine sizes were selected (n=12) in order to provide a fair representation of LHDs. The following LHDs were measured: Wagner St. 8B (8 yard) with cab, Wagner St. 8B without cab, Wagner St. 3.5 (3 yard) without cab, Elphinstone R1700 G (8yard) with cab, Elphinstone R1700 (8 yard) without cab, Elphinstone R1500 (3 yard) with canopy, Toro 1400 (9 yard) with cab, Toro 650 (9yard) with cab, EJC 210 (2 yard) without cab, JCI 500 (7 yard) without cab, JS 220 (3 yard) without cab, and JS 500 (8 yard) without cab. Mine site or manufacturer locations were identified and potential test areas were confirmed. It was necessary to have the machine and an operator available for a three hour period. Testing was carried out at five different mine sites and three different manufacturer's sales properties.

<u>Testing Materials</u>
In order to conduct line of sight testing the following equipment was used: Seat Index Point Locator (described by Golsse, 1994), a light filament and battery, tie wraps, a measurement rod with (vertically) sliding mirror, measurement tape, 4" pegs and hammer, and spray paint.

Procedure

The first step in conducting the line of sight measurements was to secure a light filament to the operator's seat at a height representative of the eye position of a five foot seven inch, 65 kilogram person (Figure 2). Four reference points extending out from the operator's position (to the left, in front, to the right, and behind) were then marked. The reference positions were then used to trace out a rectangle. Locations were marked off on the perimeter of the rectangle at known distances from the LHD. Sight lines were then evaluated at each of the marked locations (Figure 3). A measurement rod with a sliding mirror was used to record the height from the ground at which the light filament could just be seen in the mirror. If the light was not visible at that location, the machine part responsible for the visibility restriction was recorded. Mathematical equations were employed to extrapolate line of sight distances to the ground, to one meter above ground (approximating a kneeling person), and 1.7 meters above ground (representing a standing person). This information was then used to create the line of sight charts (Figure 4). A test/retest procedure was followed using an Elphinstone R1500 to insure the reliability of the testing protocol.

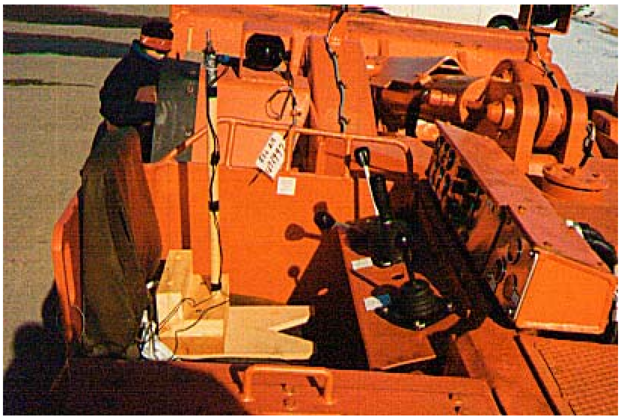

Figure 2: Seat point indicator with light filament located in the LHD operator's seat.

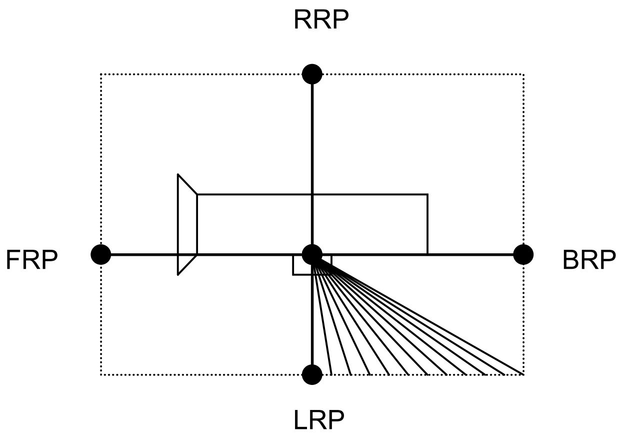

Figure 3: The location of the reference points is shown. (LRP: left reference point, FRP: front reference point, RRP: right reference point, BRP: back reference point) The dashed lines forming a rectangle represent the marked locations where line of sight measurements are taken. The solid lines from the operator's position represent line of sight measurements taken in the back left quadrant.

