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Worker safety and injury severity analysis of earthmoving equipment accidents

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ABSTRACT

Introduction: Research on construction worker safety associated with construction equipment has mostly focused on accident type rather than injury severity and the embedded factor relationships. Significant variables and their effects on the degree of injury are examined for earthmoving equipment using data from OSHA. Four types of equipment, backhoe, bulldozer, excavator, and scraper are included in the study. Accidents involving on-foot workers and equipment operators are investigated collectively, as well as separately. *Methods*: Cross tabulation analysis was conducted to establish the associations between selected categorical variables, using degree of injury as a dichotomous dependent variable (fatal vs. nonfatal) and a number of independent variables having different values. Odds ratios were calculated to determine how much a certain variable/factor increases the odds of fatality in an accident, and the odds ratios were ranked to determine the relative impact of a given factor. *Results*: It was found that twelve variables were significantly associated with injury severity. Rankings based on odds ratios showed that inadequate safety training (2.54), missing equipment protective system (2.38), being a non-union worker (2.26), being an equipment operator (1.93), and being on or around inadequately maintained equipment (1.58) produced higher odds for fatality. *Conclusion*: A majority of the earthmoving equipment accidents resulted in fatality. Backhoes were the most common equipment involved in accidents and fatalities. Struck-by accidents were the most prevalent and most fatal. Non-OSHA compliant safety training, missing seatbelt, operator not using seatbelt, malfunctioning back-up alarms, and poorly maintained equipment were factors contributing to accidents and fatalities. On-foot workers experienced a higher number of accidents than operators, while fatality odds were higher for the operators. *Practical applications*: Safety professionals should benefit from our findings in planning and delivering training and providing oversight to workers in earthmoving equipment operations.

1. Introduction

Earthmoving equipment used for various soil and material handling tasks are essential assets in the construction industry. Among them, backhoes, bulldozers, excavators, and scrapers are frequently employed on project sites due to their versatility. Backhoe, for instance, is commonly used for excavating trenches, moving and loading soil, hoisting, as well as for light demolition. Operation of such equipment on construction sites produces complexities since space is often limited and may be constrained by competing project tasks and work crews, flow of materials, and installation of temporary facilities (Sadeghpour & Teizer, 2009). On-foot workers and earthmoving equipment often work in the same area, at the same time, and in close proximity to each other. Consequently, serious safety problems are likely to arise, especially when the related operations are not effectively managed.

According to the Bureau of Labor Statistics (BLS), there were 4,386 worker fatalities in the United States private industries in 2014, the highest annual total since 2008. About 899 (20.5%) of these cases were in construction, representing nearly one in five deaths among all workers. Fatal work injury rate per 100,000 full-time equivalent workers was 9.8 for the same year. Contact with objects, which includes mobile equipment and attachments, was responsible for 114 cases, constituting 13% of fatal accidents. In 30 of these cases, the primary source of fatal injury was identified as excavating machinery (backhoe, bulldozer, and excavator). In addition, there were 200,900 recordable nonfatal cases in the construction industry, which correspond to an incidence rate of 3.6, the 5th highest rate overall for 2014 (BLS, 2014).

Safety issues related to earthmoving equipment on construction sites include mishaps like workers being caught (pinned) between two mobile vehicles, or between a vehicle and a fixed object (e.g., wall or pump); site personnel struck by swinging attachments of equipment or crushed under overturned vehicles. Electrocution due to contact with overhead or underground power lines is also a commonly recognized hazard (Kazan, 2013).

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OSHA regulations for construction industry covering earthmoving and other heavy construction equipment are not specific enough to address the related hazards, and there is no dedicated OSHA standard for these equipment. Rather, OSHA covers different safety aspects for such equipment under different regulations (e.g., 29 CFR 1926.600, 29 CFR 1926.601, 29 CFR 1926.602, 29 CFR 1926.604, 29 CFR 1926.651; OSHA, 2016). Further, there are no federal or state statutes that currently require equipment operators, except for cranes, to be certified by a recognized body. While equipment manufacturers publish safe operating procedures and appropriate warnings for each machine they market, observations on industry practices suggest that following these instructions is at the discretion of the end user.

