Comparison of operator line-of-sight (LOS) assessment techniques: evaluation of an underground load-haul-dump (LHD) mobile mining vehicle

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Transaction Paper

Synopsis

For many years line-of-sight (LOS) issues for underground mobile equipment is a growing focus of research. This research is a result of the numerous fatalities and injuries which occur in the mining industry and which are related to poor operator LOS. Three assessment methods are currently used to assess operator LOS of underground mobile equipment. The light filament (LF) method is a hands-on assessment method that is performed in the field. This method is not evaluated in this paper. The laser scan (LS) method of assessing equipment is a quick and reliable method that comes from the need to evaluate vehicles already located in the field. The computer simulation (CS) method can assess LOS issues using a computer aided drawing (CAD) model, which is useful for assessing current or prototype models. The purpose of the current research is to compare and validate different operator LOS assessment methods. Comparison of the results of the LS and CS visibility plots yielded similar quantifiable results. A visual comparison of the results further illustrate that the LS and CS methods are acceptable assessment tools for mobile equipment operator LOS evaluation. The visibility assessment methods are now being prepared as guidelines for the mining industry to assess current and potential designs.

Introduction

Several studies[1–4] have investigated operator line-of-sight (LOS) associated with driving a load-haul-dump (LHD) vehicle. Their findings indicated poor LOS was a causal factor for many underground mine accidents that have resulted in injury to pedestrians and equipment operators and damage to other equipment. In a 2004 publication Eger[4] *et al.* reported modifications to the design of operator cab posts, engine covers, light brackets, boom hoses, vent/exhaust systems, and mud guards would be beneficial for increasing operator LOS. In an effort to prevent future accidents associated with poor LOS, accurate and reliable methods to evaluate LOS during the operation of mobile mining equipment are needed.

Current techniques for analysing LOS for LHD vehicles

The next section will briefly outline several current techniques used within the mining industry to assess operator LOS for LHD vehicles. For further information on the outlined procedures please refer to the original research papers.

Light filament method for assessing LOS

The light filament (LF) method established by Eger[4] *et al.* for assessing LOS from LHD vehicles was adapted from the Forest Engineering Research Institute of Canada (FERIC)[5] standardized model originally developed for visibility testing of forest machinery. The LF method was designed for the underground mining environment, while the FERIC method utilized a 12-metre radius circle for recording operator visibility, which makes it impractical for underground applications (due to the size of most mine drifts). The methodological procedures of the LF method can easily be used by individuals with little training within the mining industry. This method has been proven to be successful[4] at providing awareness about factors resulting in poor LOS to pedestrian workers, other mine vehicles, as well as ground hazards. The documented limitations of the LF method include the time requirements to perform a static field assessment, approximately three hours for one vehicle, with additional laboratory hours required to produce a static visibility grid[4]. Furthermore, the results of the LF method are represented as a static two-dimensional (2D) horizontal visibility grid at ground level, which is a poor representation for LOS of the visual field experienced by an

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operator in the underground mining environment. In addition, this procedure lacks the quantitative ability to determine whether vehicle modification or redesign would be significantly beneficial to the operator for increased LOS. For example, if retrofits or modifications are implemented on a LHD vehicle the true benefit may not be properly represented in the static 2D horizontal visibility plot due to the three-dimensional (3D) nature of the environment.