Results and Discussion

Line of sight graphs were produced for each of the 12 LHD models evaluated (Figure 4 & Figure 5). No two machines had the same results however there were a number of trends. Preliminary analysis has shown the following machine characteristics are primarily responsible for blind spots from the operator's position:

- Operators cab (posts, and back)
- Light and light bracket combination (cross bracket & 4 light combination, large post & square light combination)

The machine characteristics found to "impair" the operator's visibility were as follows:

- Wheel well covers (some designs stick up higher than necessary)
- Bucket lip extensions
- Over sized buckets for the machines
- Light posts (more impairment if the front and rear light posts are not staggered)
- Boom if the hoses are not secured
- Radio remote if placed above the engine profile
- Air intake cylinder
- Engine (D-deck vs. Deutz)
- Radiator back (straight cut restricts visibility more than the angled cutback)
- Fire extinguisher placement if above the engine profile

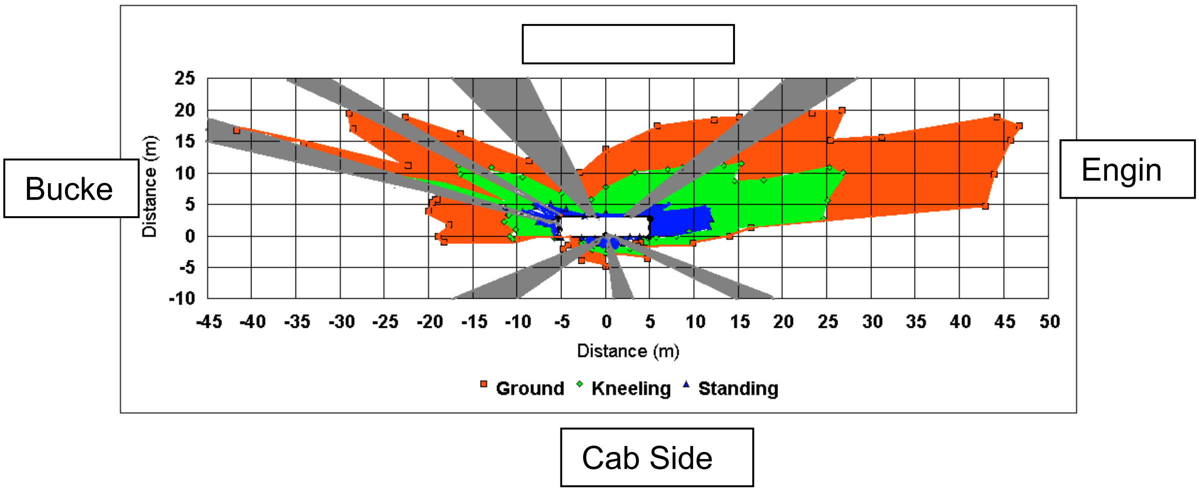

Figure # 4: Example line of sight diagram for an 8 Yard LHD vehicle with a cab. The operator is positioned at position (0,0) on the graph. The LHD vehicle is represented by the white rectangle. The area from the operators position that is not visible to the ground is shown in red, the area in which a kneeling person could not be seen is shown in green and the area in which a 1.7 meter tall person could not be seen is shown in blue. Complete blockages (blind spots) are shown in grey. Starting from the operators position and moving clockwise, the machine characteristic responsible for the seven blind spots are; cab back, cab post, light bracket and boom, light bracket, cab post, cab post, and cab post.

As expected, the distance an operator can see to the front and the back of the LHD was greatly effected by machine size. Visibility was generally better from the smaller LHDs (3 yard bucket) compared to the larger LHDs (8 yard bucket). Visibility was also better if the machine did not have a full cab. Although this result was expected, the size of the blind areas created by the cab is a concern and should not be ignored particularly since the trend in new LHD models is to have a full cab installed on the vehicle.

