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Journal of **Safety, Health & Environmental Research**

Mission: The mission of the *Journal of Safety, Health and Environmental Research* (JSHER) is to peer review theoretical and empirical manuscripts, reviews and editorials devoted to a wide variety of OSH issues and practices.

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- include a separate document indicating the title, coauthors and the person to whom correspondence should be directed, including that person's name, title, employer, phone number, fax number and e-mail address, and a short (50-word) bio of each author indicating at least the author's current position, highest degrees earned and professional certifications earned;
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- include a reference section at the end of the manuscript, using APA style to cite and document sources;
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Editorial

This is my first year to serve as the editor for the *Journal of Safety, Health and Environmental Research* (JSHER). It is with my greatest pleasure to summarize three remarkable articles in the 2016 fall issue.

The first article, "Evaluating the Use of Stretchers in Two Mobile Refuge Alternatives," by Heberger and Pollard at National Institute for Occupational Safety and Health (NIOSH), focuses on the use of stretchers in mobile refuge alternatives. In a mine emergency, a miner may have to rely on others for transportation into the mobile refuge alternative (RA) while on a stretcher. This study evaluated the time required to move three types of stretchers into two commercially available RAs. The splint stretcher had the longest average time to move into each RA as compared to the backboard and soft stretcher. This increase was mostly due to the increased time requirements for getting the splint stretcher into the airlock. The authors found for all stretchers, it took approximately two to three times longer to enter the inflatable tent-type RA compared to the rigid steel RA. This study can benefit mining companies and manufacturers of inflatable RAs.

In the second article, "Perception of Occupational Risk by Volunteers and Paid Construction Workers," Moayed and Langsdale designed a cross-sectional study and an online survey to study occupational risk perception. The authors collected 476 responders from employees of a not-for-profit organization in the residential construction sector. A set of 2-way and 3-way contingency tables were created. The final results of Chi-square/Fisher Exact tests showed that volunteers' ranked their occupational risk lower than the paid workers, and that they had lower scores in general safety knowledge and safety climate evaluation compared to paid workers. Major confounding variables were gender, education, previous work-related injury and safety training. There were indications that volunteers and paid workers think differently in regard to their occupational risk and the safety climate, which can lead to disproportionate injury rates.

For the third article, "Forklift Operator Visibility Evaluation in a Manufacturing Environment," Shen and Marks evaluate the visibility of an equipment operator in a manufacturing environment. They conducted a series of experiments to simulate typical movements and actions of a forklift in a manufacturing plant. The test bed was assessed through laser scanning to identify areas not visible to the forklift operator. Point clouds of the test bed were generated and analyzed to identify nonvisibility areas for forklift operators. This research provided scientific evaluation data of operator visibility as well as a framework for measuring operator visibility in manufacturing work environments. Results of the research can be implemented to better understand causes of struck-by incidents as well as potentially mitigate visibility concerns in the manufacturing industry.

I hope that you enjoy these articles. As always, I look forward to hearing from you and welcome your submission of manuscripts to JSHER.

Sincerely,

Sam Wang, Ph.D., P.E., CSP
Managing Editor, JSHER

Acknowledgment of Reviewers

The *Journal of Safety, Health and Environmental Research* gratefully acknowledges the following individuals for their time and effort as manuscript reviewers from Sept. 1, 2015, to July 31, 2016. Their assistance in raising the standard of the manuscripts published is immense and greatly appreciated. Although the members of the Editorial Board (names are italicized) generally review more manuscripts than others (and provide much additional support), most reviews are handled by ad hoc reviewers, chosen for their unique expertise on the topics under consideration.

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Evaluating the Use of Stretchers in Two Mobile Refuge Alternatives

John R. Heberger and Jonisha P. Pollard

Abstract

In a mine emergency where refuge is necessary, miners may sustain injuries that will render them unable to walk or crawl. In this situation, a miner may have to rely on others for transportation into the mobile refuge alternative (RA) while on a stretcher. Since requirements for mine first-aid stations were developed before RAs, stretchers should be evaluated to determine whether they are usable in an RA and within the physical capabilities of miners in a refuge. The size of the RA airlock is a concern, as it has not been determined if current airlocks will accommodate a miner on a stretcher. This study evaluated the time required to move three types of stretchers into two commercially available RAs. The splint stretcher had the longest average time to move into each RA as compared to the backboard and soft stretcher. This increase was mostly due to the increased time requirements for getting the splint stretcher into the airlock. For all stretchers, it took approximately two to three times longer to enter the inflatable tent-type RA compared to the rigid steel RA. Mining companies should consider how well their current first-aid implements work with their RAs and manufacturers of inflatable RAs should maximize the size of the outer doors leading into the airlock to allow an easier entry for stretchers.

Keywords
Refuge alternative, stretcher, backboard, first aid

In a mine emergency that would necessitate taking refuge in a mobile refuge alternative (RA), it is possible that some miners may sustain injuries which would require them to rely on others for transportation into the RA while on a stretcher. Therefore, stretchers used in underground coal mine should be designed such that they are within the physical capabilities of the miners assisting the injured miner into the refuge. This article reviews the effectiveness of assisting a simulated injured miner strapped to three commonly used stretchers into two commercially available refuge alternatives by analyzing the time required to enter each RA.

Background & MSHA Standards

Section 2 of the Mine Improvement and New Emergency Response Act (MINER Act) of 2006 (Public Law 109-236) (MSHA, 2008) requires that underground coal operators include refuge alternatives in their emergency response plan. RA requirements are stipulated in the mandatory mine safety standards promulgated by MSHA. The Code of Federal Regulations (30 CFR 75.1713-7) requires that a stretcher and broken-back board must be included in every underground coal mine first-aid kit with each kit located no more than 500 ft away from the working faces. These provisions ensure that in the case that miners need to transport an injured miner out of the mine, they can do so in the most efficient manner possible.

Title 30 CFR 7.505(a)(3)(ii) requires that RAs include an airlock (purge area of a RA) that isolates the interior space from the mine atmosphere and that is designed to accommodate a stretcher without compromising its function (30 CFR 7.505). However, the standard does not specifically state that the airlock must be large enough to accommodate a stretcher while the outside door is closed and the inside door is open, which is a necessary condition in order to bring the injured miner into the refuge alternative through an airlock (MSHA, 2008). MSHA requires at least 15 sq. ft of floor space and 30 to 60 cubic ft of unrestricted volume in a RA (a range is given here because the recommended volume depends on the height of the mine) per person (30 CFR 7.505). The size of the airlock is of particular concern, as it has yet to be determined whether current RA designs will accommodate a miner on a stretcher.

Requirements for mine first-aid stations were developed before RAs were implemented as a safe location for miners to take shelter and wait to be rescued when escape is not possible. During this time, the primary goals of first-aid stations were to provide first aid, stabilize the spine and transport the miner out of the mine. With the addition of RAs in underground coal mines, there could be a need to transport an injured miner into the RA, which is a very different process from transporting them out of the mine. RA designs should be evaluated to ensure that they will allow miners to easily transport an injured miner on a stretcher

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into the airlock, complete the purging process, and move into the main living area.

Stretchers & Confined Spaces

Just as a miner carries another miner on a stretcher, paramedics experience similar situations when positioning an injured person on a stretcher in a confined or restricted space (Ferreira & Hignett, 2005). It is actually quite common that inadequate space in stairwells and narrow elevators in apartment buildings contribute to the delay of patient transport on a stretcher (Becker, et al., 1991; Lateef & Anatharaman, 2000; Morrison, et al., 2005). Underground coal miners in low seam mines may have an additional difficulty of needing to crawl on their knees to traverse the mine.

While the space limitations of a refuge alternative may not allow for the ideal spacing, at minimum, the RA should accommodate a miner lying on a regular-sized stretcher or backboard, and two assisting miners, without compromising the overall air quality in the airlock. This means that all three miners should be able to enter the RA airlock, close the entry door, purge the airlock, open the door to the main living area, and then move into the main living area.

Methods

Materials

Simulated Injured Miner

Three 35-lb fiberglass articulated joint male manikins (Figure 1) were used as the simulated injured miners (SIMs). The SIMs were 73 in. tall with a 38-in. chest, 29-in. waist and 38-in. hips. The SIMs were widest at the shoulders, measuring 21 in. wide. When lying flat on the ground, the heads were the highest, measuring 15 in. high. The SIMs were clothed in disposable coveralls. The SIMs were meant to represent the volume of a person, not the weight. The study participants were not actual underground coal miners and measuring the participants' strength by using 95th percentile male weighted manikins would not have yielded any valuable information. The outcome of interest was how well the SIMs fit into the RAs (which had very different airlock designs) when strapped to differing stretchers.

Stretchers

A full-length soft stretcher (Figure 1A) was utilized in this study. A stretcher is part of the standard first-aid kit as required by MSHA (30 CFR 75.1713-7). This stretcher was 80 in. long x 26 in. wide x 1/16-in. thick. It weighed 4 lb and could support up to 600 lb.

A full-length backboard (Figure 1B) was utilized in this study. It was 72 in. long x 16 in. wide x 1 in. thick. It could support up to 600 lb and weighed 16 lb. A full-length backboard is part of the standard mine first-aid kit as required by MSHA (30 CFR 75.1713-7).

Instead of having both a stretcher and backboard in the first-aid kit, MSHA allows the use of a splint stretcher (Figure 1C) to take the place of a stretcher and backboard (30 CFR 75.1713-7). The splint stretcher used weighed 30 lb, was 84 in. long x 23.5 in. wide x 7.5 in. high. It had a load capacity of 2,500 lb.

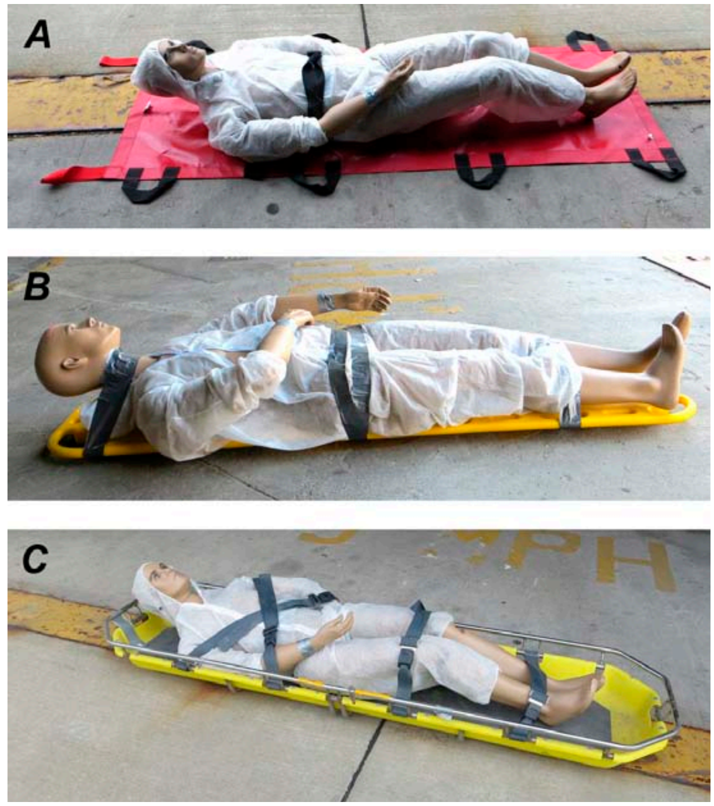

Figure 1: The simulated injured miners used were a 35-lb fiberglass articulated joint male manikin.
A) simulated injured miner on the soft stretcher;
B) on the full-length backboard secured with tape;
C) on the full length splint stretcher secured with the belts.

Refuge Alternatives

Two commercially available mobile refuge alternatives were used for this study: an inflatable tent-type RA and a rigid steel RA. The inflatable tent-type mobile RA was built by A.L. Lee Corp. It had a seven-person capacity airlock that was part of a 35-person capacity main living area. It was specifically designed for use in underground coal mines. Figure 2A (p. 300) shows that the airlock dimensions were 84 in. long x 40 in. wide x 30 in. high. The entry door was 24 in. wide x 25.5 in. high. The interior volume was 57 cubic ft. The entire airlock was surrounded by hard steel (a large steel box housed the uninflated main living area) on all sides except for the side which had the door to the main living area. This door was an inverted "U"-shaped flap that unzipped to allow access to the main area. This door was approximately 30 in. wide.

The rigid steel mobile RA was a hard-walled, eight-person capacity refuge alternative, with an eight-person capacity airlock, built by Jack Kennedy Metal Products and Buildings Inc. The interior airlock was 61.5 in. high x 89.5 in. long and had two different widths. At the widest, it was 52 in. wide while the narrowest part was 46 in. wide. The main front airlock door was 30.125 in. wide x 43.875 in. high. The interior door was 30.25 in. wide x 45.25 in. high. Interior volume was 153.5 cubic ft. Figure 2B (p. 300) provides a detailed drawing of the airlock.

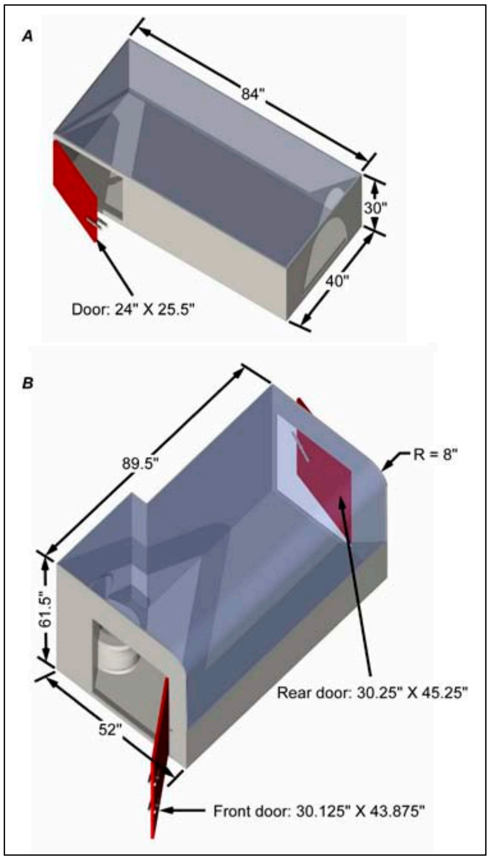

Figure 2: The dimensions of the A) inflatable tent-type and B) rigid steel mobile refuge alternative airlocks.