Laser scanning to evaluate LOS

Bhattacherya[6] developed a laser scan (LS) method, which utilizes a terrestrial laser scanning system (commonly used in surveying applications) to assess operator LOS for LHD vehicles in the field. The laser scanner uses a pulsed green laser based on time-of-flight laser ranging technology. The system measures the amount of time required for the laser to reflect from a surface, which is then used to calculate the distance between the laser scanning system and the reflection surface[7]. The information captured from the environment displays a cloud of points, which is presented as x, y, z coordinates of the Cartesian plane for areas that are in the laser scanning systems LOS[6]. Utilizing the collected cloud of points data Bhattacherya[6] developed a 2D static visibility plot similar to the output of the LF method but with increased detail. The advantages of using the LS method include its appropriateness for field assessments (portability), non-contact method, and rapid capture of large amounts of data, as well as the ability for the data to be imported into a virtual environment[6]. However, due to the laser scanner using a time-of-flight technology, boundary limitations affect the quality of the scan[6]. For example, the surface from which the laser scanner is being reflected must be relatively smooth and enclose the entire vehicle for repeatable results. Furthermore, the LS method developed by Bhattacherya[6] provide static 2D visibility plots, which are not representative of what the operator would view in the underground mining environment. However, an LS application that would display captured LOS output as horizontal and vertical visual fields would be more beneficial.

Computer simulation to evaluate LOS

Jeffkins[8] *et al.* document a successful and reliable method to evaluate LOS using a computer software package known as Classic JACK. A visibility audit[9] and target audit assessment protocol was adopted by Jeffkins[8] *et al.* to quantify the LOS available to a virtual operator situated in a computer-aided drawing (CAD) LHD model. The results yielded a visibility percentage score represented on a 2D horizontal plane positioned at a height of 1 m. Their research goes on to report that using computer simulation to assess LOS for LHD vehicles is found to be reliable. However, this method was limited by the presentation of the results in a 2D horizontal format not characteristic of the mining environment. Another method utilized by Jeffkins[8] *et al.* to evaluate LOS was the target audit, which incorporates the use of vertical visibility planes located at five locations deemed necessary for detecting objects at various heights for safe operation of a LHD within a mine drift. The advantage of this method is that LOS data is captured in vertical planes of various heights and is positioned to represent a mine drift. However, this method does not entirely surround the vehicle with visibility planes, which may allow for important attributes that limit LOS for LHD vehicles to go unnoticed. Assessing operator LOS using a boxplot method conceived by Eger[10] *et al.* surrounds the entire CAD LHD model with visibility planes (similar to the target audit) in a box orientation. However, little research has been performed to confirm the usability and reliability of this method.

Several of the LOS assessment methods discussed above are currently being used to evaluate LHD vehicles with little knowledge about the quality, reliability and applicability for a mining application (i.e. are the results representative or applicable to a vehicle operating in a typical mining drift?). Therefore the purpose of this paper is to compare the LOS output from an adapted laser scan method with a computer simulation plot method (hereby referred to as a boxplot). Each method was used to determine operator LOS when driving a small LHD vehicle. The LS method was applied in the field, whereas the CS method was used to evaluate LOS using a CAD model of the same LHD vehicle, which was situated in a virtual environment that was constructed to mimic the real-life situation. These methods are useful for assessing LOS in different applications and settings. The objective of this investigation was to review and compare the outputs of the two assessment methods in order to determine accuracy and applicability.

Methodology

A modified LS method and modified CS method (described below) were used to assess the LOS for a small LHD vehicle. The LOS analysis was performed with the vehicle orientated in a forward straight (0 degrees articulation) position with the bucket rolled up to a position for forward travel as illustrated in Figure 1.

Laser scanning method

The LS method was performed on a small LHD vehicle located in a fully enclosed shop paint bay with the dimensions as illustrated in Figure 2. Figure 3 provides the virtual