The underpinning goal of this study is to deepen our understanding of equipment accidents by explaining how frequently they occur under different sets of conditions existing onsite at the time of the accident, where these conditions are represented by various factors. Besides identifying and understanding the factors that contribute to accidents, our study focuses on determining the associations between significant factors and outcomes. Comparison of fatal and nonfatal cases is used as the metric for injury severity as previously adopted by Chi, Han, and Kim (2012). Moreover, distinction is made between the safety considerations for on-foot workers and equipment operators. The odds ratio is employed for quantification and ranking of the factors associated with injury severity. The analysis is limited to four types of earthmoving equipment; namely, backhoe, bulldozer, excavator, and scraper. Accident causation theories may consider contributing factors by grouping them under technical, human, and organizational variables. For example, Hamid, Majid, and Singh (2008) presented a fish bone model for construction accident causation using six factor categories of unsafe equipment, jobsite conditions, unique nature of the industry, unsafe methods, human elements, and management failures. In our study, we took a similar approach; however, we considered four factor categories, which were equipment characteristics, worker characteristics, safety culture characteristics, and accident characteristics.

In the rest of this paper, a literature review is presented, followed by the description of the research methodology, and presentation of results, discussions, and conclusions. The information and knowledge derived from this research is expected to help deepen the understanding of the factors involved in earthmoving equipment accidents resulting in worker fatalities and injuries, and lead to improved intervention strategies.

2. Literature review

Many studies on equipment accidents reported in the literature have been directed towards struck-by hazards. Pratt, Fosbroke, and Marsh (2001) highlighted that the majority of highway construction work zone fatalities in the United States involved workers being struck-by construction equipment or another type of vehicle. Hinze, Huang, and Terry (2005) analyzed struck-by accidents in construction recorded by OSHA between 1997 and 2000 and found that most accidents could have been eliminated if accident prevention programs had focused on major types of equipment and material involved in struck-by accidents. In another study, McCann (2006) examined heavy equipment and truck-related deaths on excavation work sites by construction industry fatality data between 1992 and 2002. Using frequency analyses, the researcher found that workers being struck by vehicles, especially when they were in back-up motion, and workers struck by vehicle loads and vehicle parts were the major causes of death for on-foot workers, while rollovers were the main cause of death for equipment operators. This research emphasized the importance of seat belts, rollover protective structures, restricted access zones around heavy equipment, and the need for spotters to warn workers near heavy equipment to reduce the risk of death. McCann also suggested that due to competing noises in the construction environment, audible back-up alarms were not always effective, and recommend further research into warning systems that alert the backing vehicle operator of nearby on-foot workers.

Hinze and Teizer (2011) investigated visibility-related fatality cases using OSHA data on equipment accidents, observing that back-up motion was involved in more than half of the cases. Ruff (2004) and Teizer, Allread, and Mantripragada (2010) also analyzed struck-by accidents due to poor visibility. Ruff (2004) examined the use collision warning technologies, such as camera systems and sensors, as safety devices. This research also revealed that there were challenges associated with implementing these types of systems, especially on trucks in the winter season or in congested highway work zones. Teizer et al. (2010) drew attention to blind spots that are prevalent around most construction equipment, emphasizing that accidents were common due to operators failing to identify the on-foot workers or fixed objects in close proximity of the work area.

A limited number of investigations have also been conducted for the mining industry that were considered relevant to our study. Md-Nor, Kecojevic, Komljenovic, and Groves (2008) performed risk assessments on fatal incidents involving loaders and dozers that occurred between 1995 and 2006 in the U.S. mining industry. The top five accident risks were found to be failure to provide adequate maintenance, lack of seatbelt use, failure to “respect” the work area, malfunctioning mechanical/electrical/hydraulic components, and not setting the parking brake before leaving. Furthermore, the study showed that the most frequent and severest hazards (highest risk) for the loaders were deficient maintenance procedures and failing mechanical, electrical, and hydraulic components. Groves, Kecojevic, and Komljenovic (2007) analyzed the equipment and machinery related injuries in the U.S. mining industry during the period 1995 through 2004, concluding that off-road, underground, and ore haulage vehicles were the most frequently encountered equipment in fatal cases. The authors underlined the need for more detailed demographic data for the mining workforce and suggested additional research on the characteristics of the operators of the different types of equipment.

