



To see or not to see ... that is the question!

Designing to maximize operator visibility in LHD equipment.

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Abstract

Each year, Ontario mining experiences approximately 160 accidents/incidents involving underground Load-Haul-Dump (LHD) equipment. A significant contributing factor to many of these accidents and injuries is the restricted visibility from the operator's work space. More specifically, since 1986 there have been five fatal accidents in Ontario mining where the lack of good visibility for the operator of an LHD has contributed to the death of a miner; either the operator or a pedestrian struck by the vehicle. Also, two Coroner's Juries, one in 1994 and another as recently as April 1997, have recommended that the visibility from the LHD operator's compartment be improved (Ontario Ministry of Solicitor General, 1994 & 1997). A review of the literature related to LHD design and visibility indicates that this problem is not isolated to Ontario mining, but is an inherent problem with the design of LHD equipment. This literature also shows that steps can be taken to improve the operator's visibility. Some of the different approaches and changes that can be made to improve the operator's visibility are discussed in this paper.

Introduction

The increased level of automation, mechanization and technology in Ontario mining has benefitted both workers and companies by increasing productivity and significantly decreasing the total physical demand on workers. However, if this equipment is not designed to meet the physical and psychological limitations of the user, accidents, injuries and fatalities will occur. Of course, it is not only mining equipment which is poorly designed from the point of view of the user. Similar design problems are seen in forklift trucks, wood harvesting equipment and construction vehicles. However, the constraints placed on the designers of mining equipment are more restrictive due to the nature of the mining environment. The design, size and shape of Load-Haul-Dump (LHD) equipment used in mining is dependent on the height and width of the mine drift. With these constraints in mind, the LHD designer attempts to maximize power, reliability, durability and load-handling ability, since it is these points which 'sell' LHDs. Safety issues, such as brake design, fire suppression systems, 'Falling Object Protection' (FOPS), etc. are also key design factors to be considered. And, in recent years, many manufactures have made significant improvements to the 'ergonomics' of the operator's compartment. Today's LHD has much improved seating, adjustable armrests and joy-stick controls and more visible displays/ indicators compared to the LHD of 10 years ago. These changes have resulted in improved operator comfort and safety. However, despite these changes and due to the constraints of the mining environment, the basic layout and design of the LHD has not changed significantly over the last 20 years.

LHDs are electric or diesel powered, rubber-tired (trackless) vehicles with a scoop or bucket on the front. They are used primarily to transport ore from the production face to ore dump points, haulage trucks or crushing stations (Figure 1). These vehicles are also used to move pieces of equipment



Figure 1: Typical LHD used in Ontario Mines

about the mine, prepare road beds, backfill stopes, etc.

Over the last 20 years, the number of LHDs used in mining has increased as the industry moved towards more mechanization and trackless operations. Along with this increase in mechanization has come a move towards an increased use of technology, improved mining engineering and a better understanding of rock mechanics. These have controlled many of the 'traditional' hazards of mining. However, the use of mechanized equipment and technology has also introduced new hazards, many of which are a result of a mismatch between the equipment design and the capabilities and expectations of the operators. This fact was highlighted by a recent study of fatal accidents in mines in Britain (Simpson, 1992). This study found that human error was a main contributor to the accidents in a high proportion of the cases. However, this study also showed that in most of these cases there were significant equipment design factors which would predispose operators to commit such an error. Thus the equipment was designed in such a way as to increase the probability of human error and thereby increase accident risk. In particular, the authors of this study noted significant ergonomic design problems with LHD equipment.

Accidents Involving LHDs

Each year, Ontario mining experiences approximately 160 accidents/incidents involving underground Load-Haul-Dump (LHD) equipment. Table 1 contains data from the accident/injury database maintained by the Mining sector of the Ontario Natural Resources Safety Association, North Bay, Ontario, Canada. This database contains information which is provided by Ontario mining companies on a voluntary basis. As such, the actual number of LHD accidents occurring in Ontario may be greater than indicated.

Table 1: Accident/injuries involving LHD equipment? in Ontario Mines (1986-1996)

Type of Accident	Number of Claims
Medical Aid	1331
Lost Time	218
Fatalities	10
Total	1559

A more detailed analysis of this data was completed to identify accident/injuries where LHD operator visibility was a primary causative factor. This analysis (Table 2) revealed that poor operator visibility was a significant contributing factor in 50% of the LHD related fatalities, 11.5% of the lost time accidents and only 3% of the medical aid injuries. So while the total number of accidents/injuries directly related to LHD operator visibility is small, these accidents tend to be severe. Not reported by either of these sources are the many 'near misses' which, save for chance, could have resulted in personal injury. It should be noted that two Coroner's Juries, one in 1994 and another as recently as April 1997, have recommended that the visibility from the LHD operator's

compartment be studied and improved (Ontario Ministry of Solicitor General, 1994 & 1997).