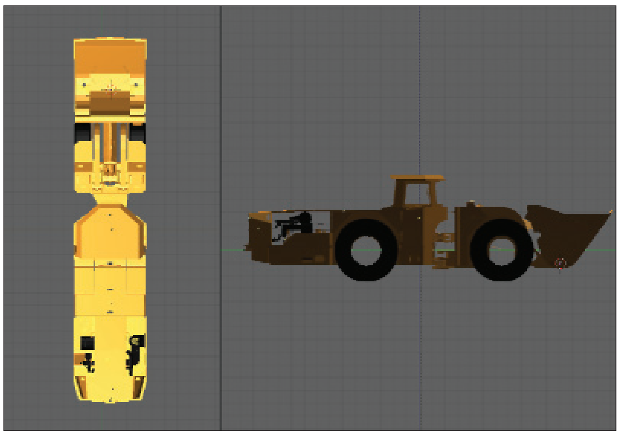

Figure 1—Vehicle orientation adapted to evaluate LOS of the LHD vehicle

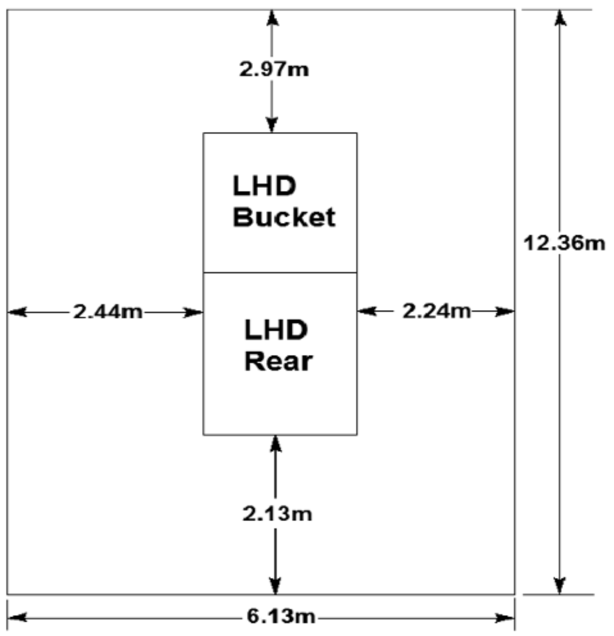

Figure 2—Recorded on-site measurements for the LS method

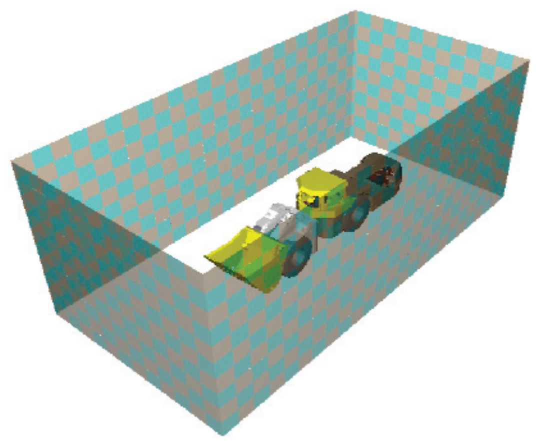

Figure 3—Orientation of paint walls represented as visibility planes surround the test LHD presented in the virtual environment

environment representation of the paint bay. The data collection techniques, established by Bhattacherya[6], were utilized to complete the LOS evaluation using laser scanning. A GS100 laser scanner affixed to a tripod was located within the operator cabin positioned over the seat at a height of 650 mm from the seat index point (SIP) with a 70 kg force applied to the seat to replicate approximate eye position of a 50th percentile male as performed in 2004 by Eger[1] *et al*. The laser scan of the vehicle was then performed and recorded.

Computer simulation method

A computer aided drawing (CAD) of the same model of LHD tested with the laser scan method was imported into the virtual environment of the computer software program Classic JACK (v4.1) developed by Unigraphics Solutions Inc. (UGS) as illustrated in Figure 3. A 50th percentile male virtual human was positioned in the cabin of the CAD created LHD vehicle, the simulated eye position was orientated at the virtual site 'bottom head sight' and located 650 mm directly over the SIP with the eye point stationary (not effected by posture) as outlined in the laser scan method.

Visibility planes were created in the computer simulation program at the same location as the boundary walls used with the laser scanning method (refer to Figure 2). Smaller visibility squares were created within the visibility planes (front, back, right, and left), which consisted of a size of 0.5 m x 0.5 m (refer to Figure 4 and 5 for visibility plane breakdown).