Participants

A convenience sample of 15 participants from the National Institute for Occupational Safety and Health (NIOSH), located at the Bruceton, PA, campus, responded to recruitment solicitations. Ten male participants had an average ± standard deviation of age, height and weight of 28 ± 5.5 years, 70 ± 2.5 in., and 205 ± 39.1 lb, respectively; as well as five female participants with an average ± standard deviation of age, height and weight of 29 ± 6.0 years, 64 ± 4.0 in. and 149 ± 28.0 lb, respectively.

The participants were generally in good health and physical condition. Males over age 45 or females over age 55 and any employee who reported pregnancy, cardiovascular disease, respiratory disease, musculoskeletal injuries, metabolic disease, claustrophobia, or who had more than one risk factor for cardiovascular disease (family history, current smoker, high blood pressure, obesity, sedentary lifestyle) were not allowed to participate. Before participating, each participant read and signed an informed consent form approved by the NIOSH Internal Review Board. All participants gave their consent to perform their task after being made aware of the study requirements and potential risks.

Procedures

A fully within-subjects experimental design was employed to investigate the effect of stretcher type and RA design on the time required to transport a SIM into an RA. The participants worked with the same researcher in teams of two and were instructed to move a SIM strapped to three types of stretchers from outside of the RA to the inside of the RA. Participants tested both an inflatable tent-type mobile RA and a rigid steel mobile RA with each type of stretcher in a fully randomized order. Stretchers were placed 4 ft away from and perpendicular to the RA entry door.

Participants (with the assistance of one researcher) first had to move the SIM from the outside of the RA and into the airlock. They then closed the outer door. Participants then were instructed to open the inner RA door and enter the main living area of the RA with the SIM. Once the SIM was inside the main living area, the participant then closed the inner door.

Times were measured with a stopwatch and recorded by another researcher. Time started when the participant signaled s/he was ready by touching the SIM. The first time recorded was after the team entered the airlock with the stretcher and closed the outer door. The second time recorded was after the team entered the main living area with the stretcher and closed the inner door behind them. Timings were recorded separately to determine whether one part of the process took significantly longer than the other.

The study ended when the participant successfully moved the SIM into the main living area of the RA and closed the door, after a 20-minute period had elapsed without being able to get the SIM inside the RA, or if the participant conceded that s/he was not able to move the SIM into the RA. The 20-minute period was selected as regulations dictate that purging of the airlock must be complete within 20 minutes of miners beginning to enter the RA [30 CFR 7.508(a)(1)].

Data Analysis Plan

Completion times for all stretchers and refuge alternative types were imported into statistical analysis software for further analysis (SPSS Statistics for Windows 19.0, IBM Corp., Armonk, NY). Data were analyzed using two-way repeated measures ANOVA and adjustments were used when the sphericity assumption was violated.

Results

All participants successfully moved the SIM into the main living area of the RA. No participant gave up or took longer than 20 minutes to maneuver the stretchers into the RAs. The results are presented in three sections. The first looks at the overall process of moving a stretcher from outside of the RA, through the airlock and into the main living area of the RA. The next two sections break the process down into two steps: 1) moving from outside the RA to inside of the airlock; 2) moving from the airlock to the main living area.

Moving Stretcher From Outside RA, Into Airlock & Into Main Living Area of RA

Mauchly's sphericity test indicates that the assumption of sphericity is met for stretcher type, and the interaction between RA and stretcher, so there was no need to correct the F-ratio. ANOVA summaries are shown in Table 1.

There was a significant main effect of RA type on total time to move from outside of the RA, into the purge area, and then into the main living area, $F(1,14) = 159.52$, $p < .001$, and a partial $\eta^2 = 0.92$, which is a large effect size. It took significantly more time to move into the inflatable RA ($\bar{x} = 50.6$ seconds) than it did the steel RA ($\bar{x} = 124.0$ seconds). There was also a significant main effect of type of stretcher used, $F(2,28) = 57.52$, $p < .001$ with a large effect size of Partial $\eta^2 = 0.80$. The splint stretcher took significantly longer time to move.

Most importantly, there was a significant interaction effect between the type of RA and the type of stretcher used, $F(2,28) = 39.24$, $p < .001$, partial $\eta^2 = 0.74$. This indicates that the type of stretcher used had different effects on the time to move into the RA depending on the type of RA. To break down interactions, contrasts were performed comparing the inflatable RA to the steel RA while the soft and backboard stretchers were compared with the baseline splint stretcher. These contrasts revealed significant interactions when comparing inflatable RAs to steel RAs both for backboards to splint stretchers, $F(1,14) = 63.85$, $p < .001$, partial $\eta^2 = 0.82$; and for comparing soft stretchers to splint stretchers, $F(1,14) = 52.55$, $p < .001$, partial $\eta^2 = 0.79$. Both effect sizes are large. Looking at the interaction graph (Figure 3), these effects reflect that the splint stretcher took significantly more time to enter the inflatable ($\bar{x} = 165.0$ seconds) than the steel RA ($\bar{x} = 56.4$ seconds), and the increase in time due to using a splint stretcher in an inflatable RA is significantly higher than using a backboard ($\bar{x} = 104.8$ seconds) or soft stretcher ($\bar{x} = 102.3$ seconds).

Source	Sum of Squares	df	Mean Square	F	p	Partial Eta Squared
Type of RA	121513.9	1	121513.9	159.5	0.000*	0.919
Error (RA)	10664.6	14	761.8			
Type of Stretcher	24841.9	2	12420.9	57.5	0.000*	0.804
Error (Stretcher)	6046.1	28	215.9			
RA by Stretcher	13890.5	2	6945.2	39.2	0.000*	0.737
Error (RA by Stretcher)	4955.5	28	177			
Contrasts Inflatable RA vs Steel RA						
Backboard vs Splint Stretcher	43524.3	1	43524.3	63.8	0.000*	0.820
Error (Backboard vs Splint Stretcher)	9543.7	14	681.7			
Soft vs. Splint Stretcher	39732.3	1	39732.3	52.5	0.000*	0.790
Error (Soft vs. Splint Stretcher)	10585.7	14	756.1			

Table 1: Total time to move from outside of RA, into airlock and inside main living area; ANOVA summary table. Statistical significance at $\alpha = 0.05$ is indicated by *.

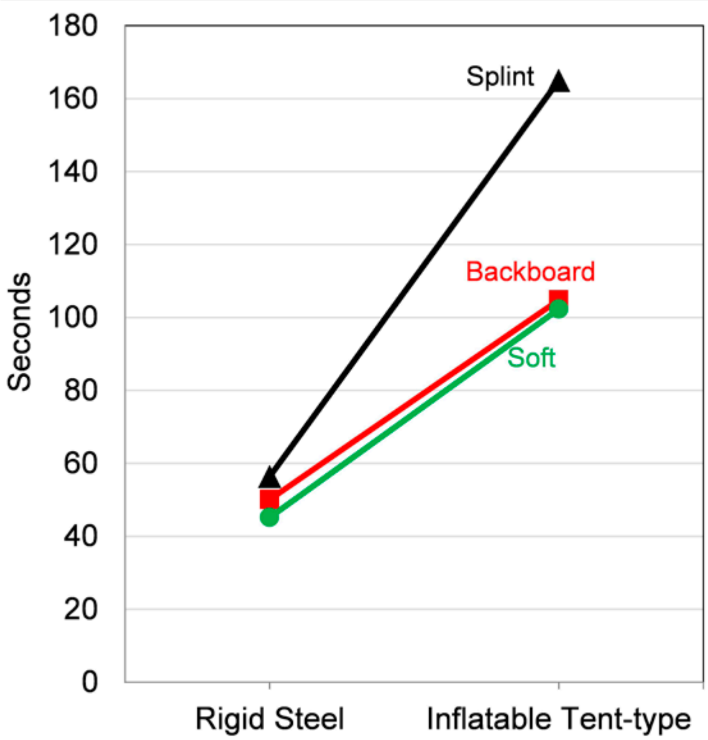

Figure 3: Average total time (rounded to whole seconds) to move the stretcher with SIM from outside of the RA into the main living area of each RA. The interaction graph shows that even though it always took longer to enter the inflatable RA, it took much longer to get the splint stretcher in the inflatable RA.

Moving Stretcher From Outside RA & Into Airlock

Mauchly's test indicated that the assumption of sphericity had been violated for the main effects of stretcher type, $\chi^2(2) = 16.12$, $p < .001$, and the interaction between RA and stretcher, $\chi^2(2) = 6.00$, $p = .05$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser adjustment. ANOVA summaries are shown in Table 2 (p. 302).

There was a significant main effect of RA type on the time to enter the purge area, $F(1,14) = 96.44$, $p < .001$. Partial $\eta^2 = .873$ indicated a large effect size. It took significantly more time to enter the inflatable RA ($\bar{x} = 63.8$ seconds) than it did to enter the steel RA ($\bar{x} = 28.4$ seconds). There was also a significant main effect of the type of stretcher used on the time to enter the purge area, $F(1.17, 16.37) = 58.36$, $p < .001$ with the splint stretcher significantly taking the most time.

More importantly, there was a significant interaction effect between the type of RA and the type of stretcher used, $F(1.46,20.44) = 47.8$, $p < .001$, partial $\eta^2 = 0.77$. This indicates that stretcher type had different effects on the time to enter the purge area from the outside depending on which type of RA was used. To break down this interaction, contrasts were performed comparing the inflatable RA to the steel RA and all stretcher types were compared to the baseline splint stretcher. These contrasts revealed significant interactions when comparing inflatable RAs to steel RAs both for backboards to splint stretchers, $F(1,14) = 60.86$, $p < .001$, partial $\eta^2 = .81$, and for soft stretchers to splint stretchers, $F(1,14) = 51.76$, $p < .001$, partial $\eta^2 = .79$. Both have large effect sizes. Looking at the interaction graph (Figure 4, p. 302), these effects reflect that the splint stretcher took significantly longer to enter the inflatable RA airlock ($\bar{x} = 94.9$ seconds) than the steel RA airlock ($\bar{x} = 32.1$ seconds), and the increase in time due to using a splint stretcher in an inflatable RA is significantly higher than when using a backboard ($\bar{x} = 49.9$ seconds) or soft stretcher ($\bar{x} = 46.6$ seconds).

Source	Sum of Squares	df	Mean Square	F	p	Partial Eta Squared
RA type	28125.3	1	28125.3	96.4	0.000*	0.873
Error (RA)	4082.8	14	291.6			
Stretcher type	13703.6	1.2	11721.3	58.4	0.000*	0.807
Error (Stretcher)	3287.4	16.4	200.8			
RA by Stretcher	8496.3	1.5	5819.5	47.8	0.000*	0.773
Error (RA by Stretcher)	2488	20.4	121.7			
Contrasts: Inflatable RA vs Steel RA						
Backboard vs Splint Stretcher	23920.1	1	23920.1	60.9	0.000*	0.813
Error (Backboard vs Splint Stretcher)	5502.9	14	393.1			
Soft vs. Splint Stretcher	26966.4	1	26966.4	51.8	0.000*	0.787
Error (Soft vs. Splint Stretcher)	7293.6	14	521			

Table 2: Total time to move from outside of RA into airlock: ANOVA summary table. Statistical significance at $\alpha = 0.05$ is indicated by *.

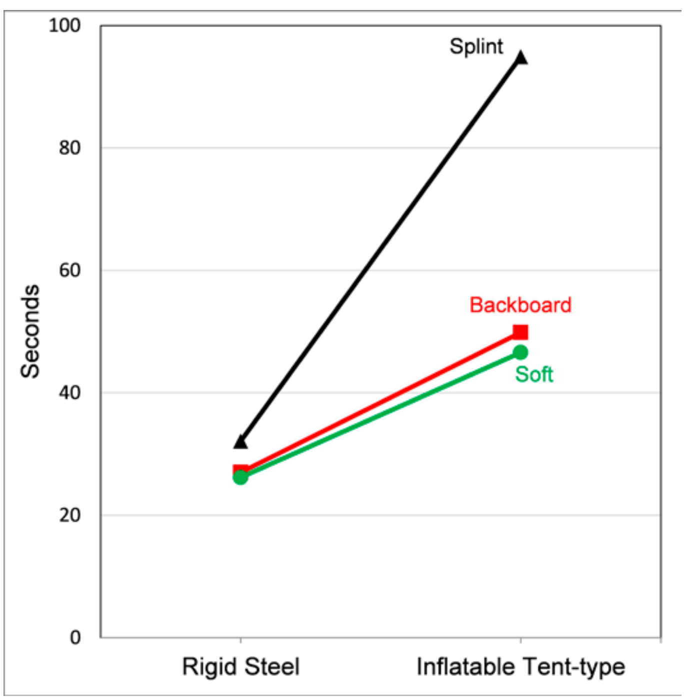

Figure 4: Average total time (rounded to whole seconds) to move the stretcher with SIM from outside of the RA into the RA airlock. The interaction graph shows that even though it always took longer to enter the inflatable RA, it took much longer to get the splint stretcher into the purge area of the inflatable RA.

Moving Stretcher From Airlock & Into Main Living Area of RA

Mauchly's sphericity test indicates that the assumption of sphericity is met, so there is no need to correct the F-ratio. ANOVA summaries are shown in Table 3. There was a significant main effect of type of RA on time to move from the purge area to the main living area, $F(1,14) = 127.39$, $p < .001$, partial $\eta^2 = .90$, which is a large effect size. It took significantly more time to move from the airlock to the main living area of the inflatable RA ($\bar{x} = 60.6$ seconds) than it did in the steel RA ($\bar{x} = 22.3$ seconds), as shown in Figure 5.