Table 2: LHD Accident/injuries in Ontario mines where operator visibility was a significant factor (1986-1996)

Type of Accident	Number of Claims
Medical Aid	37
Lost Time	25
Fatalities	5
Totals	67

As a comparison, Rushworth (1996) reports statistics for LHD accidents which took place in UK coal mines from 1986 to 1991. During this period, nine fatalities and 96 major injuries due to accidents directly involving or associated with LHDs were reported. Of these, 50% involved moving vehicles and resulted in pedestrians being run over or struck by vehicles and drivers striking or becoming trapped against the sides of mine drifts. Poor operator visibility and limited clearances were considered to be principal factors contributing to these accidents.

The following example of a fatal accident involving an LHD was reported by Boocock et al (1994):

During a routine back grading operation, the driver of a LHD received fatal crush injuries to the chest. In the opinion of the investigating team, the accident occurred as a result of the driver reversing from a heading whilst concentrating on the position of the bucket at the front of the LHD. At the time of the accident the front end of the vehicle was turned to the right, such that the angle between the long axis of the front and rear of the vehicle was 162. The driver's cab was to one side and on the rear section of the vehicle, such that the driver's back was facing the drift wall. In order to view the angle and position of the bucket, the driver must have leaned back and placed his upper torso and head outside the confines of the protective cab. While reversing and adopting this position it was felt the driver misjudged the contours of the wall and was trapped between the canopy support tube and the wall, at a point where the heading narrowed and curved. It was felt that the impact must have pulled the driver from his seat and prevented him from applying the foot brake.

Factors Influencing LHD Design

As noted above, the mining environment places many constraints upon the designers of LHDs. These constraints are not just imposed by the physical environment of an underground mine. Economic factors play a key role in the design process. Marx (1987) lists some of the many constraints imposed on the designers of LHDs:

- productivity requirements necessitate the use of the maximum possible vehicle performance, i.e., for example the maximum possible bucket capacity for a given drift cross-section. Vehicle dimensions are defined by the cross sections of the working spaces. Designers also seem to design LHDs so that the height of the vehicle is the same as the height of the tires;
- due to economic and organizational reasons there are no areas for these vehicles to turn around so bi-directional travel is required. Traditional LHD design has 'solved' this problem by having the driver sit facing perpendicular to the direction of travel;
- the need for fuel storage, radiators, exhaust emission controls etc. which can take up a lot of space;
- strength and durability requirements mean vehicle frames and cabs must be sturdy and thick walled which can result in reduced operator space and restricted visibility.

It should also be noted that safety features, such as fire suppression systems, effective braking systems, fall-on or roll-over protection (FOPS/ROPS), are often mandated by regulation or law,

whereas ergonomic and visibility issues are most likely not.

These criteria greatly reduce the freedom designers have to vary the width, height, length or bucket size on LHDs. While LHDs may be productive, cost effective, and have good safety features, they do not come close to the degree of operator comfort and 'user friendliness' which is taken for granted in today's surface 'heavy equipment.' Also, without customer pressure to improve or change the basic design of the LHD, manufacturers are reluctant to introduce such changes. The manufacturer is faced with the need to provide a large variety of vehicle types, each with a relatively low production volume. As such, ergonomic design features have not been incorporated because of the extra work and time involved. Many designers may also feel that design principles commonly used to manufacture LHDs, to meet the above stated constraints of the mining environment, are in competition with 'ergonomic' design principles.

The basic LHD which is used in mining today has these features:

- a four-wheeled, articulated vehicle consisting of an engine section at the rear and the bucket section at the front;
- a profile which is long, low and narrow. The maximum width and height of the vehicle will depend on the cross-sectional area of the mine drift;
- an operator's cab located on one side of the vehicle, usually slightly behind the articulation point. The operator sits facing across the width of the vehicle, perpendicular to the long axis of the machine;
- additional pieces of equipment such as extra lighting, emission controls and air filters, FOPS, etc. are often added after the vehicle has been purchased, and often installed with little regard for the operator's visibility requirements.

The physical and organizational constraints of the mining environment are not the only factors to influence LHD design. The US Bureau of Mines found that mechanized equipment was involved to some degree in 50% of underground mine accidents, and this equipment was considered the primary or secondary cause in 21% of the accidents (Sanders and Shaw, 1988). A number of key design factors were identified as contributing to these equipment-related accidents, including:

- control-display layout;
- poor ingress/egress;
- exposed wiring/ hot surfaces;
- sharp surfaces and pinch points;
- unguarded parts;
- restricted visibility.

The authors of the study went on to state that improved equipment design would have reduced the likelihood and severity of these accidents in 38% of the cases.

In another USBM report, Sanders and Peay (1988) reported the results of various studies which investigated the reasons why equipment design was contributing to so many human error related accidents. What they found was a general reluctance on the part of design engineers to vary their designs or to try new or innovative design concepts. Also, once designers have prepared an initial design, they are reluctant to modify their design, except in minor respects, even when new information is provided to them. The authors provided an example:

The control cab of a piece of equipment under design was originally intended for four operators. Halfway through the design process it was decided that only two operators were actually needed, or desired, for the operation of this machine. However, even when given this information, the designers made no significant changes to the control cab of the equipment, resulting in poorly located controls and displays, and significant movement required on the part of the operators to run the machine.