Laser scan data analysis

Processing of the cloud of points data collected from the laser scan were reconstructed into 3D models using 3Dipsos software designed specifically to create enhanced 3D modelling of laser scanned images. The 3D reconstructed cloud of points models were then analysed using Matlab v6.1. A series of mathematical functions were created, which separated the *x, y, z* coordinate data from the Cartesian plane into four separate front, back, right, and left planes. Visibility assessment planes were created to analyse the smaller visibility squares (0.5 m x 0.5 m), which were used for the comparison of the LS and CS data. The visibility squares were

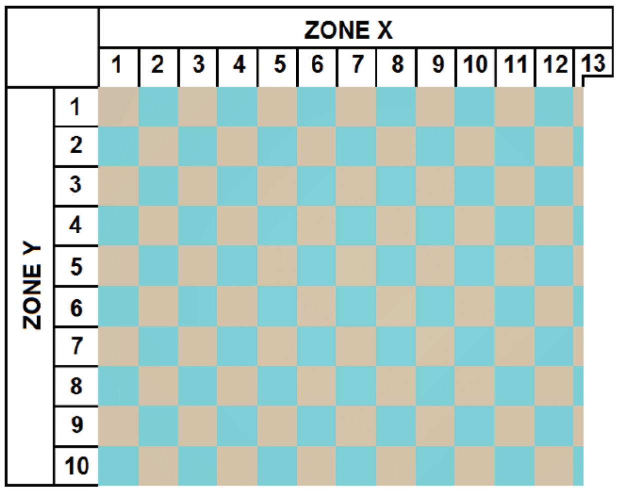

Figure 4—Visibility squares orientation in the front/back visibility planes

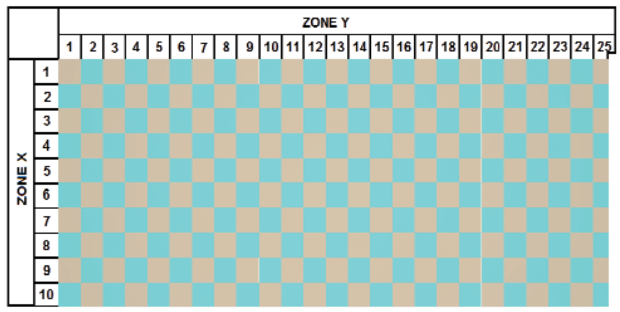

Figure 5—Visibility squares orientation in the right/left visibility side planes

used to calculate the per cent of visible area in each visibility plane (breakdown of the planes are illustrated in Figures 3 and 4). The per cent of visible area was calculated by summing up the cloud of points data that were located in each visibility square. This value was then divided by the average value of laser points, which were located in squares that were deemed 100 per cent visible by the laser scanner. The end product produced a per cent visible score for each visibility square. This process was repeated for each square to determine an individual visibility score. In addition, an overall per cent value was also obtained for each visibility plane.

Computer simulation data collection and analysis

Data collection for the computer simulation method was performed by using the coverage zone tool in the JACK program to determine LOS from the virtual operator's position. The location between the eyes was selected on the virtual operator as the point of origin; the toolkit was adjusted to a resolution of ten horizontal units and ten vertical units; and the human geometry was ignored to disregard postural changes of the virtual human and treat the eye point as a stationary point as used in the LS method. A per cent visible score of obstructed area was obtained for each visibility square as produced by the coverage zone tool and recorded into a spreadsheet. As outlined in the laser scanning method an overall per cent value was also obtained for each visibility plane.

Comparison of LS and CS data

The values obtained from each visibility square within each visibility plane for both the LS and CS methods were recorded in the same fashion. The per cent difference between each visibility square was calculated. In addition, the cloud of points data was imported into the virtual environment and overlaid with the CS collected data for the purposes of visual comparison. The visual comparisons were performed to identify areas of discrepancy in visible and/or obstructed areas between the two methods.