There was also a significant main effect of type of stretcher used on the time to move from the airlock to main area, $F(2,28) = 11.01$, $p < .001$. Contrasts revealed $F(1,14) = 12.86$, $p = .003$, partial $\eta^2 = .48$, that the splint stretcher ($\bar{x} = 47.6$ seconds) took significantly more time to move into the main living area of the RA than the backboard ($\bar{x} = 39.3$ seconds). The splint stretcher also took significantly more time to move into the main living area of the RA than the soft stretcher ($\bar{x} = 37.5$ seconds), $F(1,14) = 19.87$, $p = .001$, partial $\eta^2 = .59$.

There was not a significant interaction between type of RA and type of stretcher used (Figure 5), $F(2,28) = 2.91$, $p = .07$, partial $\eta^2 = .17$. This indicates that stretcher type did not have different effects on the time to move from the airlock to the main living area, depending on which type of RA was used.

Discussion

The splint stretcher always took the longest time to move into each RA. Moving the splint stretcher from outside of the RA and into the airlock was the driving force behind the increased time in the overall process of moving a stretcher from outside of the RA and into the main living area of the RA.

Overall, it does not matter what type of stretcher was tested—there is still an increased time difference when using the inflatable tent-type RA compared to the rigid steel RA. It took approximately two to three times longer to enter the inflatable tent-type RA with a stretcher compared to the rigid steel RA.

Splint Stretcher

The results showed that the splint stretcher was more difficult to move into the RA than the other stretchers. Since the individual characteristics of the stretchers were not tested, looking at the stretcher measurements can shed some light on why the splint stretcher took the longest time to move. Table 4 (p. 304) shows that the splint stretcher was the longest, highest and heaviest stretcher used in the study. The soft stretcher was widest and almost as long, but the flexibility of the soft stretcher allowed it to conform to the size of the SIM. It is likely that the rigidity as well as its length, width and height contributed to the difficulty in fitting the splint stretcher into the airlocks.

American Society for Testing and Materials (ASTM, 2007) standard for spinal immobilization devices does not give dimen-

Source	Sum of Squares	df	Mean Square	F	p	Partial Eta Squared
Type of RA	33100.8	1	33100.8	127.4	0.000*	0.901
Error (RA)	3637.8	14	259.8			
Type of Stretcher	1737.9	2	868.9	11	0.000*	0.440
Error (Stretcher)	2210.8	28	79			
RA by Stretcher	620.4	2	310.2	2.9	0.071	0.172
Error (RA by Stretcher)	2985	28	106.6			
Contrasts (Stretcher Type Only)						
Backboard vs Splint Stretcher	1041.7	1	1041.7	12.9	0.003*	0.479
Error (Backboard vs Splint Stretcher)	1133.8	14	81			
Soft vs. Splint Stretcher	1520.1	1	1520.1	19.9	0.001*	0.587
Error (Soft vs. Splint Stretcher)	1070.9	14	76.5			

Table 3: Total time to move from airlock and into main area of RA: ANOVA summary table. Statistical significance at $\alpha = 0.05$ is indicated by *.

sions, but does specify that a device intended for use with adult patients shall accommodate the 95th percentile adult American male. Centers for Disease Control and Prevention (CDC) reports the 95th percentile for height and weight in adult males of all races and ethnicities age 20 years and older as 74.3 in. and 270.3 lb, respectively (McDowell, et al., 2008). The European standards for heavy-duty stretchers specify that stretchers are to have a length of 1,950 mm (76.8 in.), width of 550 mm (21.7 in.), a maximum height of 300 mm (11.8 in.), and are to withstand a minimum load of 250 kilograms (551 lb) (CEN, 2012). Even though these standards are likely for wheeled stretchers used in ambulances, the splint stretcher is approximately 7 to 10 in. longer than the ASTM and European standards.

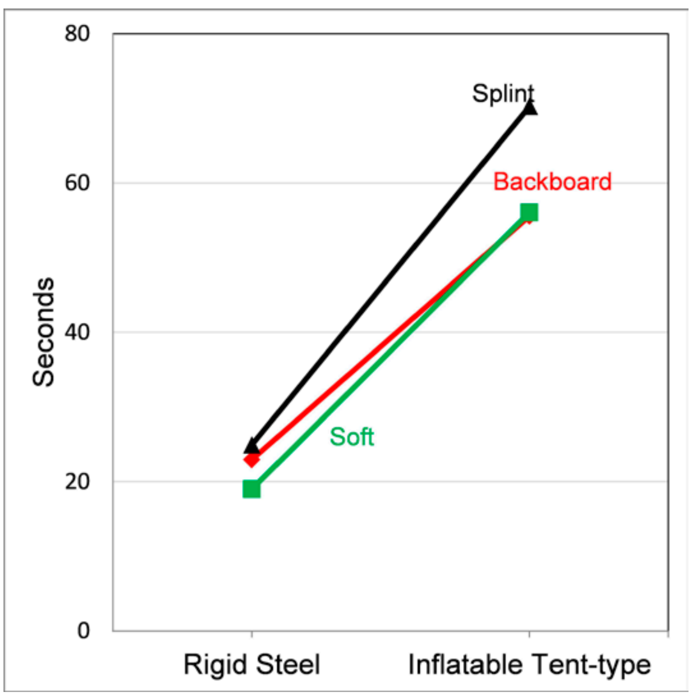

Figure 5: Average total time (in seconds) to move the stretcher with SIM from the airlock into the main living area. The interaction graph shows that the splint stretcher took the longest to move, and there is no significant interaction between RA type and stretcher type.

Airlock Design

It took participants a significantly longer time to move into the airlock of the inflatable RA than to move into the rigid steel airlock. The RAs used in the study had two different-sized airlocks as they were from two different RAs meant for two different types of mining. Therefore, a direct evaluation is not practical, but it is still useful to look at some features of the RAs that may have played a role in the increased time.

The lengths and widths of the RA airlocks were relatively similar (Table 5, p. 304). The main difference in the RAs was their height and therefore volume. The rigid steel RA had twice the height of the inflatable RA; participants had to stoop to enter the rigid steel (Figure 6. p. 305) but had to crawl to enter the inflatable RA (Figure 7. p. 305). This likely contributed to the increase in time because people can stoop-walk more quickly than they can crawl.

The emergency medicine field provides some reasonable guidelines for the dimensions of ambulance truck beds and doors, which must account for a stretcher/backboard in a confined space. The standard dimensions of the patient compartment in ambulances in the U.S., measured from the inside edge of the rear loading doors, must be at least 122 in. long, be at least 60 in. high, and have minimum volumes ranging from 275 to 325 cubic ft. The rear doors of an ambulance should have a minimum width of 44 in. and minimum height of 46 in. The patient compartment must also provide at least 10 in. of space from the edge of the stretcher to the rear loading doors (GSA, 2007). The European standards for loading doors have a width range of 900 mm to 1,050 mm (35.4 in. to 41.3 in.) and a height range of 900 mm to 1,500 mm (35.4 in. to 59.1 in.) depending on the type of ambulance (CEN, 2010). It should be noted that these dimensions also account for one or two emergency medical technicians as well as the patient, and also allow room to perform emergency procedures on the patient.

A feature worth noting is the door dimensions and door locations. Figure 2 (p. 300) shows the layout of the RAs. The rigid steel RA has the doors in line and parallel with each other. The stretchers were able to go straight into the airlocks, then straight into the main living area. The inflatable RA doors were perpendicular to each other. Participants had great difficulty getting the stretchers through the outer door while turning the stretcher 90 degrees in order to get it in line with the longest length of the

	Length (in)	Width (in)	Height (in)	Weight (lbs.)
SIM	72	21	15	35
Soft Stretcher	78.5	26	1/16	4
Splint Stretcher	84	23.5	7.5	30
Backboard	72	16	1	16
ASTM estimate	74.3	-	-	-
European standard	76.8	21.7	11.8	-

Table 4: SIM, stretcher and standards measurements.

airlock and parallel to the inner door to the main living area. The door width of the inflatable tent-type RA was also just enough to slide the splint stretcher through (with only a half-in. clearance), which may have also contributed to the difficulty in getting the splint stretcher into the airlock.

Standards and building codes for elevators also can provide guidance for dimensions of areas through which stretchers should traverse. The International Building Code states that an elevator car shall be of such a size and arrangement to accommodate an ambulance stretcher 24 in. x 84 in. (about the size of the splint stretcher) with not less than 5-in. radius corners (ICC, 2012). ANSI (2009) goes a step further and provides minimum dimensions for elevator cars depending on where the door is located. A door in the center of the elevator car must have a minimum opening of 42 in., and that car should have a minimum length of 80 in. and depth of 54 in. A door located off center of an elevator car must have at least: a door opening width of 36 in., length of 68 in. and depth of 54 in. Figure 8 (p. 306) shows examples of minimum elevator car dimensions as drawn in ANSI A117.1 standard (2009).

The emergency vehicle, building and elevator standards' measurements are generally larger than the dimensions of the RAs. Since underground coal RA airlocks will need to be purged of bad air before the miners can enter the main living area, it would not be beneficial to alter the dimensions of the airlock too much, as increasing the volume of the airlock would mean that the purging system would also likely need to be changed to effectively purge a higher volume of air. Changing the door location or type to allow for easier access into the airlock might be the best option.

Making the main door wider in the inflatable tent-type RA will likely make it much easier to get a stretcher inside, especially when having to turn the stretcher 90 degrees in order to fit into the airlock. Figure 9 (p. 306; NYC Buildings, 2011) shows a 76-in. by 24-in. stretcher fitting into elevators similar in size to the RAs; however, the door widths at 42 and 48 in. is considerably larger than the RA entry doors at 24 and 30.25 in. wide.

	Length (in)	Width (in)	Height (in)	Volume (ft^3)	Entry Door Width (in)	Entry Door Height (in)
Inflatable, Tent-type RA airlock	84	40	30	57	24	25.5
Rigid Steel RA airlock	89.5	46 - 52	61.5	153.5	30.25	45
U.S. ambulance patient compartments	Min 122		Min 60	Min 275-325	Min 44	Min 46
European ambulance standards					35.4 - 41.3	35.4 - 59.1
ANSI elevator center door location	Min 80	Min 54			Min 42	
ANSI elevator off-center door location	Min 68	Min 54			Min 36	
ANSI elevator any door location	Min 54	Min 80			Min 36	
ANSI elevator any door location	Min 60	Min 60			Min 36	

Table 5: Measurements of the RA airlocks, U.S. and European ambulance compartment standards, and ANSI elevator car standards.

Limitations

One limitation to note is that only two types of refuge alternative airlock designs from many designs were tested. Conclusions on rigid steel versus inflatable, tent type are not possible since RA features are confounded with RA type. For example, a steel RA airlock could have the same features and measurements of the inflatable type RA airlock used in this study. There could be rigid steel and tent-type RAs with similar airlock features and dimensions in which we would expect similar outcomes. Door size, door configuration, airlock dimensions, etc., must be considered.

Another limitation is that actual miners were not used. The study participants were researchers or technicians with little or no emergency medical training, and physical labor is not part of their daily tasks. It is also important to note that the SIM was just the average dimensions of a human, not an approximate weight. It would be much more difficult for anyone to move 50th percentile male weighted manikins, which would weigh about 175 lb. The purpose of the SIM was to simulate the size of a miner, and the goal of the study was not to measure strength of the participants. Future studies in this area may consider using miners as the participants and realistic height and weight manikins.

Figure 6: Moving the A) splint stretcher and B) full-length hard backboard stretcher into the rigid steel RA airlock.

Figure 7: Moving the A) splint stretcher and B) full-length hard backboard stretcher into the inflatable RA airlock.

Conclusions

In an emergency mine situation when escape is not possible, getting an injured miner into breathable air will be critical to his/her survival. Many types of stretchers and backboards are available for use. Mining companies should consider how well their current first-aid implements work with their refuge alternatives and ensure the feasibility of getting their stretchers/backboards into the airlock. It should also be noted that having a miner on a stretcher/backboard inside the airlock will decrease the number of miners able to fit in the airlock, thereby further increasing the time and purge air necessary to get all miners into a breathable air environment since the purge compartment needs to be purged for each group that enters. In these life-threatening situations, every second counts. Therefore, stretchers should be used which provide the best support for the injured miner while minimally increasing the time needed to get to breathable air inside of the refuge alternative. Moreover, manufacturers of inflatable refuge alternatives should maximize the size of the outer doors leading into the airlock to allow an easier entry for stretchers.