Although past research on construction equipment covers a variety of factors affecting injuries and fatalities, it generally lacks focus on identifying the associations between risk factors and injury severity. It is clear from the above literature review that there has been heavy emphasis on the event type (e.g., struck-by cases) as a factor contributing to construction equipment accidents, often without differentiating between various equipment. The study presented herein focuses on four specific types of earthmoving equipment, using injury severity as the pivotal outcome, and cross-tabulation (crosstab) analysis is selected to determine the associations between the factors contributing to fatality or injury. It is important to recognize that injury severity has humanitarian connotations (e.g., pain and suffering by victims and families; Darshi De Saram & Tang, 2005), and it affects costs of accidents (Waehrer, Dong, Miller, Haile, & Men, 2007). In addition, helpful information can be generated by separating the on-foot workers from equipment operators. These two groups of workers may require different foci on hazard recognition and control regarding their activities, which may guide the design and implementation of training programs and field supervision.

3. Methodology

This section describes the data source and research methodology. Fig. 1 displays the logic diagram that was followed for data acquisition and organization. Data used in this research were acquired from occupational accident reports available on the OSHA website. Using a data filtering

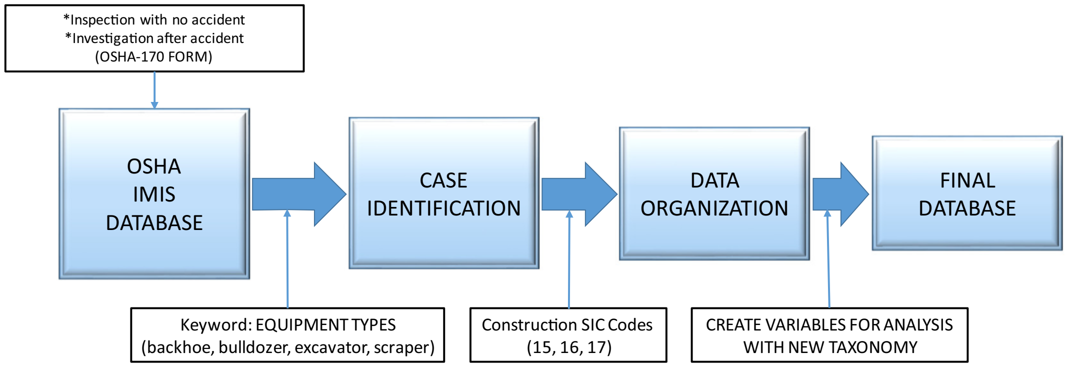

Fig. 1. Data acquisition and organization logic diagram.

approach by keywords, a total of 1,200 cases were identified, spanning the period from 1982 to 2014. Assistance from OSHA was received in drawing data from OSHA's Integrated Management Information System (IMIS) database. This database is regularly reviewed and validated by OSHA to ensure the overall accuracy and quality of the information (OSHA, 1998). The data on the IMIS database is derived from citations and finalized decisions, and it is rich with raw information. Organization and formatting of this data enable statistical analysis.

OSHA, by law, investigates all cases that result in fatalities from a work-related accident or any accident that involves inpatient hospitalization of one or more employees. In general, accidents involving construction equipment have severe outcomes on workers, due to large equipment size, mobility, and power. Most of such accidents end up with at least hospitalization if not resulting in fatality onsite. The IMIS database captures a great majority of the fatal accidents, as well as the accidents leading to hospitalization. A small fraction of the nonfatal accidents not requiring hospitalization is also included in the IMIS database; these cases were merged into the nonfatal injury category for the purposes of this research. It is also

Table 1
Research variables and their frequencies.