Results

LOS generated outputs from the LS method (imported into a virtual environment) along with the output from the CS method are illustrated in Figure 6. An overlay technique was used to visually compare the 3D generated plots. Differences are observed in Figure 7, and per cent differences between the two methods are reported in Table I.

The 3D representation was separated into front, back, right and left visibility planes for the LS method and CS method (Figure 8). The per cent difference for the visibility squares within each visibility plane are presented in Table I, (A) front visibility plane, (B) left visibility plane, (C) back visibility plane, and (D) right visibility plane. The values represented in Table I are recorded and displayed as the per cent difference between the computer simulation method and laser scan method for each visibility square for each plane (CS percentage score minus LS percentage score). Hence, a large positive value would denote a large variation between

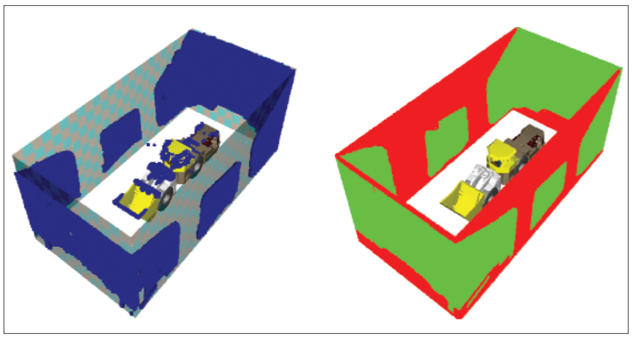

Figure 6—LS method cloud of points output with blue representing visible area (left) in virtual environment and CS method output with green representing visible area and red represents the obstructed area to operator (right)

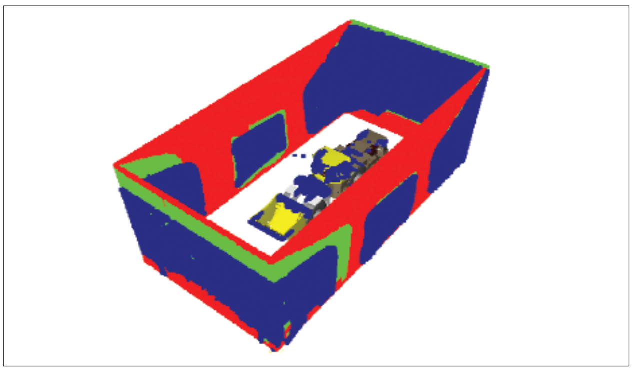

Figure 7—Overlay of LS output (blue area represents visible area) and CS output (green area represents visible area and red represents obstructed area)

Table I

Per cent difference of visible area for the LS and CS assessment methods

(A) Front visibility plane

Zone Y	Zone X 1	2	3	4	5	6	7	8	9	10	11	12	13
10	54.55	54.55	60.33	63.64	63.64	63.64	63.64	63.64	63.64	63.64	63.64	70.25	83.12
9	86.70	86.00	82.60	81.20	78.80	76.20	77.10	81.60	74.50	79.10	71.90	71.70	77.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.90	28.10	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	27.80	35.70	33.10	24.20	30.60	14.60	0.00	14.30	0.00
6	0.00	0.00	12.80	33.50	64.40	64.90	85.40	60.70	25.90	13.60	0.00	36.90	0.00
5	0.00	0.00	0.00	41.40	65.90	76.10	75.20	69.20	35.80	0.00	14.40	72.00	0.00
4	0.00	0.00	24.80	47.30	61.00	70.30	79.10	59.40	45.50	25.40	0.00	32.40	0.00
3	0.00	0.00	10.87	19.67	29.00	34.24	38.92	41.58	40.97	25.20	0.00	26.70	0.00
2	-28.10	-43.72	-2.90	-2.70	0.00	0.00	0.00	0.00	7.09	5.04	-45.61	-11.54	-30.31
1	21.89	-13.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-26.70	0.00	-21.73