It was also noted that prior to beginning any design, design engineers almost never consider how the equipment is to be used, the population from which the operators will be taken, the sequence of use of controls, or which functions/controls are most important or most frequently used. The authors

went on to state that "no matter how much expertise the design engineers had or the type of design problem being considered, the typical designer does not consider human factors [ergonomics] when designing."

LHD design and visibility

It has already been stated that the basic LHD design results in a vehicle which is long, low and relatively wide, in relation to its height. This design is the primary cause of poor visibility for the operator. Specifically, the low vehicle height and the centrally located driving position make it difficult for the driver to see anything other than objects or locations on the same side of the machine as the driver. To determine what visual cues LHD drivers felt were important when operating their vehicles, Boocock and Weyman (1994) interviewed a number of LHD drivers. The drivers reported that they primarily look along the near side of the vehicle when driving both forward and backward. These 'sightlines', down the operator's side of the LHD are their primary means of navigation. The drivers also stated that they are constantly checking the position of their vehicle in relation to the near wall of the drift, and they tend to position the LHD as close to the close wall of the drift as possible to minimize the likelihood of contact with the opposite side of the roadway. It was noted that in an attempt to maximize their view of the roadway drivers will often lean out of the cab, risking injury through contact with the drift wall.

Boocock and Weyman (1994) also reported that LHD drivers find it difficult to judge the location of the sides and corners of the LHD when driving and seeing people or obstacles which are close to the sides or corners of the vehicle. They found that the postures adopted by the drivers in order to improve their visibility can interfere with their ability to use the LHD controls or place their bodies outside the protection of the cab. Operators felt that the cab design and the design of the seat restricted their postures and prevented them from adopting a posture which optimized their field of vision. Structural supports for FOPS canopies and walls of operator cabs also impair the driver's visibility.

As the LHD operator's performance seems to depend on good visibility along the sightlines down the near side of the vehicle, it would seem logical to have adequate illumination in this area. This is not usually the case however and vehicle lighting is a common source of complaints amongst LHD drivers. Most vehicle lighting is directed along the length of the drift, to provide illumination to the front and rear of the LHD. This does not provide adequate lighting along the driver's sightlines which are to the side of the vehicle. Many drivers noted that they use their cap lamps as a primary source of illumination to see the near side drift wall and objects close to vehicle. It was also noted that when the bucket is fully loaded, the vehicle lights on the front of the machine can become ineffective and add a significant amount of glare when the light beams reflect off the muck in the bucket.

Studies of LHD driver's visibility

There are many different methods available for assessing operator visibility in mechanized equipment. The Ontario Ministry of Labour used a simple direct line of sight method to assess the visibility from an eight yard LHD (scooptram). To conduct this assessment, a 5' 7" (170 cm) LHD operator was asked to identify the location at which he could see a small light, held at ground level and then again held at a height of 5'5" (165 cm). Figures 2 and 3 provide results of this assessment as reported in the Ontario Ministry of Labour Hazard Alert (1994).