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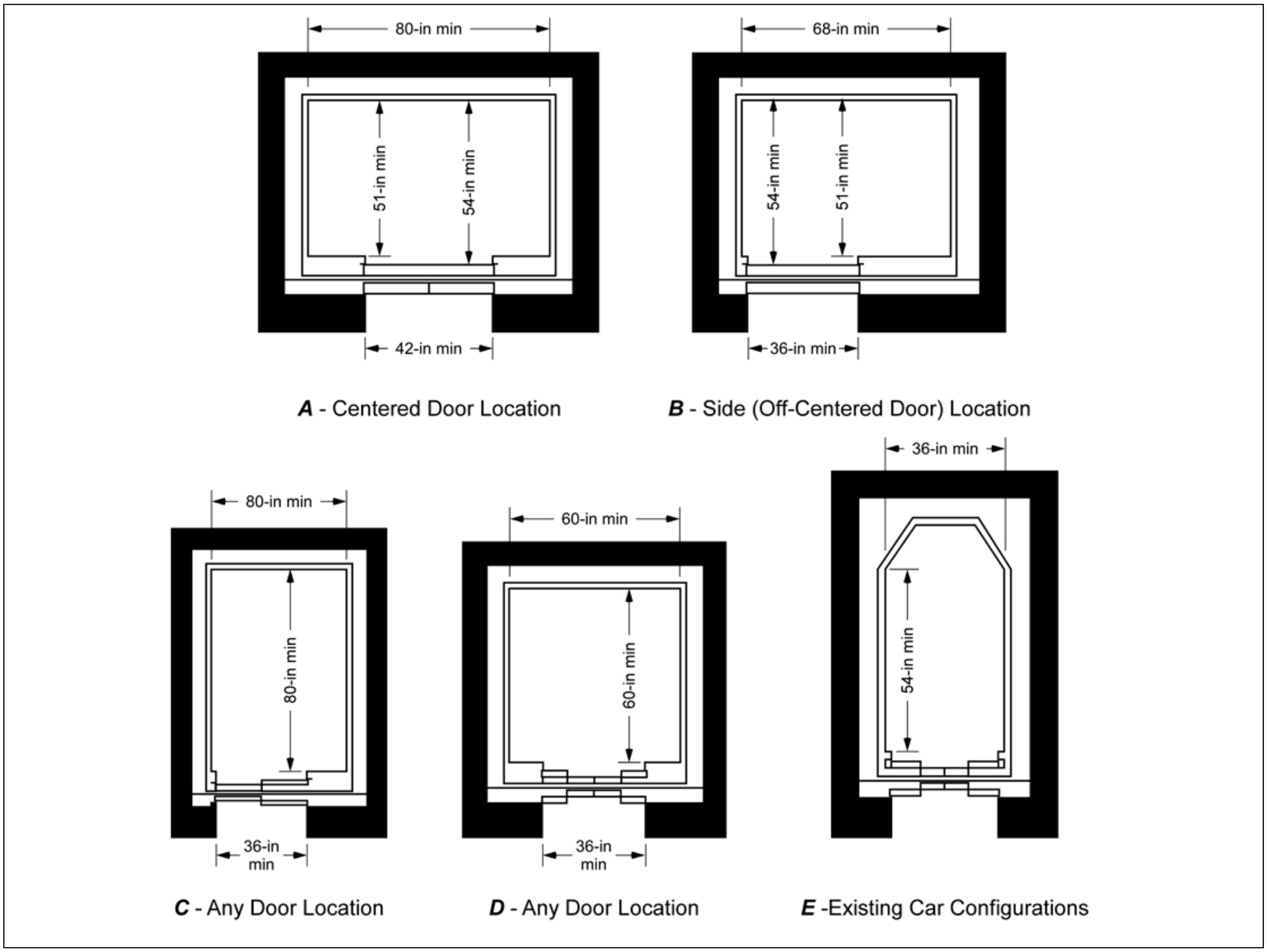

Figure 8: Examples of different configurations and interior elevator car dimensions (adapted from Fig 407.4.1 in ANSI, 2009).

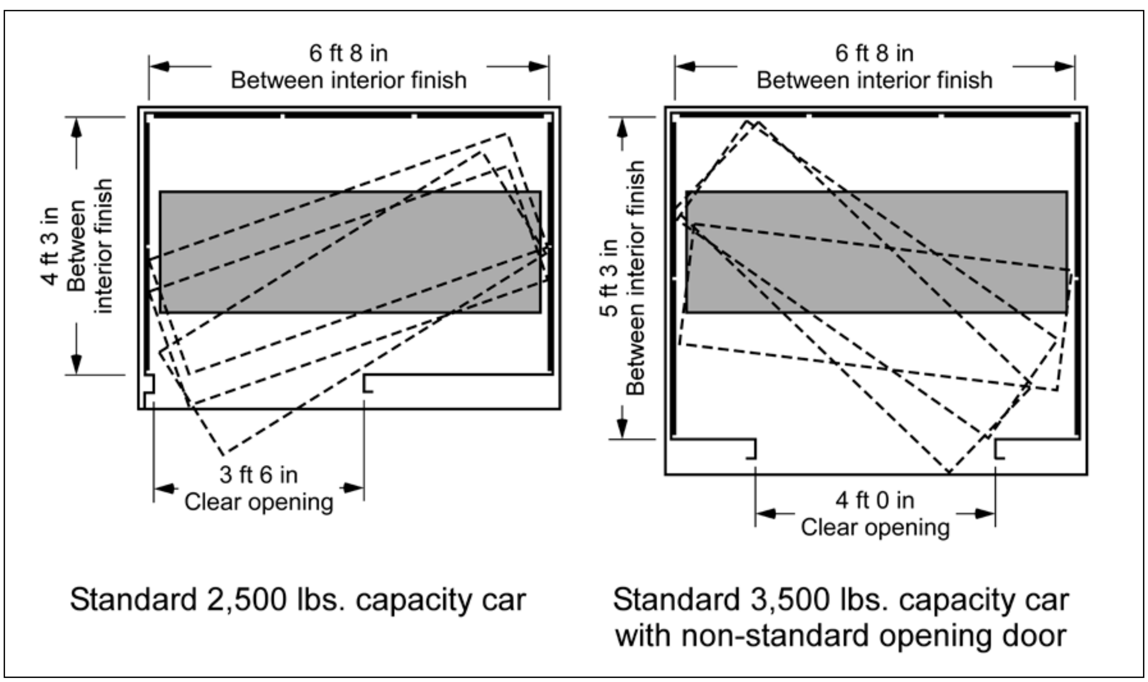

Figure 9: Elevator cars designed to accommodate stretchers. The dashed outline indicates how a 76 in. x 24 in. stretcher can maneuver into an elevator car and the grey area indicates stretcher fitment (adapted from Figure 1 in NYC Buildings Department, 2011).

Perception of Occupational Risk by Volunteers & Paid Construction Workers

Farman A. Moayed and Christopher J. Langsdale

Abstract

Introduction: *Numerous not-for-profit organizations in the U.S. are involved in residential construction and their workforce are more or less partially comprised of volunteer labor. This has become a unique and multidimensional challenge for such organizations to develop a successful and sustainable safety programs for their workforce. Regardless if individuals are paid or volunteer, working on a residential construction site poses serious hazards that may lead to injury, illness and/or fatality.*

Objectives: *To quantify and compare risk perceptions, safety climate perceptions and general safety knowledge among volunteer and paid construction workers in a not-for-profit organization.*

Method: *A cross-sectional study was designed and an online survey was distributed among employees of a not-for-profit organization in the residential construction sector. Respondents (N = 476) completed four sections of the survey: 1) demographic information; 2) perception of occupational risk; 3) safety climate; and 4) safety knowledge. Participants quantified their subjective assessments using five-point Likert scales.*

Results: *A set of 2-way and 3-way contingency tables were created and the results of Chi-square/Fisher Exact tests showed that overall, depending on the type of hazard, volunteers' ranked their occupational risk lower than the paid workers and they had lower scores in general safety knowledge and safety climate evaluation compared to paid workers. Major confounding variables were gender, education, previous work-related injury and safety training.*

Conclusion: *Despite the limitations of this study, there were indications that volunteers and paid workers think differently in regard to their occupational risk and the safety climate of the host organization, which can lead to disproportionate injury rates. Considering the fact that volunteers are not covered by the OSH Act, it is a moral duty of all employers (particularly the not-for-profit organizations) to ensure the safety of their volunteer workforce.*

Keywords
Construction safety, volunteer, not-for-profit, risk perception

The participating not-for-profit organization reliance on volunteer labor to complete its mission (providing decent and affordable housing for all) generates a unique and multidimensional challenge for the organization to maintain site safety. Specifically, the skill level of workers may range daily from none at all to master carpenters; for some volunteers, their first time on a construction site may be their one and only time volunteering with this organization, and each individual volunteer may contribute anywhere from 8 hours to more than 1,000 hours a year.

Regardless if individuals are paid or unpaid, working on a construction site poses serious hazards that may lead to injury, illness and/or fatality. One of the largest not-for-profit organizations in the U.S. (Habitat for Humanity International, HFHI) reports that in the last 10 years it has accounted losses of $17 million in injury, illnesses and fatalities, and more than 50% of these claims were fall-related incidents (HFHI, 2012). According to OSHA (2005), volunteers would not be considered as "employees," therefore, the volunteer workforce in not-for profit organization is without protections and oversight from OSHA.

Furthermore, volunteers are usually required to sign a release and waiver of liability that releases all liability for injury, illness, death or property damage resulting from the activities of their time with any organization before volunteering for their intended organization. Ultimately, not-for-profit organizations usually are not subject to the same legal requirements as private construction companies, yet some of them (such as HFHI) have expressed recognition of a moral obligation to ensure construction safety and build trust within the communities they serve (HFHI, 2012).

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Hazard	Subjectively Evaluated Values by Workers		Objectively Estimated Values by Antonucci *et al.*	
	Potential Injury	Ranked Likelihood of Occurrence	Potential Injury	Ranked Likelihood of Occurrence
Falls	4.0	3.1	5.0	3.7
Vibration	3.3	2.9	4.0	2.5
Splinters	3.4	3.2	4.0	3.0
Wounds	3.7	3.2	4.0	4.5
Heavy Loads	3.4	3.1	4.0	4.5
Noise	3.6	2.9	4.0	3.2
Dust	3.6	2.9	4.5	3.0

Table 1: Side-by-side comparison of potential injury and probability of occurrence (Antonucci, et al., 2010).

The purpose of this study was to analyze the perception of occupational risk by volunteers and paid construction workers at a not-for-profit organization. The researchers were investigating three different hypotheses: Hypothesis 1: There is no statistically significant correlation between the type of employment (volunteers versus paid staff) and perception of occupational risk; hypothesis 2: There is no statistically significant correlation between the type of employment and perception of organizational safety climate; and eventually hypothesis 3: There is no statistically significant correlation between the type of employment and general safety knowledge. During this study other potential confounders were investigated along with the main exposure and outcome variables.

Literature Review

A literature review was conducted using available databases on the Indiana State University library website between September and October 2012. The literatures were retrieved from EBSCOhost, ScienceDirect, Business Source Premier, MEDLINE, PsycINFO, Academic Search Complete and Academic Search Premier by using one or combination of following keywords: risk perception, construction safety, occupational training, occupational safety, risk management and volunteer labor.

Perception of Risk

It appears the evaluation of risk as perceived by the individuals are not one-dimensional; instead shaped by analytical, social, cultural, and psychological factors. Specifically, the perception and acceptance of risk have been found to be influenced by certain characteristics including: age, past injuries, work experience, job position, and personal intuition.

Antonucci, et al. (2010) analyzed the occupational perception of risk for Italian construction workers (N = 300). The study focused on seven hazards: 1) falling from heights, 2) cuts and wounds to body, and 3) eyes, 4) manual handling of loads, 5) noise, 6) slips and trips, and 7) dust inhalation. Participants quantified their perception of severity and the probability for injury in each category on a scale of one to five. Subsequently, the researchers calculated each occupational risk and designed objective values of severity and probability for the hazard categories after reviewing data from the National Institute of Insurance Against Accidents at Work (INAIL) on work-related injuries, injury and illness rates from the U.S., and observations made by staff. By comparing participants' subjective values with objective ones, workers were found to give lower ratings for every risk category (Table 1).

Even though falling from a height was considered the greatest risk, it was also the most underestimated risk. Yet, the possibility of avoiding the risk of falling from a height and of eye injury was the highest; in contrast, the risks the participants considered unavoidable were manual material handling, vibration and dust. In addition, the results showed participants reported higher risk perceptions for hazards producing immediate injury as opposed to those producing occupational illnesses. The researchers found correlation between personal experience with on-the-job injury and their perception of risk. Overall, the study found safety training to have a limited influence on workers' perception of risk.

Hallowell (2010) sought to quantify the perception of risk and risk tolerance among construction workers and their managers. With a sample size of 51 (comprised of plumbers, electrical technicians, carpenters, construction suppliers, roofers, excavators, framers, excavation support system specialist and cast-in-place concrete specialists), it was determined that perception surveys can be used to detect the differences in attitudes between groups and illustrate the leading factors to improve safety performance.

The researcher found workers held different attitudes, perception of risk and acceptable residual risk when compared to managers (i.e., managers were significantly less tolerant for residual

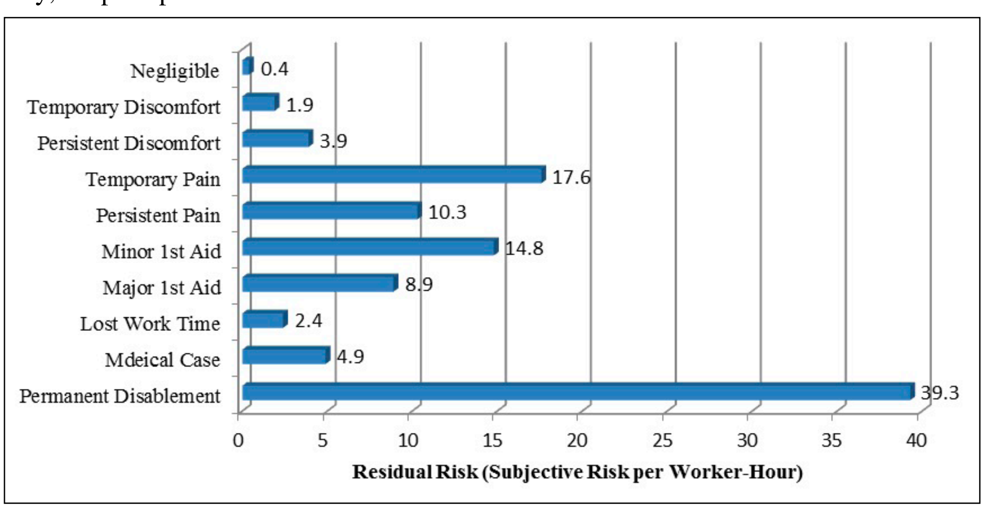

Figure 1: Residual risk among construction workers (Hallowell, 2010).

risk). The only demographic element with statistical significance was when comparing risk tolerance between workers who were injured previously; they had a 25% greater risk tolerance than those who had not been injured before.