(B) Left visibility plane

Zone Y	Zone X 1	2	3	4	5	6	7	8	9	10	11	12	13
10	37.19	4.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	53.18	88.43	49.59	10.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	39.04	41.73	51.76	54.42	38.02	10.74	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	23.62	0.00	0.00	0.00	38.05	94.21	23.14	0.00	-18.53	-37.77	0.80	0.00
6	0.00	20.65	0.00	0.00	0.00	0.00	100.00	45.45	0.00	-100.00	-12.40	-9.92	-19.83
5	0.00	17.68	0.00	36.35	0.00	0.00	100.00	45.45	0.00	-93.39	-2.48	0.00	0.00
4	0.00	27.02	0.00	57.85	0.00	0.00	100.00	45.45	-0.14	-90.91	0.00	0.00	0.00
3	0.00	54.88	0.00	13.62	-4.13	0.00	100.00	42.98	0.00	-90.91	0.00	0.00	0.00
2	-61.98	23.04	0.65	-15.11	-95.04	-44.63	80.17	36.36	0.00	-93.39	-13.22	-19.83	-29.75
1	-2.41	-6.49	-17.01	0.00	-13.72	-23.20	9.92	12.40	0.00	0.00	0.00	0.00	-10.18

Zone Y	Zone X 14	15	16	17	18	19	20	21	22	23	24	25
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.29	-5.15	-6.82
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-19.50	-19.01	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	4.99	-40.50	-1.65	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	-71.07	-13.22	0.00	0.00	0.00	0.00	0.00
6	-30.58	-40.50	-75.21	0.00	4.96	-5.79	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	-42.15	0.00	1.65	-7.44	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	-35.54	0.00	0.00	-18.18	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	-27.27	0.00	0.00	-28.93	0.00	0.00	0.00	0.00	0.00	0.00
2	-39.67	-49.59	-71.07	0.00	0.00	-51.24	-2.48	0.00	0.00	0.00	0.00	0.00
1	-0.71	0.00	0.00	0.00	0.00	0.00	14.88	31.83	-16.68	-20.86	-5.37	-27.68

(C) Back visibility plane

Zone Y	Zone X 1	2	3	4	5	6	7	8	9	10	11	12	13
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	12.68	8.57	9.82	7.53	0.00	0.00	0.00	0.00
2	0.00	0.00	9.05	-5.43	29.31	1.65	0.00	0.00	3.31	18.32	9.67	-1.07	0.00
1	0.30	31.62	8.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	-24.30

(D) Right visibility plane

Zone Y	Zone X 1	2	3	4	5	6	7	8	9	10	11	12	13
10	72.73	42.15	11.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	53.10	100.00	95.04	57.85	6.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	64.60	60.20	70.10	49.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	49.50	33.90	19.50	-27.27	-64.50	0.00	0.00	0.00	8.26	0.83	11.57	14.05
6	0.00	51.50	32.10	16.10	-20.66	-100.00	-1.20	0.00	0.00	30.62	-27.27	-23.14	0.00
5	19.40	43.70	26.30	58.60	-18.18	-100.00	-5.30	0.00	0.00	15.15	0.00	0.00	0.00
4	0.00	42.70	23.10	61.90	-18.18	-100.00	-9.10	0.00	0.00	54.35	0.00	0.00	0.00
3	0.00	44.40	25.20	40.40	-9.92	-100.00	-7.30	0.00	0.00	54.55	0.00	0.00	0.00
2	-52.89	6.84	8.31	39.77	-9.09	-100.00	-1.50	0.00	0.00	8.01	0.00	0.00	0.00
1	23.46	-13.59	-1.60	4.81	-4.94	-22.30	-0.20	0.00	0.00	25.38	59.56	54.55	38.02