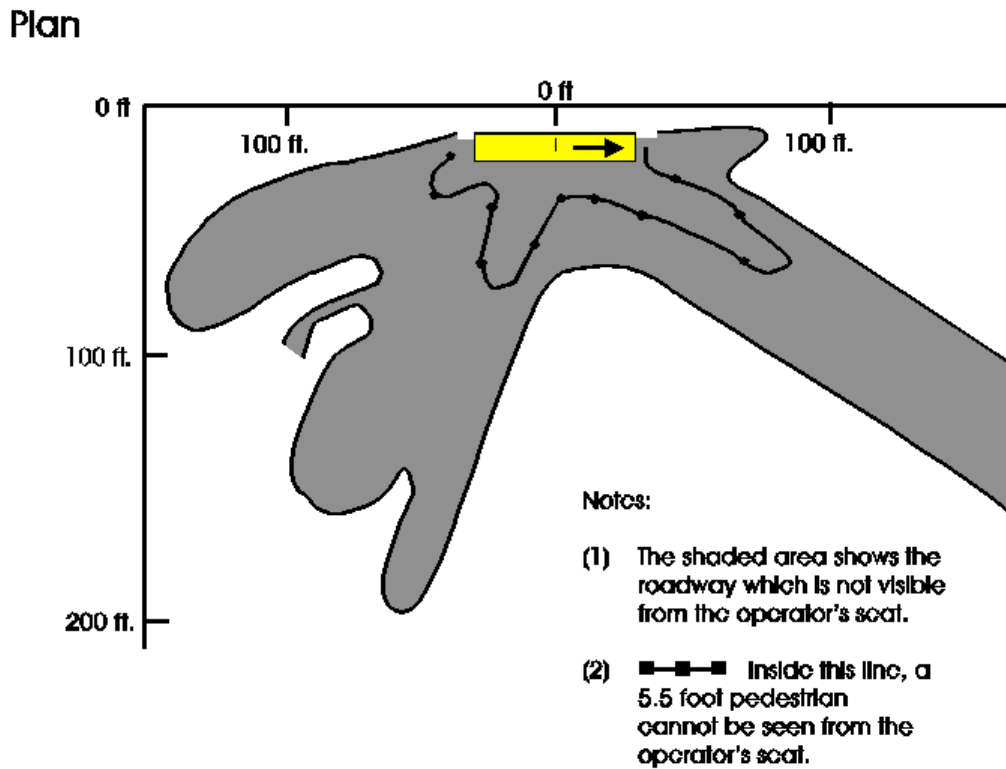


Figure 2: Plan view, results of Ontario Ministry of Labour visibility assessment

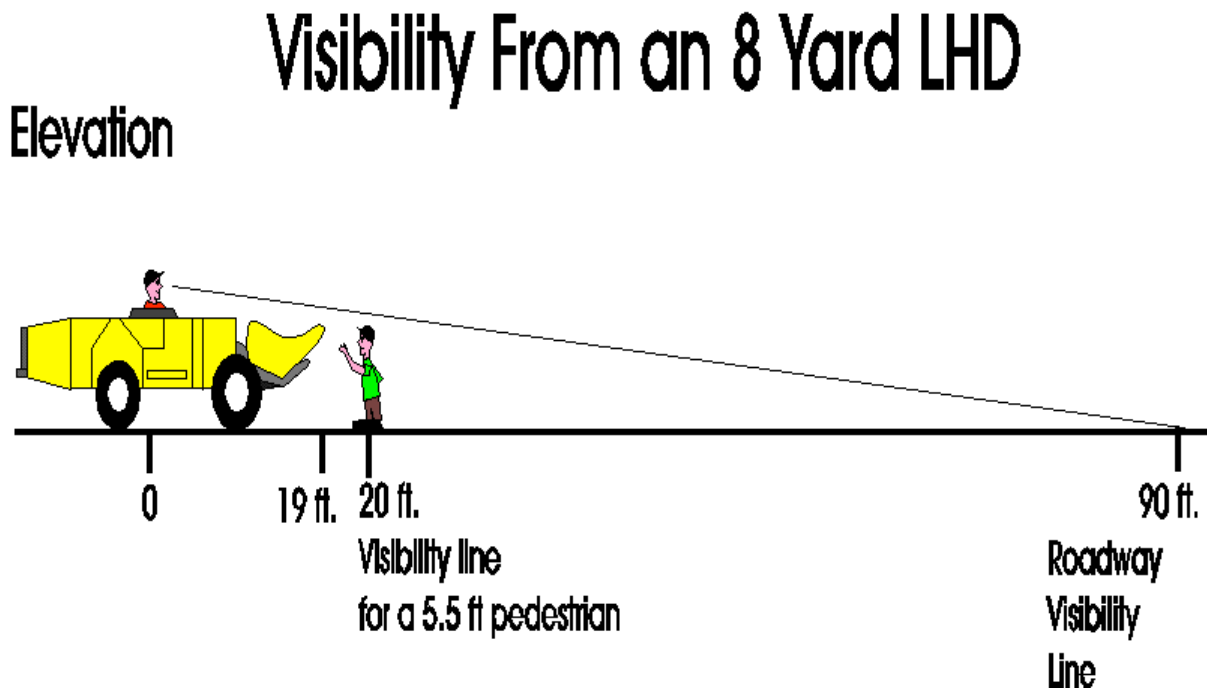


Figure 3: Side view, results of Ontario Ministry of Labour visibility assessment

When driving forward, the floor of the roadway is only visible at a distance of about 90 feet (27.5

m) from the driver. Also, the operator is unable to see the pedestrian when he is closer than 20 feet (6.1 m) from the operator. This is significant, since the operator requires at least 20 feet to stop the vehicle when traveling at five miles per hour (USBM, 1996). Also, since the operator has such a poor view of the roadway, especially to the front, right hand side, any obstacle or person entering the path of the vehicle from that direction may not be seen.

Boocock and Weyman (1994) used a computer aided design system to assess the visibility from an LHD after it had been involved in a fatal accident. The authors did not report what make, model or size of LHD they assessed (see Figure 4), however it was reported that the driver's eye height was approximately 5' 7" (170 cm) from the ground. Based on the figures provided in the Ontario Ministry of Labour Hazard Alert, it is felt that the LHD assessed by Boocock and Weyman was a lower profile unit, with the operator in a lower seated position. Figure 5 shows the results of the computer aided visibility assesment.