Figure 1 demonstrates that the largest residual risk (difference between perception of risk and actual risk) was for permanent disablement among construction workers (39.3) and the smallest residual was for negligible injuries (0.4). In other words, the participating construction workers' risk perception for permanent disablement was significantly different from the actual risk, while their risk perception for negligible injuries was very close to the actual risk.

Another major outcome of Hallowell's (2010) study was that upper-level management's perception of current and acceptable risks for temporary discomfort criterion was higher than workers/lower-level management's perception and in contrast workers/lower-level management's perception of current and acceptable risks for persistent discomfort, temporary pain, persistent pain and minor first-aid criteria was higher than upper-level management. However, there was not significant difference between upper-level management and workers/lower-level management regarding their perception of current and acceptable risks for major first aid, lost work time, medical case, permanent disablement and fatality criteria (Figure 2).

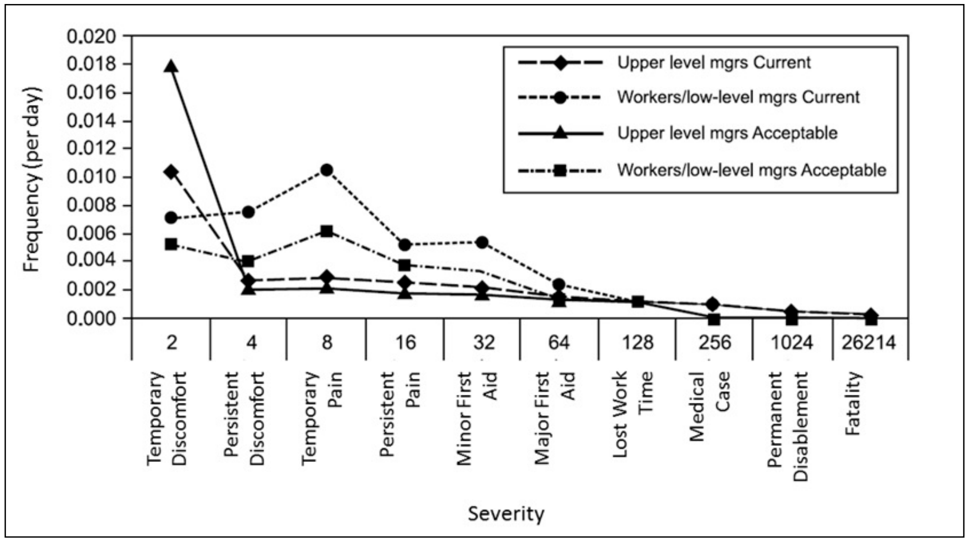

Figure 2: Risk perceptions (Hallowell, 2010).

Accident Reporting & Accident Factors

The construction industry remains one of the most hazardous, with the highest rate across all industries for fatalities and costs related to both fatal and nonfatal injuries. Although injury rates appeared to decline between 1999 and 2003, it is assumed to be the result of underreporting. The construction industry remains a hazardous environment that experiences both location- and industry-specific incident factors and contributing causes (Welch, et al., 2007). Since volunteer workers are not officially covered under the OSH Act, it is not easy to find valid and reliable data regarding incidents involving volunteers and it is important to study how the safety and health of this group of construction workers might be affected because of reporting requirements and procedures.

Welch, et al. (2007) examined whether the decline in injury rates within the construction industry was a result of incorrect/inaccurate in reporting (misclassification of injuries or under reporting) or improvement in safety. Their study found that underreporting of injuries was present throughout all the industries included in the study. Through the combined analysis of rates from two large construction contractors they found lost-time injury rates declined 92% between 1988 and 1999. Yet, during the same time period the rate of restricted work activity increased from 0.7 to 1.2 per 100 workers between 1990 and 2000, and fatalities remained high for the construction industry demonstrating no statistically significant change. The researchers found inconsistencies between BLS data and other sources (such as reports from emergency room visits) from 1998 to 2003, while the number of injuries during the same time period appeared to decline. It was concluded that the construction industry holds a "disproportionate share of work-related deaths in the United States."

Specifically, small contractors (less than 20 employees) were found to have been responsible for more than half of all construction deaths from injuries. In contrast, these same establishments reported lower non-fatal injuries compared to larger employers, specifically, those with 50 to 249 employees. The researchers suggested three potential reasons for the decline of injuries in the construction industry: 1) since the late 1980s safety and health performance became a criterion for receiving government construction contracts; 2) employers may underreport to avoid increases to their workers' compensation premiums; and 3) lack of incentive to report occupational illnesses and difficulty in diagnosing work-related diseases.

One characteristic of volunteer jobs in construction is that a large portion of volunteers have a primary job and work in construction sites as volunteers after the regular working hours which can be considered irregular work schedule and/or overtime work. Dong (2005) analyzed data from the National Longitudinal Survey of Youth from 1992 to 1998 and compared work hour history and specific injury data in order to identify any associations that may exist between long work hours or work schedules and worker safety among construction workers. Although the researcher did not stratify the dataset for volunteer workers, the results showed evidence that overtime and irregular work scheduling had an adverse effect on worker safety.

Specifically, the injury rates of workers increased when the work shift exceeds 8 hours compared to those who worked less than 8 hours a day (15.0% vs. 10.4%, with OR = 1.57 and 95% CI: 1.56-1.58). Additional factors associated with increase in injury rates were shift work, multiple jobs, working early, and working late in the day. The potential adverse safety and health outcomes include sleep deprivation, injury, fatigue and stress. The study suggests that working long hours and irregular work scheduling should be considered a contributing factor for serious incidents.

	Men		Women	
	< 45 y	≥ 45 y	< 45 y	≥ 45 y
Percentage of reported slip, trip and fall accidents of all reported accidents	17%	26%	18%	34%
Average of sick leave for reported slip, trip and fall accident compared to all reported accidents	35 d vs. 21 d	43 d vs. 31 d	28 d vs. 22 d	38 d vs. 25 d

Table 2: Slip, trip and fall incidents for two different age groups (Kemmlert & Lundholm, 2001).

Construction Incidents

Workers on construction sites face a number of specific occupational hazards that correlate with certain demographic and individual characteristics differently, such as age, gender, work experience, and worker behavior. One study showed that slip, trip and fall incidents affect workers age 45 or older at a greater frequency than their younger coworkers. Older workers were also found to take longer sick leave time because of their injury than younger workers (Table 2) (Kemmlert & Lundholm, 2001).

Kaskutas, et al. (2009) studied and measured fall hazards at residential construction sites by surveying 197 residential construction locations over a 1-year period and interviewed 506 workers. Along the fall prevention and protection methods, they found that inexperienced workers and apprentice carpenters were less likely to understand their fall prevention plan than experienced journeymen (90% versus 79%). In addition, a correlation was found between "frequency of safety to fall protection training" (Spearman's rho = 0.70) meaning that workplace safety climate may influence safety behavior.

In a different and somewhat comparable study, 1,025 apprentice carpenters were surveyed in order to identify individual and organizational contributing factors for fall-from-height incidents. The strongest independent risk factor leading to falls was work experience of 1 year or less (OR = 3.11 and 95% CI: 1.42-6.80). Despite formal apprenticeship program which included classroom as well as on-the-job training, half of the apprentices lacked the necessary knowledge of fall hazard prevention (Kaskutas, et al., 2010).

Safety Climate & Culture

Some studies have shown that the safety climate and culture of an organization can affect the likelihood of workers using personal protection equipment (PPE), individual attitudes toward safety policies and procedures, and safety knowledge reducing injury rates. Lombardi, et al. (2009) identified various factors that influence whether workers use personal protective eyewear and the potential obstacles that employers face in maintaining compliance. Interviewing 51 subjects (36 male and 15 female), it was concluded that the use of personal protective eyewear depended on personal risk perception which was a function of work exposure, age of the worker and work environment. Some of the barriers were identified as poorly fit protective eyewear, somatic health effects caused by using eyewear, poor vision (e.g., fogging and scratching), as well as management support and enforcement or lack thereof (Figure 3).

In another study about the impact of safety training programs on reducing injury rates for a large railway construction project, a pre- and post-training analyses included 2,795 workers during the entire construction phase (2002-06) by incorporating an interrupted time-series model (ITS). The researchers introduced two training modules: basic and job-specific modules and they found a 21% (p-value = 0.003) reduction in injury rates among workers with the basic module training and a 26% (p-value = 0.002) reduction in injury rates for those who completed the job-specific module.

However, after considering the potential confounding factors only a 6% reduction in injury rates was estimated following training. Although the results were considered to have a "moderately positive impact," it was not statistically significant and it remained uncertain how influential safety training was and how workers' perception could reduce injury rates (Bena, et al., 2009).

To assess the impact of hazard awareness training on baseline knowledge, attitudes and work practices among construction workers (roofers and pipefitters) and to identify potential changes in safety climate, Sokas, et al. (2009) surveyed 175 employees with a follow-up survey 3 months after training. The study

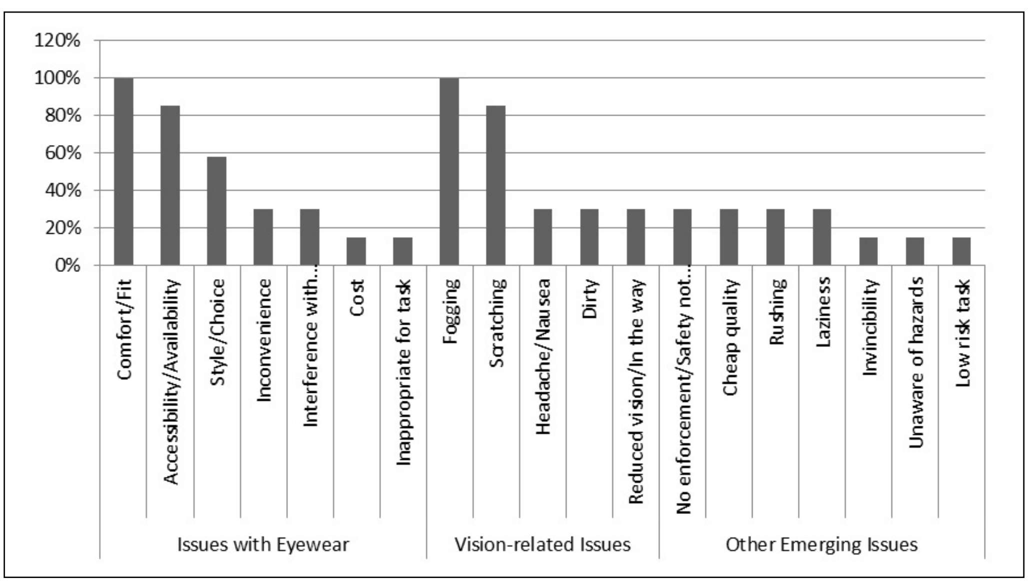

Figure 3: Percent of focus groups raising issues (Lombardi, et al, 2009).

measured work experience, safety knowledge, attitudes and self-reported work practices. Although the gains in safety knowledge were statistically significant, the improvements were modest. The results showed improvement in safety knowledge regarding fall hazard (p-value < 0.0001) and electrical hazard (p-value = 0.0005). Employees' attitude toward workplace safety showed improvement regarding fall and electrical hazards (p-value = 0.005 and 0.004, respectively). The safety climate from the baseline survey did not influence knowledge, yet researchers found the current safety climate was associated with individual attitudes toward safety; hence, those who had a positive safety climate at work were more likely to hold positive attitudes toward safety. The researchers also stated that Mexican-born construction workers had less formal education and poorer preliminary scores, yet they had greater positive attitudes at baseline which increased on the follow-up survey.

In a qualitative study, Törner and Pousette (2009) captured the conditions and descriptions of high standards of safety within the construction industry following interviews of experienced construction workers and front-line managers. They found socio-psychological preconditions were necessary in creating high standards of safety, which were: upper management attitudes, formal conditions, safety being a collective value, norm and behavior which interact with individual attitudes and reinforcing each other to improve safety performance. They suggested that these results were dependent on open and trusting relationships created between front-line managers and peer workers. Together safety culture and safety climate were important contributors to high standards in safety on the studied construction sites.

Volunteer Construction Workers

At the end of the literature search, only one article was found that systematically included volunteer construction workers as target population to study the health effects of construction safety. The researchers used a combination of qualitative interviews, quantitative demographic data collection, and a 12-item questionnaire designed to evaluate health and function of older volunteers in Habitat for Humanity (N = 40). Based on the test scores, the results showed older volunteers were not found to be physically healthier but were mentally healthier than their non-volunteer counterparts.

Of the 40 participants, a total of eight reported several musculoskeletal conditions affecting their knees, backs, shoulders and hips. The health and function of volunteers were assessed significantly better than the general U.S. population in terms of vitality, social functioning, mental health and mental component score (all p-values < 0.01). The researchers concluded that participants were able to contribute a large portion of the construction process as a result of adjusting to individual limitations (Brown, et al., 2009).

The literature review suggests that the ability to perceive risk differs between groups of individuals and influenced by analytical, social, cultural, and psychological factors. Today, construction workers experience a disproportionate rate of fatalities in the U.S. These incidents were mostly comprised of: falls from heights, slips, trips or falls at the same level, and being struck by a falling object. It can be assumed that among construction workers those least experienced and/or those lacking proper safety training are more susceptible for injury.

Meanwhile volunteer workers seem to have all the predispositions that make them more vulnerable to occupational incidents on construction sites such as: age ranging from very young to old, volunteering in addition to their full-time job (extended work hours or irregular work hours), no or lack of safety training, and no or lack of construction experience. Therefore, it was the intention of the present researchers to quantify perception of risk and safety climate among volunteer construction workers and compare with paid workers.