Zone Y	Zone X 14	15	16	17	18	19	20	21	22	23	24	25
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.65	20.40	0.02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.65	43.45	15.90	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.28	-25.20	-8.26	16.40	0.00	0.00
7	2.48	0.00	0.00	0.00	0.00	-48.20	-41.32	0.00	0.00	0.00	0.00	0.00
6	-7.44	-21.49	-57.85	0.00	0.00	-100.00	-22.31	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	-27.27	0.00	0.00	-100.00	-32.23	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	-19.83	0.00	0.00	-100.00	-42.15	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	-14.05	0.00	0.00	-83.30	-52.07	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	-11.57	0.00	0.00	-21.40	-63.64	0.00	0.00	0.00	0.00	0.00
1	50.41	56.20	22.31	0.00	0.00	5.79	28.60	29.65	5.63	19.03	32.83	38.81

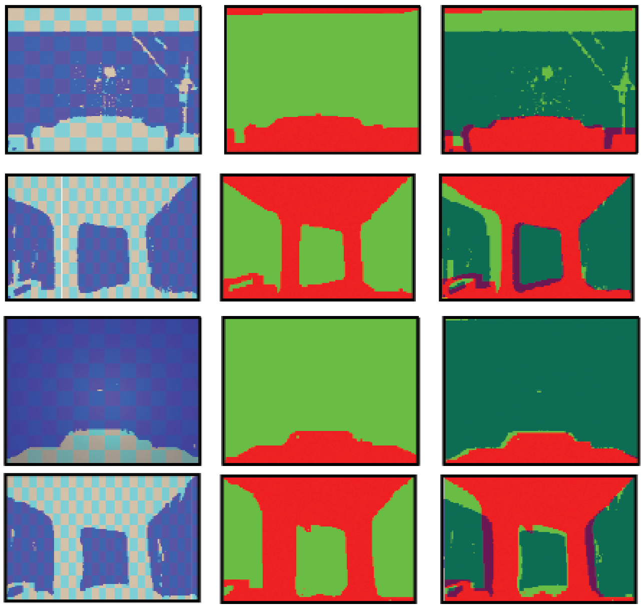

Figure 8—Illustration of LS output (blue area—visible to operator), CS output (green area—visible to operator, red area—obstructed to operator) and overlap (purple area—LS determined the area to be visible and CS determined the area to be obstructed) for each plane from within the LHD cabin: (a) Front visibility plane (b) Left visibility plane (c) Back visibility plane and (d) Right visibility plane. Images on the left were generated with the LS, images in the middle column were generated with CS and the right column shows the overlay between the two methods

Table II

Overall per cent difference for individual visibility planes

Visibility plane	Laser scan	Per cent visible (%)		
		Computer simulation	Difference	Adjusted difference
Front	50.42	77.09	26.68	15.49
Back	85.48	86.41	0.9	0.9
Right	45.54	47.07	1.53	1.53
Left	50.22	50.18	-0.04	-0.04

the two assessment methods where the computer simulation method reported a visible area and the LS method reported an obstruction. Likewise, a low value or near zero percentage score would denote little variation between the CS and LS output (i.e. CS reports slightly better visible area than reported by the LS method). A per cent score of zero would denote that CS and LS methods are reporting the same values for that specific area. A zero or low positive or negative value indicated a good correlation and large positive or negative values indicates a large variation. The overall results for the visibility difference for each individual visibility plane are displayed in Table II. Table II presents an adjusted difference for the front plane. This was performed where there was a lack of recorded data for the laser scanning method (Figure 8a). The adjusted difference was determined by removing the top section of the computer simulation to eliminate the missing information. In other words, the comparison for the front plane was performed only up to the 4 m point. The strengths and weakness of the LS and CS evaluation methods as performed in this paper are summarized in Table III.

Discussion

In general, the results of the LS method and CS method comparison yielded similar findings in operator LOS as reported in Table I and presented in Figure 8. The results demonstrate that variations do exist between the data collected by the two methods; however, the results are promising and indicate that each method depicts the general shape of the operator visibility profile.