Variables	Values	Variables	Values
Equipment characteristics		**Worker characteristics**	
Equipment type	Backhoe	SIC code[a]	1623
	Excavator		1794
	Bulldozer		1611
	Scraper		1629
			Other (16)
Equipment part involved	Body/superstructure	Union status[a]	Non-union
	Equipment attachment		Union
	Carried/pushed load	Task assignment[a]	Not regularly assigned
	Other		Regularly assigned
		Occupational group	On-foot worker
			Operator
Back-up motion (OF)	Not present	**Safety culture characteristics**	
	Present	Safety program	Not present
			Present
Rollover protection system (EO)	Not present	Safety training	Not provided
	Present		Provided
Seat belt (EO)	Not present	Wearable worker protective system	Not used
	Present		Used
Back-up alarm	Not working	Protective systems installed on equipment	Not present
(OF)	Working		Present
		Equipment maintenance	Not adequate
			Adequate
Accident characteristics			
Degree of injury[a]	Nonfatal	Human factor[a]	Misjudgment of hazardous situation
	Fatal		Inappropriate choice/use of equipment/methods
Event type[a]	Struck-by		Inoperable/malfunctioning safety/warning devices
	Caught in or between		Insufficient engineering and administrative control
	Electrocution		Human system malfunction
	Fall from elevation		Distracting actions by others
	Other		Other
Environmental factor[a]	Material handling equipment/method	Activity prompting accident	Pipe installation/trench excavation
	Overhead moving/falling object action		Site grading and rock removal
	Squeeze point action		Lifting/rigging
	Work-surface/facility-layout condition		Site clearing and grubbing
	Pinch point action		Loading/unloading material/equipment
	Blind spot		Backfilling and compacting
	Flying object action		Riding equipment/on equipment
	Flammable liquid/solid exposure		Equipment maintenance
	Catch point/puncture action		Excavation other than trench
	Other		Demolition
			Other

[a] Original OSHA taxonomy; OF: On-foot worker; EO: Equipment operator.

acknowledged that there has been an unknown number of equipment-related accidents that are not recorded on the IMIS database during the period for which the data are analyzed; this represents a limitation for our study.

Categorical variables were constructed under four groups in our research as shown in Table 1, covering equipment, worker, safety culture, and accident characteristics. Each variable under a given characteristic consisted of various values (levels). All of these were extracted from the IMIS database by either using the original OSHA taxonomy, or a modified taxonomy developed by our research team. A total of 20 variables were created through this approach. The original OSHA taxonomy was directly adopted for seven of the variables (indicated by the asterisk sign in the table), while new, modified taxonomy was generated for the remaining 13 variables. The values for variables adopted from the original OSHA taxonomy was consolidated resulting in fewer values, ending up with more practical and easier to understand terminology. An example is the reduction of the number of values from 24 to 7 for the "human factor" variable through merging and collapsing them. If there are too many values with small observation counts, it might be difficult for a researcher to see any meaningful pattern (Kass, 1980). The hypothesis testing for proportions technique (Al-Ghamdi, 2002) was used to decide whether the different values could be merged and/or collapsed. Collapsing the values approach was applied when the number of values was high, but the number of observations was low. A significance level of 5% was used in merging. The variables of SIC code, event type, and environmental factor were handled in a similar fashion.

The construction of the variables and values that were not part of the original OSHA taxonomy required additional effort and refinement. Safety training is an example. Most of the construction safety literature suggest that safety training improves workers' hazard recognition skills and safety behavior (Hinze et al., 2005; McCann, 2006). After deciding to include safety training as one of the new categorical variables, OSHA citations issued to employers for safety training violations guided us in determining the values, as "provided" or "not provided" for each case. Note that if a citation was vacated by the Occupational Safety and Health Review Commission (OSHRC) after an appeal, such cases were considered as "provided."

In addition, it was recognized that certain variables were only relevant to a single occupational group, either on-foot worker (OF) or equipment operator (EO), as indicated in Table 1. Obviously, while seat belt usage is an important exposure for an operator, it has no relation to on-foot workers. Therefore, evaluating seat belt use for on-foot workers does not make much sense. Another example is the back-up alarm condition; this variable most likely has little or no relevance to equipment operator injuries.