Objectives

This study had three hypotheses to study in order to understand the differences between volunteers and paid construction workers regarding their attitudes toward their occupational risks and worksite safety conditions. The primary hypothesis was formulated as:

$H1_0$: There is no statistically significant correlation between employment type (volunteer vs. paid worker) and perception of occupational risk.

$H1_a$: There is statistically significant correlation between employment type and perception of occupational risk

The secondary hypothesis could be stated as:

$H2_0$: There is no statistically significant correlation between employment type and perception of organizational safety climate.

$H2_a$: There is statistically significant correlation between employment type and perception of organizational safety climate.

And finally, the third hypothesis was:

$H3_0$: There is no statistically significant correlation between employment type and general safety knowledge.

$H3_a$: There is statistically significant correlation between employment type and general safety knowledge.

Methodology

The rationale behind this methodology was in line with Slovic (1987) who conducted a meta-analysis of psychometric studies on risk perception and risk analysis. These early psychometric studies reported feelings of dread or avoidance to be the major determinant in risk perception and risk acceptance. Psychological evaluation of contributing factors toward worker safety should assess individual risk perception and external socio-psychological factors. The researcher concluded that perception of risk was not only quantifiable, it was also predictable because the majority of people determine risk from what are known "intuitive risk judgments," whereas the acceptance of risk originates from social, cultural and psychological factors. Thus, individuals lacking information regarding hazards may still be able to perceive and accept risk based on quantitative and qualitative characteristics (Slovic, 1987).

A cross-sectional study was designed and conducted to assess the two main groups of workers: general volunteers and paid staff on one construction work site affiliated with a not-for-profit organization. Meanwhile an invitation was sent to different social media sites and professional societies affiliated with the host organization. The objective of this study was to quantify risk perception, safety training, safety climate perceptions and safety knowledge. An online survey questionnaire was developed containing four main sections: 1) demographic characteristics; 2) perception of occupational risk; 3) safety climate; and 4) safety knowledge. The first section (24 questions) collected demographic data from each participant regarding age, gender, race, marital status, education, construction experience, type of worker, and any history of previous occupational injuries. The second section (28 questions) was based on Antonucci et al. (2010) study and was modified to fit the current project. In detail, the perception of risk section assessed personal risk perception for seven occupational work hazards (i.e., falling from heights, cuts and wounds to body, hazard to eyes, manual handling of loads, noise hazard, slips and trips, and dust inhalation). For each of these seven hazard categories, participants identified the perceived potential severity (*S*) for injury and ranked the perceived likelihood/probability (*P*) of such accident to occur. The responses were used to estimate the risk (*R*) as the product of probability and severity ($R = P \times S$).

The third section of the survey (10 questions) evaluated the overall safety climate at the job site using a Likert scale that was designed to provide insight on the employer's commitment to safety, current safety and health conditions, confidence in leadership, PPE availability, adequate safety training, hazard communication, peer support and potential for future injury. For each of the 10 questions participants quantified their response on a five-point scale from strongly disagree to strongly agree. The fourth and final section of the survey was to assess participant's general safety knowledge (17 questions). The questions in the fourth section of this survey were based on the two optional online safety training videos offered by employer to volunteers.

Prior to data collection, Institutional Review Board (IRB) approval was obtained to make sure the privacy of subjects was protected and they were not exposed to additional risks. Construction workers (paid workers and volunteers) from a construction site in the state of California were approached while leaving the site and were invited to participate in the study; also online invitation were sent via professional societies and social media. Contact information of potential participants was collected and the URL of the online survey was emailed to them later in the day. Simultaneously, public invitations to the online survey were posted through social media and through networking in professional clubs and organizations.

The inclusion criteria were age (must be 18 years or older) and work experience on construction sites either as volunteer or staff in their lifetime. The online survey started with an informed consent form and the only incentive offered to participant was entry into a raffle to receive one of five available $20 gift cards from a franchised coffee company, which was optional. The data collection started after the IRB approval was received and lasted for 25 days (Feb. 10 to March 6, 2013), during which 476 responses were received. The data were anonymous and stored in a spreadsheet on a secure external hard drive for further statistical analysis using SAS System 9.0 for Windows. Accordingly, numerous 2-way and 3-way contingency tables were created and appropriately Chi-square or

	Male (% in group)	Female (% in group)
General Volunteer (58.3%)	98 (37.7%)	162 (62.3%)
Paid Workers (40.4%)	68 (37.8%)	112 (62.2%)
Decline to Respond (1.3%)	2 (33.3%)	4 (66.7%)
Total	***168***	***278***

30 missing data points.

Table 3: Participant demographics by gender.

Ethnicity	Male	Female
White / Caucasian	156	241
Asian	7	17
Hispanic / Latino	6	7
Black / African American	4	3
Multiracial	4	2
American Indian / Native American	5	1
Pacific Islander	0	2
Decline to Respond	5	9
Total	***187***	***282***

7 missing data points.

Table 4: Ethnicity distribution by gender.

Severity of outcome
1- Generally no injury
2- Slight injury, generally not requiring medical care
3- Injuries usually requiring medical care without permanent damage
4- Injuries usually requiring medical care and possibly causing permanent damage
5- Possible fatal injuries
Probability of accident
1- Never
2- Unlikely
3- Somewhat likely
4- Likely
5- Very likely

Table 5: Description of levels of probability of incidents and severity of outcome.

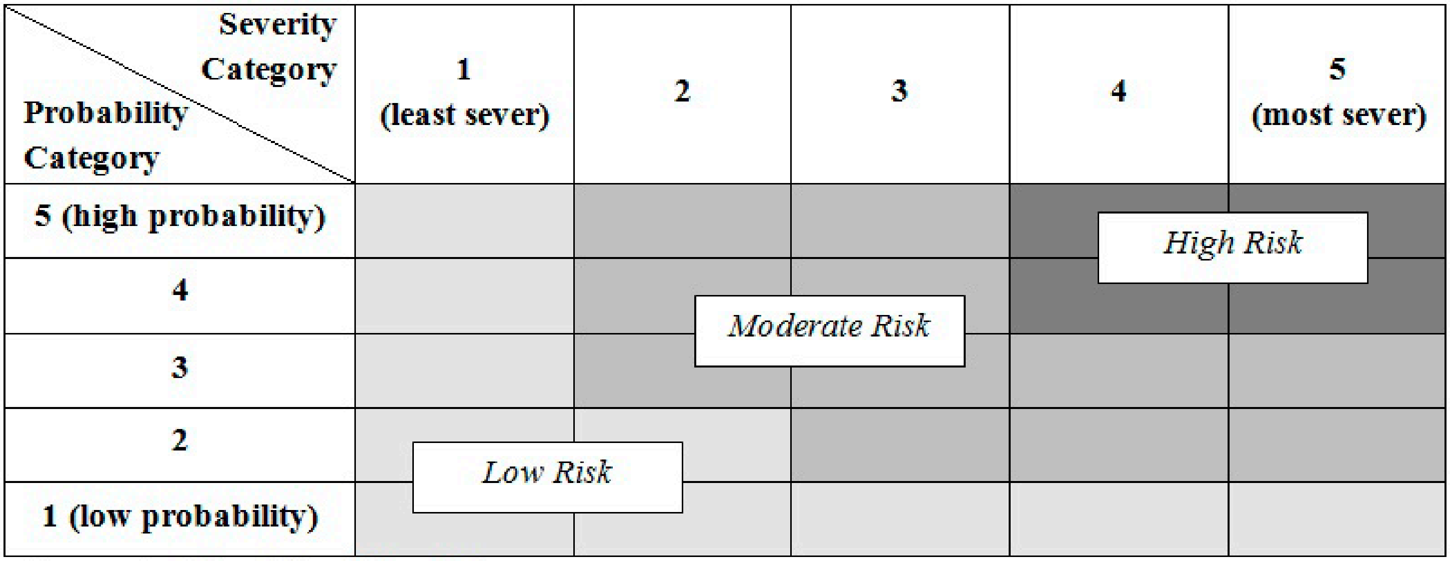

Figure 4: Heuristic risk matrix.

Fisher Exact tests were conducted to study correlations between employment type and perception of risk and safety climate with 0.05 level of significance.

Results

Among all participants (N = 476), the majority of respondents were female (62.3%) rather than male (37.7%) and typically were general volunteers (58.3%) (Table 3). The average age of participants was 36.8 years with standard deviation of 17 years and a majority of them (96.2%) identified English as their primary language followed by Chinese (1.2%), Korean (0.7%), Spanish (0.5%) with a total of 1.2% of other languages (i.e., Arabic, French, Polish, Russian, Telugu, Vietnamese).

Regarding the socioeconomic status of participants, the results showed that 40.3% of subjects had bachelor's degree (the largest subgroup) followed by some college, master's degree, doctoral degree (33.6%, 16.1% and 4.7%, respectively) and high school diploma/GED, vocational school and some high school education were the lowest proportion of sample (5.2%). The majority of participants were employed at the time of answering the questionnaire (59.2%), 24.9% were students and 11.3% were retired, followed by 1.2% unemployed. When participants were asked about their employment and the industry sections in which they were employed, the answers ranged from temporary employment or self-employed all the way to management in private, public and nonprofit sectors.

As shown in Table 4, a majority of participants identified themselves as White/Caucasians (83.76%), followed by Asian, Hispanic/Latinos, and other ethnicities or multiracial. The data showed that more than half of the participants (55.2%) were single/never married, about 37% were married, about 7% were divorced, 1.4% were widowed and 1.6% declined to respond.

As noted, the main objective of this study was to assess the risk perception among volunteers and paid construction workers (Hypothesis 1). To achieve this objective, subjects were asked to rank their perception regarding the probability of incidents and severity of outcomes for certain type of hazards (i.e., fall, slip and trip, eye injuries, dust inhalation, cuts and wounds, noise and manual lifting). Their responses were used to develop a heuristic risk matrix (Figure 4) for each hazard for comparison. The description of levels of probability and severity are provided in Table 5. The wording of some of the descriptions were modified depending on the type of hazards. Later, Chi-square tests (or Fisher Exact tests if appropriate) were conducted to investigate possible correlation between the type of employment (volunteer or paid worker) and risk perception.

Tables 6 and 7 (p. 314) represent a summary of participants' perception regarding the probability of an incident occurring for each hazard and the level of severity of outcome. These data were used to categorize participants risk perception into three levels (i.e., low, moderate, high) defined in Figure 4.

The results of Chi-square/Fisher Exact tests indicated that there is no statistically significant correlation between the subjects' employment type and risk perceptions except for slip and trip hazards (p-value = 0.0108) and eye injury hazards (p-value = 0.0423) where volunteers generally had lower risk perception. Because the sample was predominantly white and female (lack of diversity), the researchers were unable to study the effect of some potential confounders such ethnicity/race and education on subjects' risk perception. However, whenever possible, a series of 3-way contingency tables were created to study the effect of other variables by conducting Chi-square/Fisher Exact tests.

When considering gender as a potential confounder, the researchers found no significant difference between male and female subjects' risk perception. Previous injury on a different construction site appeared to be a potential confounder for slip and trip hazard and eye injury hazard; that is, volunteer subjects who had no injury on a different site in the past had lower risk perception for slip and trip and eye injury compared to paid workers (p-value = 0.0081 and 0.0463, respectively). Meanwhile the results showed previous injury on the same construction site was a potential confounder for slip and trip hazard. In other words, volunteer subjects who had no injury on the same site in

Severity of Outcome	Hazards: Falls	Slips and trips	Eye injuries	Dust inhalation	Cuts and wounds	Noise	Loading and lifting
Level 1	2 (0.5%)	10 (2.3%)	6 (1.6%)	35 (9.1%)	1 (0.3%)	58 (15.4%)	15 (4.1%)
Level 2	38 (8.9%)	224 (52.5%)	35 (9.1%)	160 (41.7%)	118 (30.8%)	114 (30.3%)	109 (29.2%)
Level 3	154 (35.2%)	105 (24.7%)	79 (20.5%)	85 (22.1%)	152 (39.7%)	31 (8.2%)	86 (23.0%)
Level 4	149 (35.1 %)	49 (11.4%)	246 (63.9%)	89 (23.2%)	70 (18.9%)	96 (25.5%)	126 (33.8%)
Level 5	82 (19.3%)	39 (9.1%)	19 (4.9%)	15 (3.9%)	42 (11%)	77 (20.5%)	37 (10.0%)
Total number of responses	***425***	***426***	***385***	***384***	***383***	***376***	***372***

Table 6: Summary of responses to the severity of outcomes for different hazards perceived by participants.

Probability of Accidents	Hazards: Falls	Slips and trips	Eye injuries	Dust inhalation	Cuts and wounds	Noise	Loading and lifting
Level 1	9 (2.1%)	4 (0.8%)	5 (1.3%)	5 (1.3%)	0 (0.0%)	18 (4.8%)	0 (0.0%)
Level 2	226 (53.7%)	152 (30.9%)	161 (41.8%)	157 (41.0%)	97 (25.3%)	160 (42.6%)	101 (27.1%)
Level 3	127 (30.2%)	237 (48.2%)	156 (40.5%)	138 (36.0%)	185 (48.3%)	119 (31.6%)	180 (48.3%)
Level 4	42 (10.0%)	84 (17.1%)	50 (13.0%)	63 (16.4%)	72 (18.8%)	58 (15.4%)	78 (20.9%)
Level 5	17 (4.0%)	15 (3.1%)	13 (3.4%)	20 (5.2%)	29 (7.6%)	21 (5.6%)	14 (3.8%)
Total number of responses	***421***	***492***	***385***	***383***	***383***	***376***	***373***

Table 7: Summary of responses to the probability of incidents for different hazards perceived by participants.

the past had lower risk perception for slip and trip compared to paid workers (p-value = 0.0227). Subjects were also asked to categorize their past injuries; cuts/lacerations cited in 11 cases and back strain cited in six cases were the leading injuries among 54 cases. Regarding the past injuries on the same site, there were 20 cases of scrapes/bruises and skin irritations, 15 cases of bludgeoned (beaten) fingers, nine cases of falls from heights, seven cases of puncture wounds, followed by five cases of back strain leading the list of injuries among 80 cases.