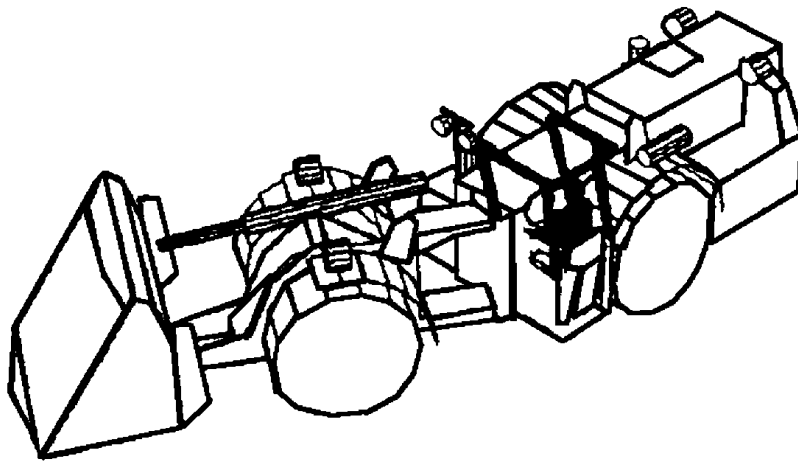


Figure 4: Graphic of LHD assessed by Boocock and Weyman (1994)

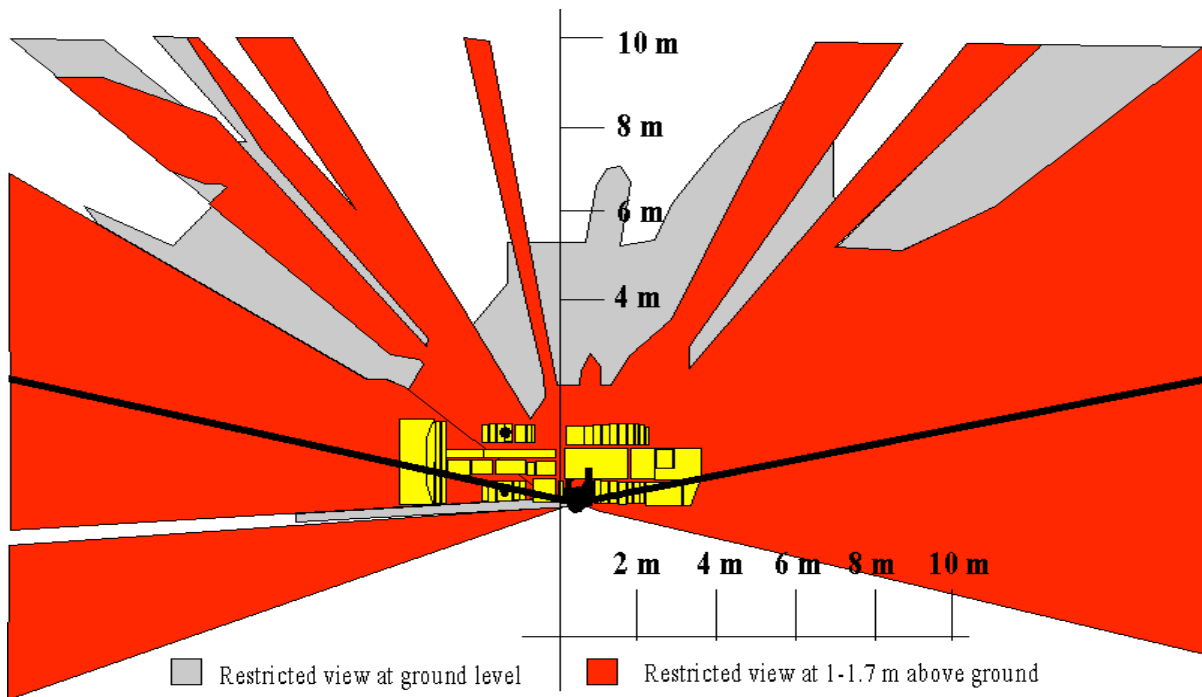


Figure 5: Top view, results of Boocock and Weyman (1994) visibility assessment

The results of this assessment show that when the LHD is driving forward, the roadway floor is visible at a distance of 246' (75 m), over the top of the lowered bucket. Also, the canopy supports on the vehicle in question were found to directly impair the driver's forward and rearward vision. Vision to the rear is poor, with the obstructed area extending approximately 165' (50 m).

Improving the LHD operator's visibility

Visibility refers to how well the human eye can see something. Assessing visibility involves much more than just determining whether or not there is a clear line of sight between the object and the viewer's eye. Table 3 lists issues which need to be considered when assessing visibility (adapted from USBM, 1996).

Table 3: Issues that affect visibility

Field of Vision:	If the object or area of interest is not actually in the person's field of vision it won't be seen. The field of vision is the area that can be seen by the operator, with and without movement of the eyes, head, neck and trunk.
Line of Sight:	The visibility of an object decreases if the view of the object is physically obstructed.
Illumination:	There needs to be adequate illumination in the work area to see the objects or areas of interest. If not, the object won't be visible.
Contrast:	The difference between the luminance of the object of interest and the luminance of the background the object is seen against. The greater the luminance difference, the greater the contrast, and the greater the visibility.
Colour Detection:	The ability to detect colour differences depends on genetics and the amount of available illumination.
Visual Acuity:	A measure of the ability to resolve distinct objects or fine details with the eye

Adaptation Level:	Visibility is greater when the eye is adapted to the luminance level of the target and its surrounding area. For example, a miner who is working in the brightly lit face area and then steps into a dimly lit crosscut is temporarily 'blinded.'
Observer Age:	The measured contrast sensitivity of a person decreases as he or she ages.
Object Size:	All things being equal, the visibility of an object increases as it becomes larger in the observer's field of view.
Time:	Generally, within limits, the longer the viewing time, the greater the visibility.
Movement:	Movement of the target object or the observer decreases visibility.