The final dataset was input into the Statistical Package for Social Sciences software (version SPSS23). Two types of data analysis were performed. Frequency analysis was intended for data overview and classification, and crosstab analysis to examine the association between the variables and determine significance. Degree of injury (injury severity) was selected as the dependent variable. Two values were considered: fatality and nonfatal injury. Odds ratio was employed for quantifying the impact of the variables (factors) on the degree of injury as part of cross-tabulation, followed by ranking.

Frequency analysis was used to get an overall sense of the research variables, and for screening the data to determine the variables to be included in crosstab analysis.

Crosstab analysis was performed using three different data sets: (a) all data combined together (aggregate); (b) fatality or injury cases pertaining to equipment operators; and (c) cases where the on-foot workers were the victim. Bivariate crosstab analysis (Babbie, 2010) was performed to investigate whether a significant relationship existed between pairs of the research variables. A contingency table is formed as a matrix with rows representing the values of one categorical variable and columns representing those of another. In addition to establishing the frequencies of each value for a given variable, Pearson chi-square analysis is performed to determine the significance of the relationship (Sims, 1999). A p-value less than 0.05 based chi-square analysis is `accepted as significant, implying that there is an association between the variables examined in cross-tabulation. It is also possible to compute the odds ratio (OR) that represents the odds of the occurrence of an outcome (dependent variable) in the presence of an exposure (independent variable) compared with the odds of the outcome occurring in the absence of that exposure (Szumilas, 2010). OR is calculated by

$$\boldsymbol{OR} = \frac{\text{(n)occurrence of outcome when exposure present X (n)absence of outcome when exposure absent}}{\text{(n)absence of outcome when exposure is present X (n)occurrence of outcome when exposure absent}} \tag{1}$$

If OR is less than 1, it implies that exposure has a lowering effect on the risk of occurrence of the outcome. An OR greater than 1 is simply interpreted as the exposure having an increasing effect on the same outcome.

In addition to binary (2×2) crosstab analysis using dichotomous variables, multilevel ($2 \times k$) analyses were also performed to accommodate variables having more than 2 values. It is important to note, however, that odds ratio can only be calculated for the 2×2 contingency tables.

SPSS software used for data analysis in this research also allows to cross tabulate three variables by utilizing "layers;" the software automatically nests rows of cross-tabulation to include the third variable. Each cell of the contingency table displays the frequency for the appropriate combination of categories. This allows researchers to answer questions such as "how many fatal accidents occurred when an operator was not using a seat belt?"

4. Results and discussion

Table 2 summarizes the cross-tabulation results involving degree of injury and the independent variables found to be significant. The highest frequency of accidents, as well as fatalities, was observed for backhoe cases. This finding matches that of McCann (2006), although our research data covers more recent years. Among the four equipment types selected for this research, the backhoe is the most versatile and is therefore used for a variety of tasks on construction sites, functioning as an excavator or loader, and it sometimes serves as a mobile crane to lift or carry material. Furthermore, it is relatively smaller in size than a bulldozer or excavator and can travel at much higher speeds being wheel-mounted, rather than being on tracks. These characteristics make backhoes more popular on a wide range of construction work. On the other hand, these characteristics also create unique hazards depending on the task performed.

It is also observed in Table 2 that, while bulldozers are involved in slightly higher number of fatalities (200) than excavators (176), the accident occurrence rate is moderately higher for excavators (298) compared with bulldozers(248). Scraper shows the smallest number of accidents with fewest fatal and nonfatal injuries, 28 and 81, respectively.

Results presented in Table 2 indicate that workers are very frequently victims in accidents involving struck-by and caught in/or between events, collectively representing 82.4% of the cases. Other event types, electrocution, and fall from elevation (equipment) are much less frequent. Struck-by accidents have been the focus of many studies (e.g., Hinze et al., 2005), and our results specific to this exposure are in line with previous findings. McCann (2006) also reported that being struck by heavy equipment and being struck by equipment loads or parts, and caught-in between situations were the major causes of fatality.