In regard to safety training for volunteers as a potential confounder, this study showed that there was statistically significant correlation between the employment type and risk perception for slip and trip hazard among those who watched the safety video before volunteering (p-value = 0.0129). It appeared that volunteers who watched the safety training video had lower risk perception for slip and trip (which seems counterintuitive); an opposite outcome was observed for eye injury hazard: the volunteers who watched the safety training video had higher risk perception (p-value = 0.0076).

Another potential confounder considered in the study was previous work experience in construction. The results indicated that there was a statistically significant correlation between subjects employment type who had previous work experience in construction and risk perception for eye injury (p-value = 0.0037). That is volunteers with previous experience in construction had higher risk perception for eye injury compared to the staff. Among all participants in the study, about 82% (n = 349) were not employed in construction in the past and among all volunteers about 90% (n = 352) had volunteered for less than 25 days during a 6-month period prior to survey. The researchers did not find subjects' self-reported skill level to be a contributing factor.

Regarding the second hypothesis, the questionnaire had a 10-item section about the organizational safety climate. Participants answered each question using a five-point Likert scale to express their opinion about the safety climate (culture) at the construction sites. All answers were weighted equally to estimate an overall score indicating each participant's perception of safety climate divided into three groups (i.e., low score, average score, high score). The results of Chi-square/Fisher Exact tests indicated that there was a weak correlation between the employment type and the safety climate scores (p-value = 0.0450). It appeared that more volunteers tended to rate the safety culture at the construction site as average compared to majority of paid workers who rated the safety climate as high.

To investigate potential confounders, the researchers looked into the following factors: gender, ethnicity, education level, previous injury/illnesses outside the organization, previous injury in the organization, watched safety training videos, previous construction experience and eventually skill level. A set of 3-way contingency tables were created and Chi-Square/Fisher Exact tests were conducted accordingly. The results showed that among paid workers, female subjects had higher scores in safety climate evaluation (p-value = 0.0102) compared to volunteer participants. Education was another confounder in that paid workers with some college and bachelor's degree had higher scores in safety climate evaluation (p-value = 0.0224 and 0.0076, respectively) compared to volunteers. Also, comparing the volunteer participants versus paid workers, the latter group with no previous injury in the organization had higher scores in safety climate evaluation (p-value = 0.0164). Finally, paid workers with previous construction experience had a higher score compared to volunteers (p-value = 0.0498). Other potential confounders either showed no significant correlation, or were not possible to estimate because of the number of cells with zeros in their contingency tables.

Finally regarding the third hypothesis, the questionnaire had one section to evaluate the participants' general knowledge in construction safety. Twelve equally weighted questions with multiple choice answers were included to estimate a score indicating each participant's general knowledge in construction safety. The scores were divided into three groups (i.e., low score, average score, high score). The results of Chi-Square/ Fisher Exact tests indicated that there was a statistically significant correlation between the employment type and the general safety knowledge score (p-value = 0.0049). The data showed that paid workers of the not-for-profit organization had higher scores compared to volunteers.

The researchers investigated possible confounding affects for several factors such as gender, ethnicity, level of education, previous injury or illnesses in other organizations, previous injury in current organization, previous construction experience, skills level, as well as whether subject had watched the safety videos. After constructing a set of 3-way contingency tables, the results indicated that gender could be a confounding factor (p-value = 0.0325) as female subjects had higher safety knowledge among paid workers compared to male subjects and also the Chi-square test indicated that Caucasian subjects among paid workers had a higher safety score than volunteer counterparts (p-value = 0.0212). Subjects with no previous injury or illness in the same or other organizations among paid workers had higher scores compared to volunteers (p-values = 0.0391, 0.0066, and 0.0311, respectively). Furthermore subjects who had watched the safety video (not the fall safety video) among paid workers had higher scores compared to volunteers (p-value = 0.0267). Further tests for other potential confounding factors either were not possible to estimate (because of the number of cells with zeros in their contingency tables) or did not show any statistically significant correlation.

Discussion

As described in the previous section, results of the data analysis were mixed. Despite the size of the dataset that created high hopes for robust results, very few significant correlations were found between the employment type and risk perception, safety climate perception and safety knowledge. Nevertheless, the results indicated that there were gaps and differences between volunteers and paid construction workers regarding the way each group perceived its occupational risks, the safety climate of the workplace as well as the level of safety knowledge.

Among the seven construction hazards considered in this study (falls, slip and trip, eye injury, dust inhalation, cuts and wounds, noise and manual material handling), the only significant correlations found were about the risk perception for slip and trip as well as eye injury hazards. The volunteers had lower risk perception than paid workers. When it came to safety climate, paid workers had higher scores for (subjectively) evaluating the safety climate of the participating organization compared to volunteer subjects and similarly in regard to general safety knowledge paid workers had higher scores than their volunteer coworkers.

It was beyond the scope of this study to determine the cause of such correlations, but it can be speculated that such differences between volunteers and paid workers could be due to level of experience, or amount and quality of safety training, or even prior work-related injuries. The potential confounders studied in this project were gender, ethnicity/race, education, optional safety training videos provided by the host organization, construction experience and skill level, and prior work-related injuries within and outside of the host organization. The results were neither robust nor consistent and depending on the type of hazard, different factors played confounding roles in data analysis (e.g., sometimes gender was a confounding factor and other times level of education or previous work related injury were confounding variables).

Conclusion

Considering the fact that OSH Act does not cover the volunteer workforce, it is the moral duty of all organizations (for and not-for-profit) to provide a safe work environment for everyone regardless of their employment status. This ultimate goal cannot be achieved without including volunteers. As indicated in the literature review section, there has been shortage of published scholarly articles by researchers regarding the differences between volunteers and paid workers, so much so that this study might be one of the first to include volunteers in a research project.

It is important to keep in mind that this study was limited to one construction site and online participants via social media and professional societies affiliated to one not-for-profit organization. The data collected through the online survey were subjective and the dataset had its own shortcomings despite the large sample size. The dataset was biased by different variables, specifically by gender, race/ethnicity and some socioeconomic factors such as education. It is not right to expect a cross-sectional study such as this one to explain any cause-and-effect relationship between variables, but it might be possible to use the results of this study as first building blocks of future studies.

Overall, the results showed that volunteers and paid workers had different ideas about the risks of their occupation and there were different factors that could confound such differences. It is necessary to improve and/or expand the finding of this study in order to generate robust results and come up with new or even different methods, policies and procedures to improve the safety conditions at construction work sites and close the gap between volunteers and paid workers. First, it is essential to have a better understanding about the differences and even similarities between volunteers and paid workers in construction before making any changes in safety programs and that would require inclusion of volunteers in research projects. That means samples of participants need to be a better representative of volunteers and paid workers in terms of demographic information.

In addition to better sampling of the population, the quality, content and the delivery method of safety training programs for both paid workers and volunteers in every organization benefiting from a volunteer workforce should be considered in more details. It is not clear whether volunteers need similar safety training session as paid workers or whether their training session should be customized or tailored toward their tasks and assignments during the volunteer period; therefore, it is important to consider this factor as one of the important and potential confounders.

The authors strongly recommend having the middle and upper-level management participate in studies similar to this. It is important to know how managers think about volunteers, their contributions and their differences compared to paid workers. There has been no research about management's point of view regarding the safety gap between volunteers and paid workers (as indicated in this and some other articles), which should be studied in order to improve safety conditions for everyone at construction sites.

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Forklift Operator Visibility Evaluation in a Manufacturing Environment

Xu Shen and Eric Marks

Abstract

A typical manufacturing environment is characterized by a multitude of interactions between pedestrian workers, equipment and materials. This dynamic work environment often fosters nonvisible areas that impede a person's line-of-sight. The lack of visibility for equipment operators in manufacturing environments can contribute to struck-by events that results in injuries and potentially fatalities. The objective of this research is to create a framework to evaluate the visibility of an equipment operator in a manufacturing environment. Experiments were conducted to simulate typical movements and actions of a forklift in a manufacturing plant. The test bed was assessed through laser scanning to identify areas not visible to the forklift operator. Point clouds of the test bed were generated and analyzed to identify nonvisibility areas for forklift operators. The primary contribution of this research is scientific evaluation data of operator visibility in a manufacturing environment as well as a framework for measuring operator visibility in manufacturing work environments. Results of the research can be implemented to better understand causes of struck-by incidents as well as to potentially mitigate visibility concerns in the manufacturing industry.

Keywords
Forklift operator visibility, point cloud data, manufacturing safety

The U.S. manufacturing industry represented 8.3% of the total workforce, 12.6% of workplace injuries and 7.3% of workplace fatalities in 2014 (BLS, 2016). This disproportionate percentage of injuries indicates the inherent hazardous work environment typical of manufacturing facilities. Much improvement is needed in manufacturing safety to promote the well-being of employees and foster a safe work environment.

Typical manufacturing environments can be defined by dynamic interactions between equipment, employees and materials. This constantly changing environment is characterized by several visibility issues for manufacturing plant personnel (Godwin, et al., 2007). Blind spots, defined as nonvisible areas, exist when an individual's line-of-sight is obstructed (Hills, 1980). In manufacturing environments, the visibility of equipment operators can be impaired by obstructed line-of-sight from materials or machines. The objective of this research is to create a framework for quantifying and evaluating the visibility of a forklift operator within a manufacturing plant facility.

International Organization for Standards (ISO, 2011) has published visibility standards for work environments and equipment operators through Code 5006 and ISO Code 14401-1. Although these standards are prescribed to manually measure visibility, laser scanning was deployed in this research as the strategy to measure visibility within a manufacturing plant environment. Benefits of using a laser scanning for measuring operator visibility include producing a three-dimensional spatial point clouds, automated data processing, improved accuracy in measurements and decreased human error bias (Marks & Teizer, 2013). A test bed was established in a paper manufacturing environment to assess the visibility of a forklift operator using a laser scanner. The scope of this research is limited to manufacturing environments and results of visibility measurements are portrayed in 2-D surface area.

Literature Review

The U.S. manufacturing industry experienced 314 fatalities, which represented 7.3% of all workplace fatalities in 2014 (OSHA, 2016a). Furthermore, the manufacturing industry recorded 483,300 injuries in 2014 which represented 12.6% of all workplace injuries experienced in the U.S. that year (OSHA, 2016b). It is estimated that at least 100 manufacturing employees are fatality injured each year from forklift struck-by incidents (NIOSH, 2001). Additionally, it is estimated that 35,000 employees are seriously injured after being struck by forklifts in the manufacturing environment. (Marsh & Fosbroke, 2015; OSHA, 2016b). Forklift-related crush injuries of the foot and ankle have become increasingly common in manufacturing environments. (Hong, et al., 2015).

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Limited visibility in work environments can directly impact the overall safety of employees of the manufacturing industry (Hinze & Teizer, 2011). Blind spots are a frequent cause of visibility-related fatalities in industries that require equipment and pedestrian employees (Teizer, et al., 2010). Areas invisible to forklift operators in manufacturing environments can cause hazardous areas for pedestrian employees (Choi, et al., 2009).

Visibility Measurement Methods

Approaches to calculate and measure blind spots can be classified into two categories: 1) manual and 2) computer simulation models (Bostelman, et al., 2014). The most common form of visibility measurement implements a Seat Index Point (SIP) apparatus for a manual technique based on the ISO 5353 code (ISO, 2011). This code prescribes a light be illuminated at the average operator's eye height level in a dark area. A two-dimensional grid on the ground surface is used to quantify areas where the light does not reach the ground (ISO, 2011). This method along with other manual methods of visibility measurement are time-consuming when compared to automated methods (Marks, et al., 2013).

In recent years, computer simulation methods including computed-aided design (CAD) techniques have been implemented to measure visibility (Liu, et al., 2008). These techniques were able to automatically collect precise profiles and dimensions of the equipment and environment. Interactive software allows for visibility measurements in three approaches: 1) utilization of models and specifications from an original equipment manufacturer; 2) laser scanning equipment to create a real-life model; and 3) create a panoramic photograph from the operator's viewpoint (Agronin & Albanese, 2012). Based on these approaches, algorithms were created to detect blind areas by automatic imaging ray tracing projected from the operator's eye location (Teizer, et al., 2010). These algorithms were used to explore the impact of the design of equipment on the visibility of an equipment operator (Marks, et al., 2013).

Forklift Visibility

Forklifts are used in abundance in the manufacturing industry for handling materials and other tools. Insufficient visibility for forklift operators can cause injuries and fatalities because the operation of a forklift is largely dependent on the available vision to gather necessary information during operation (Barron, et al., 2005). Research has shown more than 80% of forklift-related incidents were connected with limited visibility (Collins, et al., 1999a; Collins, et al., 1999b). Several researchers have investigated the impact of equipment design on operator visibility. (Bostelman, et al., 2014; Choi, et al., 2009; Marks, et al., 2013). These studies failed to include the impacts of the surrounding work environment for assessing operator visibility.

Methodology

Four sequential processes were implemented for this research: 1) data collection including laser scans of manufacturing site and forklifts; 2) data processing including registration and preliminary edits of laser scans; 3) blind spot identifications including visibility of both the forklift and manufacturing environment; and 4) data integration to find the overlaid blind spots of both forklift operator visibility and the manufacturing environment.

A 3-D laser scanner was used to collect several spatial point clouds. Raw data generated from the spatial point clouds were transformed to operator visibility diagrams and quantifiable blind spot information. Non-visible areas for forklift operators were identified from two different sources: 1) components of the forklift obstructing the operator's line-of-sight called *secondary visibility hazards* and 2) components of the manufacturing environment obstructing the operator's line of sight called *tertiary visibility hazards*. Areas that include invisible areas from both the forklift obstructions and object obstructions in the manufacturing environment are denoted as a *primary hazard*.