All of the above factors are important, since they directly affect whether important objects or areas are seen by the vehicle driver. However, the goal of any visibility assessment is not just to maximize the area an operator can 'see', but to improve the safety of the operator and pedestrians, reduce the probability of vehicle collision and improve operator comfort and productivity. This requires an understanding of what the driver needs to see in order to do the job safely and efficiently. The USBM (1996) provides an excellent review of what should be involved in a complete visibility assessment. The process is too detailed to describe in this paper, but the key points include:

- **Specifying information requirements:** before conducting a visibility assessment, it is important to know what information the operator needs to do the job safely. This can best be done by doing a thorough task analysis of the job.
- **Identify, rate and locate important visual features:** much of the information required to operate an LHD will be visual. It is important to know what visual features will provide the required information to the operator, how important these features are (which will depend partly on how likely their occurrence), and where the visual feature is in relation to the operator.
- **Specifying visibility requirements:** two approaches for specifying visibility requirements are noted:
 - specifying areas of unobstructed vision (visual windows) of a specific size and location. These visual windows must be specified either in terms of visual angle or in terms of the size of the area that needs to be seen and the distance the area is from the operator.
 - specifying specific points in space that must be visible to the operator, also known as Visual Attention Locations (VAL). When doing this it is also necessary to specify whether the operator can see without any head or torso movement, with head but no torso movement, or with both head and torso movement.
- **Assessing actual operator visibility:** once it has been determined what visual features an operator needs to see and where these features are located, it is possible to determine whether the design of a particular piece of equipment or operator cab will allow the operator to see these features. A more detailed description of how visibility is assessed is provided below.
- **Assess the illumination of visual features:** it is also necessary to ensure that visual features that must be seen are properly illuminated, since it is no good to make sure that an unobstructed view of the feature is provided if there is not enough light to see it. In the mining environment it is important to evaluate the amount, quality, angle and location of lights mounted on LHDs to ensure that they are able to illuminate the areas that need to be seen by the operator and do not create problems by obstructing vision or creating glare.

Visibility Assessment Methods

A variety of different techniques are available to assess driver visibility. Variations of three different techniques have been used by most researchers. These techniques are the shadow graph, panorama

photographic and the line-of-sight methods.

The line-of-sight method is the simplest to perform and can be done from either inside or outside the cab. From the inside, an operator sits in the cab and is asked whether or not he/she can see a target or a particular visual feature. The process is simple to do and tells the analyst whether the target can or cannot be seen. This method can also be done by mounting a camera above the seat at eye level and then photographing the 'target'. This produces a permanent record of the vehicle's obstructions. When using this method from the outside, a 'target' which represents the position of the operator's eyes is placed inside the operator's cab. The analyst then moves to each visual attention location and a picture is taken. If the target can be seen in the photograph then it is determined that an operator would be able to see the visual feature. The USBM (1996) provide a complete description of and the benefits to be gained from this type of method.

Shadow-graph techniques require one or more light sources to be positioned in the cab of the vehicle being studied. A version of this technique is recommended by the international standard ISO 5006-1 (1991). For the ISO method, the vehicle is centred in a circle with a 12 metre radius. Two light bulbs are positioned in the operator's seat to represent the position of the operator's eyes. The shadows cast by the lights on the circumference of the circle indicate obstructions to the operator's vision. The width of the shadow at the circumference of the circle and the distance between neighbouring shadows is used to rate the acceptability of the visibility from the operator's position. Variations on the ISO 5006-1 (1991) method are described by the Forestry Engineering Research Institute of Canada (Golsse, 1994) and in the Society for Automotive Engineers standard SAE XJ1091 (SAE, 1980).

The third technique involves using cameras to take planimetric (Hella et al, 1991) or panoramic (USBM, 1996) photographs to identify visual obstructions. The panoramic technique involves placing a camera at the operator's eye position and taking a series of overlapping pictures as the camera is rotated 360. Pasting the pictures provides the analyst with a panoramic composite of what an operator would see. The analyst must then decide whether or not the required VALs are visible in the pictures and hence visible to the operator.

All three of the above assessment techniques can be effectively used to assess the visibility from the operator's cab of an existing vehicle. These assessments allow for the identification of obstructions in the operator's visual field. This information can then be used to plan machine modifications or retrofits to improve the operator's visibility. The drawback to all of these different assessment methods is that they cannot be used until after the machine has been built. They are useful when all that is required are relatively minor modifications and retrofits, but major design changes are likely not possible or are too expensive after the machine has been manufactured. Using a computer-aided design method can help to overcome this problem.