The frequency distributions of the environmental factors cross-tabulated with the degree of injury point out that more than one-third of the incidents are related to "materials handling equipment or method," followed by "overhead moving and falling object action,"

Table 2
Cross-tabulation of degree of injury vs. research variables – aggregate data.

		Degree of injury		Total	p-Value
		Nonfatal	Fatal		
Equipment type	Backhoe	193 (16.1%)	352 (29.3%)	545 (45.4%)	*0.0002*
	Excavator	122 (10.2%)	176 (14.7%)	298 (24.8%)	
	Bulldozer	48 (4.0%)	200 (16.7%)	248 (20.7%)	
	Scraper	28 (2.3%)	81 (6.8%)	109 (9.1%)	
	Total	391 (32.6%)	809 (67.4%)	1200	
Event type	Struck-by	207 (17.3%)	449 (37.4%)	656 (54.7%)	*0.0003*
	Caught in or between	88 (7.3%)	244 (20.3%)	332 (27.7%)	
	Other	31 (2.6%)	45 (3.8%)	76 (6.3%)	
	Electrocution	27 (2.3%)	46 (3.8%)	73 (6.1%)	
	Fall from elevation	38 (3.2%)	25 (2.1%)	63 (5.3%)	
Environmental factor	Materials handling equipment/method	114 (9.5%)	300 (25.0%)	414 (34.5%)	*0.001*
	Overhead moving/falling object	57 (4.8%)	112 (9.3%)	169 (14.1%)	
	Squeeze point action	48 (4.0%)	115 (9.6%)	163 (13.6%)	
	Work-surface/facility-layout condition	45 (3.8%)	89 (7.4%)	134 (11.2%)	
	Other	38 (3.2%)	60 (5.0%)	98 (8.2%)	
	Pinch point action	25 (2.1%)	42 (3.5%)	67 (5.6%)	
	Blind spot	17 (1.4%)	40 (3.3%)	57 (4.8%)	
	Flying object action	21 (1.8%)	19 (1.6%)	40 (3.3%)	
	Flammable liquid/solid exposure	19 (1.6%)	12 (1.0%)	31 (2.6%)	
	Catch point/puncture action	7 (0.6%)	20 (1.7%)	27 (2.3%)	
Human factor	Misjudgment of hazardous situation	163 (13.6%)	389 (32.4%)	552 (46.0%)	*0.0034*
	Inappropriate choice/use of equipment/method	68 (5.7%)	170 (14.2%)	238 (19.8%)	
	Inoperable safety/warning device	65 (5.4%)	106 (8.8%)	171 (14.2%)	
	Other	67 (5.6%)	83 (6.9%)	150 (12.5%)	
	Insufficient engineering/admin controls	13 (1.1%)	47 (3.9%)	60 (5.0%)	
	Human system malfunction	10 (0.8%)	11 (0.9%)	21 (1.8%)	
	Distracting actions by others	5 (0.4%)	3 (0.3%)	8 (0.7%)	
Safety training	Provided	272 (22.7%)	383 (31.9%)	655 (54.6%)	*0.0000*
	Not provided	119 (9.9%)	426 (35.5%)	545 (45.4%)	
Wearable worker protective system	Used	317 (26.4%)	577 (48.1%)	894 (74.5%)	*0.0003*
	Not used	74 (6.2%)	232 (19.3%)	306 (25.5)	
Protective systems installed on equipment	Present	348 (29%)	625 (52.1%)	973 (81.1%)	*0.0000*
	Not present	43 (3.6%)	184 (15.3%)	227 (18.9%)	
Equipment maintenance	Performed	320 (26.7%)	599 (49.9%)	919 (76.6%)	*0.003*
	Not performed	71 (5.9%)	210 (17.5%)	281 (23.4%)	
SIC code	Other	120 (10%)	230 (19.2%)	350 (29.2%)	*0.001*
	1623	109 (9.1%)	182 (8.5%)	291 (24.3%)	
	1794	85 (7.1%)	151 (12.6%)	236 (19.7%)	
	1611	47 (3.9%)	117 (9.8%)	164 (13.7%)	
	1629	30 (2.5%)	129 (10.8%)	159 (13.3%)	
Union status	Non-union	259 (21.6%)	660 (55%)	919 (76.6%)	*0.0000*
	Union	132 (11%)	149 (12.4%)	281 (23.4%)	
Task assignment	Regularly assigned	358 (29.8%)	707 (58.9%)	1065 (88.8%)	*0.032*
	Not regularly assigned	33 (2.8%)	102 (8.5%)	135 (11.3%)	
Occupational group	On-foot worker	294 (24.5%)	494 (41.2%)	788 (65.7%)	*0.001*
	Operator	97 (8.1%)	315 (26.3%)	412 (34.3%)	
	Total	391 (32.6%)	809 (67.4%)	1200	