The per cent difference between the CS method compared to the LS method for the back visibility plane was 0.9 per cent, the right visibility plane 1.5 per cent, the left visibility plane -0.04 per cent, and the front visibility plane 26.7 per cent. With the top section variance removed by deleting the first two rows of the front plane, thereby eliminating the error, the total difference between the two LS and CS methods was found to be 15.5 per cent. This difference results in a decrease of 11.2 per cent visible area compared to the 26.7 per cent difference found with the initial assessment.

The discrepancies found between the output methods may be attributed to the methodological set-up of the LS field assessment. Some possible reasons for the differences may be attributed to the laser scanner position being slightly offset from the seat index point (SIP), which may not have been accurately recreated in the CS virtual environment. Similarly, if the laser scanner was not positioned exactly horizontal the laser scan would inaccurately report the data collected[6]. In addition, the vehicle orientation may not have been reproduced in the virtual environment as exactly encountered during the field LS assessment (i.e. the vehicle

Table III

Summary of strengths and weaknesses of the two methods

	Laser scanning method	Computer simulation method
Strengths	• Portable (can be used in field) • Rapid (~1h per scan) • Great for replicating real world in a virtual environment • 2D and 3D representations • Applicable for assessing aftermarket addition/ modifications	• Rapid • Current and prototype models can be evaluated • Potential modifications to vehicle designs can be easily evaluated • Allows the operating environment of the vehicle to be modelled • 2D and 3D representations • Dynamic environment (can account for operator postural changes)
Weaknesses	• Static environment • Expensive • Requires trained individual for operation • Quality of scan depends on environment • Not representative of the mining environment (depends on setting) • Additional lab hours required to produce the output plots	• Expensive (software) • Requires trained individual to perform the assessment • Not suitable for field assessments • Not representative of aftermarket modifications (without CAD model)

articulation during LS might not have been exactly 0 degrees as recreated in the CS method). If a small discrepancy with the orientation of the LHD vehicle in the field compared to the virtual environment exists, this would explain some of the differences in the output between the LS and CS methods.

Laser scanners use time-of-flight technology, which could also account for differences in LS and CS results[7]. This technology requires a relatively smooth reflection surface. Any variations in the walls of the paint bay such as doorframes or hanging objects that may have been captured in the laser scanner cloud of points data may have slightly modified the visible area captured during the field assessment. Variations in vehicle dimensions through manufacturing processes of components between the field LHD (LS) and the CAD LHD (CS) may have also influenced the resultant outputs of the two methods. Additional components fitted to the vehicle (post original CAD model) could include: boom hoses, valve covers, cabin glass seals, as well as after market add-ons such as fire extinguishers, wheel chocks, etc. In this case the equipment was close to the original design and had not been retrofitted yet.

Conclusions

Manufacturers of LHD vehicles are continually working to improve LOS for their vehicles by incorporating additional windows to the current cabin design and relocating components such as light brackets and hoses, in addition to rounding vehicle corners. However, the industry is lacking a 3D method for LOS evaluation, which can be easily used in field applications or with CAD models. A 3D evaluation method would allow manufacturers to locate and select vehicle components for maximum operator LOS and it would enable health and safety professionals within mining companies to evaluate LOS from existing vehicles in order to identify retrofit modifications or changes to mine layouts. An accurate LOS assessment method would also allow for an informed vehicle selection process for specific mining environment areas, in addition to complementing mine planning and layout strategies while developing mine infrastructure such as designated pedestrian walkways. The comparison of the LS and CS method illustrated that both methods are capable of visually displaying operator LOS issues. The LS output demonstrated accurate depictions of the general shape of the LOS outputs produced from the CS output. From these findings two independent visibility assessment techniques have been calibrated against each other.

Future recommendations include the collection of a detailed set-up of the laser scan method for accurate replication in the virtual computer simulation environment. Future testing could also examine different size LHD vehicles and conduct field testing in different environments.

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