The distance from the corners of each LHD tested, in order to see a 1.7 meter tall pedestrian is summarized in Table 1. The number of blind spots and machine characteristics responsible for restricted visibility are also presented.

(*Note: caution should be used when applying these results to similar LHD models and even LHDs of the same model type since most LHDs tested were modified to some degree from the original manufacturer model type)*

Application

Results from this study to date have been used to conduct a "visibility awareness" campaign in the Ontario Mining Industry. A general safety meeting/information package title, " Visibility and the Safe Operation of Load Haul Dump Vehicles" has been developed for use by the mining industry in increase awareness of the "visibility hazard" and to provide the mines and miners with strategies to minimize the hazard. A knowledge transfer program has been pilot tested at a small gold mine in North Eastern Ontario, which included:

- "see and be seen" program for underground pedestrians involving lamp and hand signals,
- changes to the LHDs to improve visibility
- increased use of reflective markers on clothing and equipment,
- increased signage of hazards in LHD areas,
- improved lighting in LHD areas,
- modifications to road access areas,

This program will be delivered to the rest of the Ontario Mining Industry in the fall of 2001.

Future Research

The results from the line of sight testing, which identified design features resulting in restricted visibility will be evaluated using computer simulation tool, JACK, in order to provide recommendation for design improvements. The use of cameras and mirrors to further improve visibility will also be tested with the computer simulation tool.

Table 1: Summary of Line of Sight Testing Results

LHD Model/Manufacturer	**Distance (m) (From each corner of the LHD at which a 1.7 m tall pedestrian can first be seen)**				**Number of Blind Spots & Causes**	**Primary Causes of Impaired Visibility**
	FLC	FRC	BRC	BLC		
Elphinstone R 1700 G	0.57	4.8	2.1	1.3	6 (cab, cab posts, lights and light brackets)	LF: wheel well cover & bucket lip FRC: light bracket and boom BRC: air intake cylinder BCK: engine
Elphinstone R 1500	0	BLK	0	0	6 (lights, light brackets, boom, and cab posts	BRC: air intake cylinder BCK: engine & radiator
Wagner St 8B (cab)	1.5	4.3	2.5	3.4	5 (cab, cab posts, lights)	RS: air intake RBC: flap on back of cab window
Wagner St 8B	0	2.4	2.8	0	1 (boom & hoses)	FRC:bucket & boom FR: fire extinguisher BR: remote box BCK: engine
Wagner St. 3.5	0.2	0	0.8	0.3	1 (air intake cylinder)	Front: bucket lip BCK: engine & wheel well cover
Toro 1400	0	2.5	11.2	0	5 (cab, cab posts, lights & light brackets)	FR: lights, boom BCK: engine
Toro 650	0.4	4.8	6.8	2.6	7 (cab, cab posts, lights, light bracket & boom)	FRC: Boom and lights BCK: engine
EJC 210	0.25	0	0	0	0	LFC: edge of the bucket & wheel well cover RFC: light & light bracket BCK: engine and radiator cover
JCI 500	0	0.55	0	0	3 (upper, inner and outer light brackets)	BRC: air intake BLC: wheel well cover
JS 220	0	0	0	0	0	RF: light brackets RB: hydraulic oil tank & remote box
MTI 7 Yard	1.9	2.6	5.6	0	0	FRC: lights, boom BR: mud flaps over wheel well BCK: engine

Legend: FRC- front right corner, FLC-front left corner, BRC-back right corner, BLC-back left corner, BCK - back, LS- left side

Conclusions

Line of sight testing and feedback from LHD operators indicate visibility from LHDs is restricted and the extent of the restriction varies between models. The design, size and placement of "components" can adversely affect visibility. When evaluating LHD visibility or looking to modify existing LHD models to improve visibility, the location and type of lights & light brackets, the height of the engine profile, the size of the bucket, the presence of a cab, the sitting height in the cab, and the location of the remote box should be considered.

Improvements to LHD vehicle designs are needed in order to minimize visibility impairments. In addition, procedures and work practices that help to prevent visibility related accidents and incidents from occurring need to be implemented.