"squeeze point action," and "work-surface or facility-layout condition." The same order more or less appears for fatal accident frequencies. Clearly, fatal cases signifying injury severity are considerably more frequent than nonfatal cases.

Misjudgment of hazardous situation (46.0%), inappropriate choice or use of equipment or methods (19.8%), and inoperable safety or warning device (14.2%) surface as leading human factors categories in accident frequency. Fatal accident frequencies show the same trend, 32.4%, 14.2%, and 8.8%, respectively. The "other" category, observed in 12.5% of the cases, was identified as such by the investigating OSHA compliance officer without providing further details.

Table 2, overall, highlights that, while 45.4% of the cases entailed OSHA citation because adequate safety training was not provided to workers in compliance with safety regulations, in the remaining 54.6% of the cases compliance with safety training regulation did not come out to be an issue. This suggests that accidents can occur even when the victims were provided proper safety training. However, it was observed that lack of adequate safety training was a factor in considerably more fatal cases (35.5%) than nonfatal cases (9.9%), representing a significant association between safety training and injury severity.

The table additionally shows that in 25.5% of the cases, the victims were not using a wearable worker protective system such as hard hats, reflective vests, and so on at the time of the accident. Further, fatality occurred in 19.3% of the cases in which a wearable worker protective system was not used. Nevertheless, in 74.5% of the cases, victims were using wearable protective systems, but fatalities were still at a high frequency (48.1%). Similarly, in 18.9% cases, equipment protective systems were inadequate; they were either missing or malfunctioning for roll-over protection systems, hydraulic controllers, audible alarms, horns, or brakes. In 15.3% of the cases, related equipment protective systems were not installed or were in poor working condition. Again, in 81.1% of the cases, there were no problems with the protective systems when the accident occurred, leading to a high fatality frequency of 52.1%. These results collectively show that wearing protective gear, or having properly installed and functional equipment protective systems do not necessarily save the worker from injury or fatality.

OSHA requires that before starting work, a maintenance check must be performed on the equipment to ensure safety. Our results indicated that equipment maintenance was not performed in only 23.4% of the cases, while it was not a problem for a large majority (76.6%) of the accidents. It was further discovered that performing maintenance checks did not prevent fatality in about half of the cases (49.9%).

SIC code information provided in Table 2 displays the diversity of worker groups involved in the accidents incorporated in the OSHA IMIS database. Accident, fatality, and nonfatal injury frequencies are shown for workers classified in SIC codes 1623 (water, sewer, pipeline, communication, & power line construction), 1794 (excavation work), 1629 (heavy construction) and 1611 (highway and street construction). The reason for having the largest percentages (29.2%) for the "other" category is that they cover 16 additional SIC codes that have minor frequencies (Kazan, 2013).

Union status of the victim is also classified by OSHA in its database. Our analysis revealed that a much larger percentage of the victims (76.6%) were non-union, compared with those belonging to a union (23.4%). In addition, the fatality frequency stood out to be 55% of 919 total non-union workers recorded in the database, in contrast to a much lower fatality frequency for union workers (12.4%). It is important to note, however, that the number of non-union workers is much higher than union workers in the construction industry (BLS, 2016), hence these results might be somewhat indicative of the non-union/union ratio. On the other hand, union workers receive more organized and extensive job skills and safety training that may play a role in this finding (Gillen, Baltz, Gassel, Kirsch, & Vaccaro, 2002).