Data Collecting

Spatial point clouds of both the forklift and the manufacturing environment were generated and collected automatically with a 3-D laser scanner. The commercially available 3-D laser scanner was positioned at an operator's average eye height as specified by the ISO standard code 5006 (ISO, 2011). This code also specifies a 12 m visibility radius extended from the operator's positon for the visibility assessment area (ISO, 2011). The 3-D laser scanner generates approximately 3 million data points in a 360 degree radius in approximately 20 minutes. Three independent locations were selected and scanned to evaluate the visibility of the testbed manufacturing environment. For these scans, the laser scanner was positioned at 3.5 m vertically from the ground surface to simulate an average pedestrian employee's eye height.

Data Processing

The point cloud data captured by the 3-D laser scanner was calculated through a previously developed blind spot detection tool (Marks, et al., 2013; Teizer, et al., 2010). The tool identifies areas not visible to the equipment operator by the algorithm of tracing an imaginary path projected from the position of the operator's eyes to the nearest obstruction from all angles. If the traced path of the laser was intercepted by an objective or forklift equipment component, the area was deemed invisibility to the operator on the ground surface. For this work, the profiles of obstruction were extended to include equipment visibility obstructions as well as other objects that obstruct visibility in the manufacturing environment. The resulting visibility was calculated from 2-D projections in the plan view, front view, rear view and side views.

After the laser scans have been completed, the individual point clouds are registered together based on several known points that appear in each individual scan. By registering the individual point clouds, one 3-D environment based on the actual manufacturing environment is created for visibility assessment. This 3-D environment allows for unlimited visualization points within the scanned environment.

The completed registered scan was then exported into a commonly used construction design software for visibility measurement and analysis. Users then followed typical forklift travel paths in the 3-D registered laser scan to view visibility of a particular person at a specific location. Areas absent of points on the ground surface were identified and deemed invisible areas. At each selected point along the forklift travel path, a 12 m radius circle was projected along the ground surface to calculate the visibility percentage of the forklift operator at that specific location. Visibility measurements were assessed in two parts: 1) invisible areas created by obstructions from forklift equipment components; and 2) invisible areas created by obstructions in the manufacturing environment.

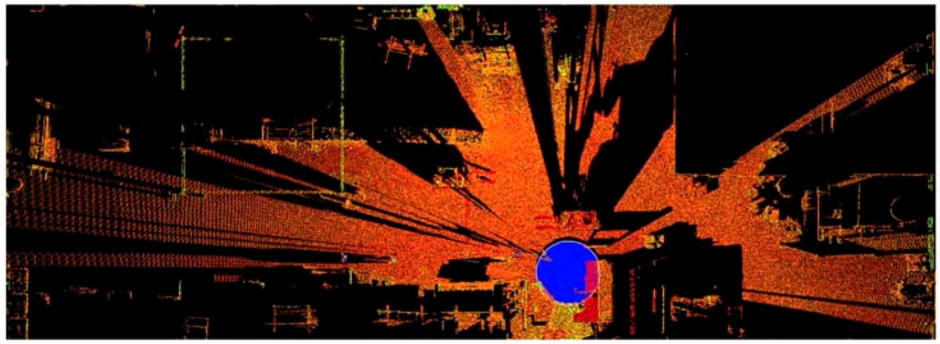

Figure 1: Visibility circle for one laser scan station in the testbed.

Data Analysis

After measuring the blind spot data for both the forklift and manufacturing environment in the 12 m radius visibility circle at each location, the percent visibility was calculated. The following three categories were created to demonstrate the perceived hazard with regards to forklift operator visibility in the scanned manufacturing environment:

•Primary hazards: Invisible areas resulting from forklift obstructions and object obstructions in the manufacturing environment.

•Secondary hazards: Invisible areas resulting from forklift obstructions.

•Tertiary hazards: Invisible areas resulting from obstructions in the manufacturing environment

Case Study

A corrugated box manufacturing plant in the southeastern U.S. was selected to create a testbed for evaluating the visibility of a forklift operator. The testbed was created in a large enclosed 19,200 sq. ft maintenance room with multiple equipment obstructions and forklift travel paths. Three locations in the maintenance room were selected as scan locations to create a point cloud for the entire area. The measured visibility on the ground surface is shown in Figure 1 from one scan station in the maintenance room. All black areas are invisible to a person standing at the scan station. The blue circle indicates the 12 m visibility radius circle around the laser scan location.

Table 1 summarizes the visible area, blind spot area and percent visibility for each of the three independent laser scan locations in the testbed. This summation shows the overall visibility of a person standing at each scan station. By registering each of these scans together, a 3-D visibility map becomes available so that the visibility perspective can be any location within the testbed.

The point clouds from the three scan locations were combined through a registration process. Results of the registered point cloud showed areas not visible after integrating all three scan locations. The registered point cloud also enables 3-D visualization of the entire testbed.

Forklift Operator Visibility

In addition to scanning the manufacturing environment testbed, a forklift was also scanned to assess the visibility of operators around the piece of equipment. The type of forklift used in the manufacturing plant and for visibility measurements was a Toyota Core IC Cushion. The forklift was 2.5 m in length, 1.1 m in width and 2.0 m in height. As specified by ISO code 5006, the laser scanner was positioned at the approximate average eye height of a forklift operator (ISO, 2011). The resulting scan shows invisible areas to the forklift operator due to equipment components that obstruct the operator's line-of-sight. Of the entire 12 m visibility radius around the forklift operator, 28.8 sq. m or 6.4% of the visibility circle is nonvisible to the operator. These invisible areas are caused by the four corners of the forklift equipment cabin.

A 1 m width visibility square was also formed around the forklift operator to analyze the front, rear and side view visibility. This assessment shows the forklift operator's visibility of a 1.8 m person standing 1 m from the forklift operator. For example, the front view visibility for the forklift operator of a 1.8 m profile is approximately 57%. The same value for the rear view of the forklift operator is 33%. These values are shown in Figure 2.

Scan stations	1	2	3
Visible area (ft^2)	3,460	3,468	3,633
Blind spot areas (ft^2)	6,065	6,057	5,892
Percent visibility (%)	36.3	36.4	38.0

Table 1: Visible area, blind spot area and percent visibility of each scan location.

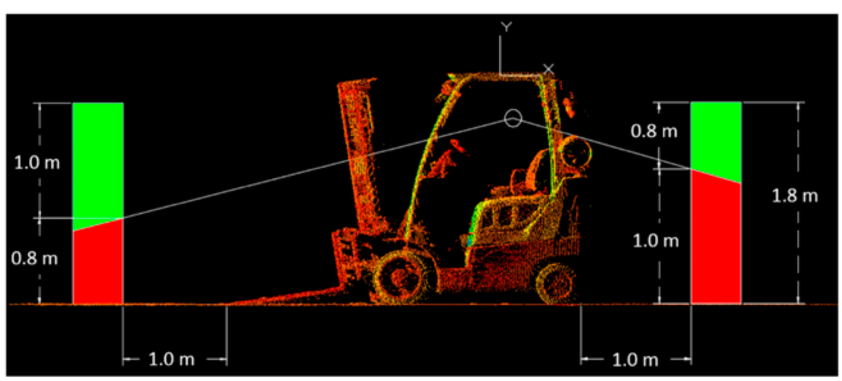

Figure 2: Front and rear visibility of the forklift operator.

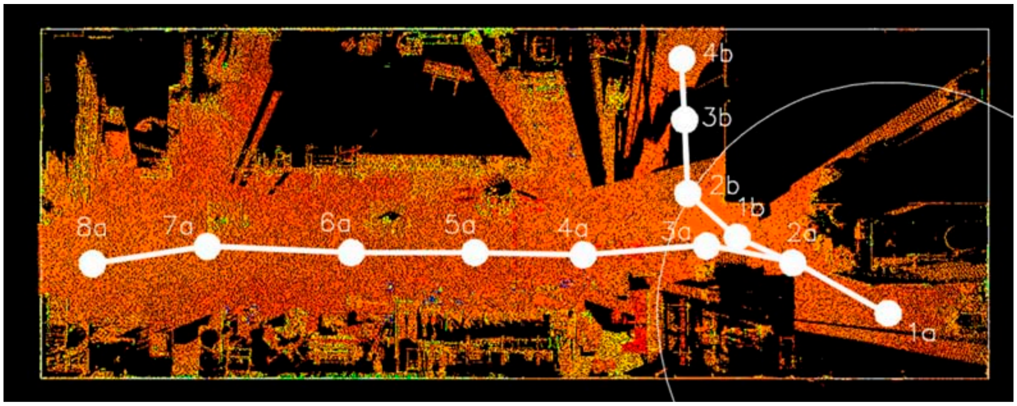

Figure 3: Visibility locations of the registered point cloud.

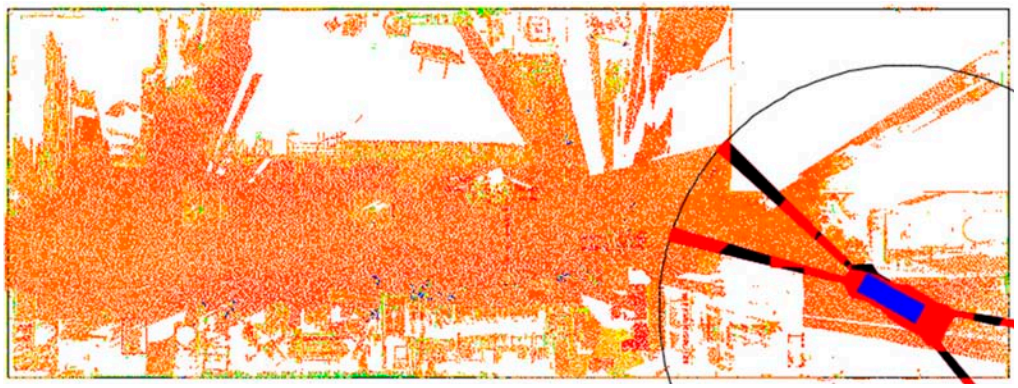

Figure 4: Overlaying of forklift visibility point cloud and registered point cloud for manufacturing testbed environment for visibility point "1a."

Overall Visibility Analysis

Several visibility points were identified along two forklift travel paths in the testbed. These points represented potential limited visibility locations for forklift operators. Using the registered point cloud, each identified point was analyzed for visibility of the forklift operator. The registered point cloud and identified visibility analysis locations are shown in Figure 3. The paths are denoted as path "a" and path "b" and each visibility location has a unique identification number. A 12 m radius visibility circle was drawn around each identified visibility location to analyze the forklift operator visibility within the visibility circle. The 12 m radius visibility circle for visibility location "1a" is shown in Figure 3.

"Primary hazards" were calculated by overlaying the visibility of the forklift laser scan point cloud and the registered point cloud of the manufacturing testbed environment. Figure 4 shows overlaying of the two point clouds, forklift laser scan and manufacturing testbed environment, to demonstrate the primary hazardous areas for visibility location "1a."

The visibility measurements were completed for each visibility location identified in Figure 3. The visibility values from the overlaying of the forklift laser scan point cloud and registered point cloud of the manufacturing environment were divided into "forward visibility" and "rear visibility." Forward visibility refers to a forklift traveling the path moving from right to left in Figure 3 and rear visibility refers to a forklift traveling the path moving from left to right in Figure 3. Table 2 presents the primary hazardous visibility areas with each corresponding visibility location and each travel direction. This table also gives the overall testbed visibility within the 12 m radius visibility circle at each given visibility location.

Based on the results of the visibility analysis, visibility locations "1a" and "2a" have the highest primary hazardous areas in terms of forklift operator visibility. This is true for both the forward and backward forklift travel direction along the path. The manufacturing testbed visibility is most limited at visibility location "2a."

Conclusion

This research created a framework for quantifying and measuring the visibility of a forklift operator within a manufacturing plant facility. To quantify the visibility of a forklift operator, this framework includes blind spots obstructed by the forklift equipment components and materials and machines that obstruct the view of the manufacturing environment. A case study in an active manufacturing plant and forklift was conducted to evaluate and validate the proposed framework. The forklift was laser scanned along with three independent locations along the forklift travel path to create a registered point cloud for 3-D visualization of the manufacturing environment. After processing the data, twelve visibility locations were selected along the forklift travel path to demonstration the calculation of visibility quantities. The visibility categories include "primary hazardous" areas in which invisible locations caused by components of the forklift and manufacturing environment are overlaid.

The main contribution of this research is a framework for measuring and analyzing the visibility of forklift operators in manufacturing environments to better understand interactions between pedestrian employees, moving equipment and equipment operators. The intent of this paper is to present scientific evaluation data of this framework in an attempt to enhance safety performance in manufacturing environments. Future research should explore other pieces of manufacturing equipment using this method to capture the visibility of an entire manufacturing plant. Furthermore, the point cloud accuracy could be increased by increasing the number of scan locations. The number of scan locations should be based on availability of space in the manufacturing environment and desired accuracy of the data.

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Visibility location	Testbed visibility	Percentage of non-visible primary hazards	
		Forward travel	Backward travel
1a	46.4%	2.6%	2.8%
2a	42.9%	2.5%	2.7%
3a	50.3%	1.7%	1.8%
4a	61.3%	1.3%	1.3%
5a	69.9%	0.9%	0.1%
6a	71.2%	0.0%	0.0%
7a	75.7%	0.0%	0.0%
8a	70.9%	0.1%	0.0%
1b	53.0%	2.8%	2.9%
2b	47.6%	1.7%	2.0%
3b	47.7%	1.0%	0.9%
4b	42.4%	0.9%	0.8%

Table 2: Visibility values of the selected visibility locations along the forklift travel paths.

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