Using a computer-aided design (CAD) system to perform visibility assessments is both cost effective and versatile. The main benefit to this approach is that a CAD system can be used both before and after a piece of equipment has been built. As such, it allow changes to be made to the basic design prior to manufacture, where any required modifications are easier and less costly. Existing vehicles can also be assessed and the assessment results used to generate ideas for modifications and retrofits. The CAD systems described in Boocock and Weyman (1994), Boocock et al (1994) and USBM (1996) all produce various computer generated visibility charts, in two and three dimensions. The systems can be used to quickly evaluate design changes, different sizes and postures for operators and different cab layouts and positions. The visibility charts produced by these systems can also be used as training aids since they provide information about restricted operator visibility during various tasks (i.e. driving straight, turning corners, etc.) and when transporting different loads. The potential dangers to both the operators and pedestrians can be highlighted. It should be noted that this type of training was recommended by a recent Coroner's Jury (Ontario Ministry of Solicitor General, 1997).

Modifying existing LHD equipment

In an ideal world, any new LHD brought into service today would be designed to optimize the operator's visibility and all existing LHDs would be quickly replaced by the new designs. However,

this is not likely to happen. This leads to the conclusion that the only practical way to improve the operator's visibility on LHDs currently in service in Ontario mining is through on-site modifications. Any such modifications must endeavour to improve the operator's visibility while ensuring that any such changes do not compromise the safety of the operator.

Rushworth (1996) describes a process which was used to improve the overall ergonomics of the operator's cab in three LHDs and one locomotive. First, the operator's cabs were evaluated to identify specific ergonomic design problems, including poor visibility, lack of space, poor control/display relationships, etc. Using this list, a 'retrofit index' was developed to assess where in-house 'retrofit solutions' would be most effective. For each identified problem a quality score was assigned to reflect the quality of the standard of ergonomics in a given operator's cab. Each quality score was then weighted to reflect the relative importance of each problem to the safe and effective operation of the vehicle. The final, weighted score for each problem was used to focus attention on the least safe aspects of the cab design. The results of this process lead to a total of 63 modifications being made to three LHD cabs, many of which helped to improve the operator's visibility. These modifications are described below.

LHD #1: (Gullick Dobson MP100)

- modified seat design and raised seat to sight lines;
- added a reinforced, pivoting back rest to seat;
- added an adjustable height canopy to improve sight lines;
- redesigned canopy to eliminate the nearside support. This improved visibility and eliminated a potential crush point if the operator was leaning out of the vehicle;
- lowered the front fenders to remove a visual obstruction;
- moved a set of hydraulic controls to remove a visual obstruction;
- moved headlights to extendible arms beside the cab. The lights on the extendible arm can be adjusted to shine down the sides of the machine so the operator can better see along this important sight line.

(the above modifications resulted in a 26% reduction in the total area obscured from the driver.)

LHD #2: (Emico 912)

- extended the back of the cab outwards, reinforced and raised to improve visibility along the near side of the vehicle;
- provided a new seat which was raised to improve sight lines;
- chamfered the front engine cover to improve visibility;
- lowered the front fenders to remove a visual obstruction;
- relocated a number of displays to remove a visual obstruction.

LHD #3: (Emico 913)

- similar modifications to the Emico 912;
- used to test the potential of video cameras to aid the drivers. It was found that the cameras are particularly useful in spotting people and obstacles at the front right-hand corner of the vehicle (a key blind spot area) and for turning into corners which were on the opposite side of the vehicle.

Boocock et al (1994) also report on an effort to modify the design of an LHD operator's compartment after a fatal accident. A team comprised of the accident investigation team, representative from the LHD manufacturer and the mining company were assigned the task of developing a list of modifications to improve the operator's visibility. The suggested modification to the LHD design involved repositioning the driver's seat and changing the design of the canopy supports. A section of the vehicle's main body was removed directly in front of the existing seat location and in to the centre of the vehicle. The seat was then raised and turned 180 and the driver's controls were adjusted to suit this new layout (see Figure 6).

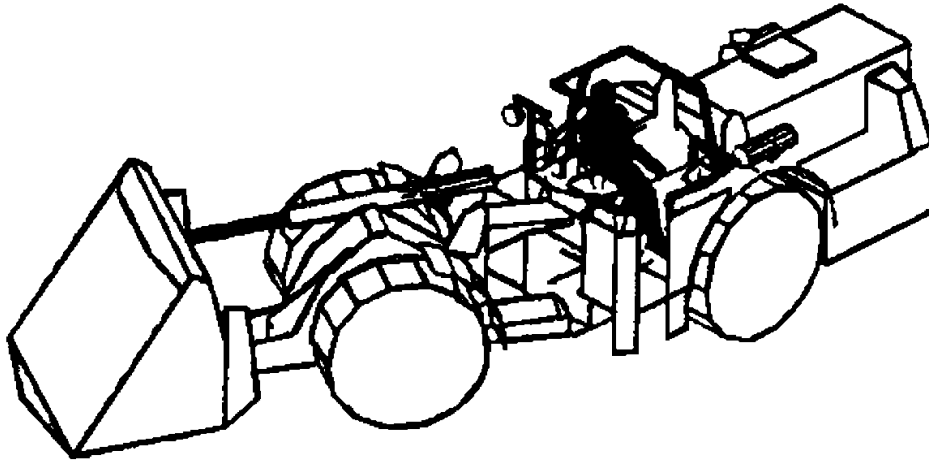


Figure 6: Graphic of modified LHD from Boocock et. al. (1994)

These modifications resulted in an improvement to all round visibility. Figure 7 shows the new visibility map for the new design. When compared to the visibility map in Figure 5, it is clear that a significant improvement has resulted. Now, with the bucket lowered, it is possible to see a 5' 7" (170 cm) tall pedestrian at all four corners of the vehicle and the roadway at only 50' (15 m) and 42' (13 m), front and back respectively.

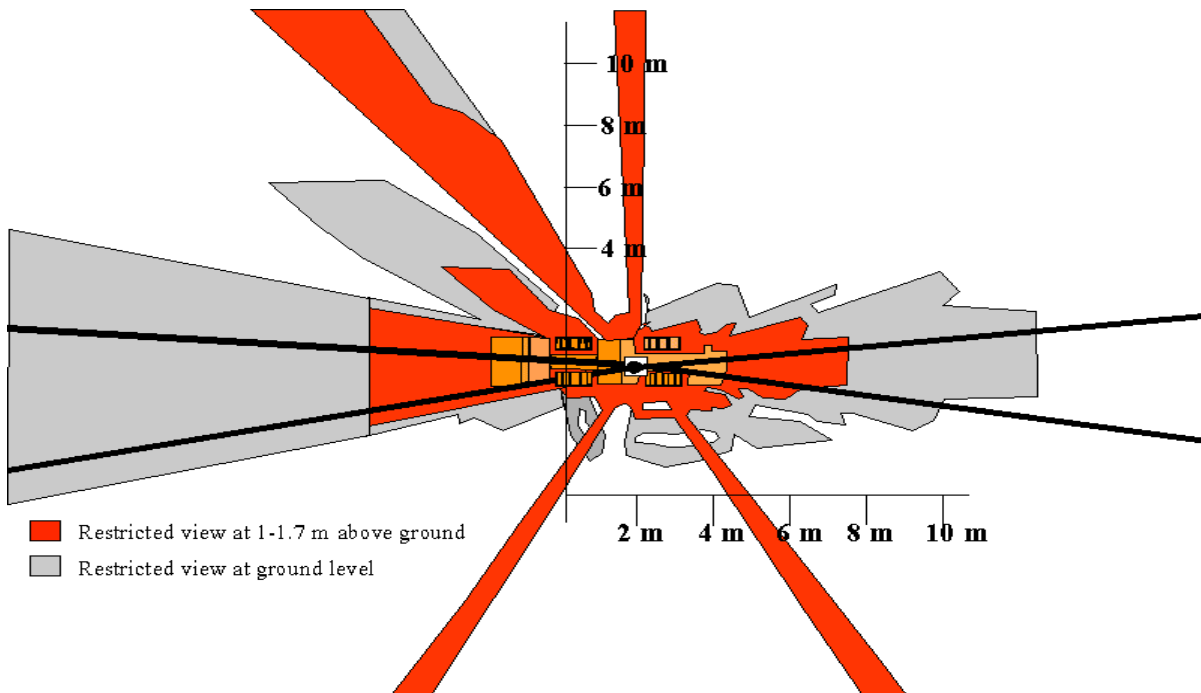


Figure 7: Top view, Boocock & Weyman (1994) Modified LHD assessment

Conclusions

The mining environment places significant constraints upon the designers of LHD equipment. Given the nature of these constraints, it is unlikely that vehicles of this type are ever going to meet optimum ergonomic guidelines. However, this does not mean that attempts should not be made to improve the ergonomics of the operator compartments, both to improve safety and comfort and to improve

efficiency and productivity. To accomplish this, designers need to 'break out of the box' and begin to investigate new and novel LHD designs and not rely on the old, ergonomically poor design.

In the meantime, mining companies need to investigate in-house modifications and retrofit options to improve the visibility from the operator's compartment. The lack of visibility has been listed as a significant contributory factor in a number of serious and fatal injuries, both in Ontario and in other mining locations. Effective modifications will involve eliminating visual obstructions from the operator's line of sight, improving the illumination of important visual features and along the driver's primary sight lines, ensuring that the driver's seat is positioned appropriately to maximize visibility, and designing FOPS canopies and cabs which provide optimized visibility.

Such modifications will entail some expenditures. However, the improved visibility will result in improved operator safety and comfort, reduced wear and tear on the equipment, fewer vehicle accidents and collisions and improved productivity. As noted by Rushworth (1996),

"perhaps the best indication of the perception of the value of the improvements is a report that LHD drivers now get in early to be the first to get access to the modified LHDs."

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