Results in Table 2 further disclosed that a great majority of the victims (88.8%) were working on their regularly assigned tasks when the accident happened, while only 11.3% of the victims were new to the tasks they were assigned. Interestingly, more than half of the fatalities occurred when workers were engaged in their regularly assigned tasks. It is generally believed that new workers are more susceptible to experiencing accidents than experienced workers (Breslin & Smith, 2006), so this outcome needs further investigation.

A notable finding in this research is that 809 (67.4%) of the cases analyzed resulted in fatalities, while 391 (32.6%) ended up in nonfatal injuries. The higher percentage of worker fatalities observed are indicative of the likelihood of severe consequences when an accident occurs during work activities involving heavy equipment. Mobility of equipment with power, speed and size, lack of effective site planning and control, and inadequate training contribute to this phenomenon.

Finally, an important distinguishing variable in this research is victim's occupational group. In viewing Table 2, it is noted that 788 on-foot workers fell victim to an accident, constituting 65.7% of the total cases, while 412 (34.3%) were equipment operators. In addition, on-foot workers were killed in 494 cases (41.2%), whereas equipment operators suffered fatalities in 315 cases (26.3%).

Four variables in our dataset are specific to the occupational group (see Table 1). The results presented in Tables 3–5 highlight findings for on-foot workers, while Tables 6 and 7 relate to equipment operators. Table 3 on degree of injury versus on-foot worker- specific variables, exhibits the results of crosstab analysis for degree of injury versus back-up motion, and versus back-up alarm condition. It is observed that 19.2% of the accidents occurred when the equipment was traveling in the reverse direction (back-up motion), and 14.5% of these accidents resulted in fatalities. Nonfatal injury frequency for reverse direction cases was considerably less (4.7%). It is also noted that 75 (9.5%) of the cases involved equipment that did not have working back-up (audible) alarms. In 61 (7.7%) of the cases, the accident led to fatality. Only 14 cases (1.8%) resulted in nonfatal injuries when the back-up alarm was not functioning.

Taking a step further, a layered cross tabulation analysis was conducted for degree of injury and equipment type when the equipment was in back-up motion. As seen in the Table 4, backhoes and bulldozers were together responsible for 60.9% of the back-up accidents. It is also observed that fatality resulted in 25.8% cases when bulldozers were in reverse motion, followed by backhoes (22.5%), scrapers (19.2%), and excavators (7.9%).

Table 5 further reveals that in 56.3% of the 151 cases, even though the back-up alarm was working while equipment was moving in reverse direction, it was not helpful in alerting the on-foot workers present in the danger zone. It is possible that multiple back-up alarm signals from various vehicles at the same time may have influenced workers' judgment, making the signal(s) ineffective. Therefore, in such cases, the job site noise level may have drowned out the back-up alarms. An additional analysis into the 85 cases where on-foot workers were involved in an accident while an equipment was backing up with a functioning alarm, 45 cases were recorded by OSHA as misjudgment of hazardous situation under the human factor category.

Table 6 summarizes the results of crosstab analysis for degree of injury versus seat belt, and versus rollover protection system (ROPS). While the seat belt variable was found to be statistically significant in relationship to degree of injury, ROPS was not. It is noted missing, defective, or inoperable seatbelts are few in number (59), representing 14.3% of the 412 cases. However, 53 of 59 such accidents resulted in fatality, showing the high level of associated risk. In contrast, in 353 (85.7%) of the cases were designated as seat belt being in good condition. Yet, 63.6% of these accidents still resulted in a fatality. It is also observed in the table that, in 92.5% of the accidents the equipment had ROPS, but the operator died in 70.1% of the cases, indicating that ROPS in and of itself cannot prevent an injury or fatality.

Continuing with seat belts, the 353 cases covered in Table 7 underline the fact that having a seat belt in the equipment does not necessarily mean that it will be used. Further layered analysis between degree of injury and seat belt usage, revealed that in 102 (28.9%) of the cases, seat belts were in place and operable; however, operators chose not to use them. It is not surprising that 77 (21.8%) of these accidents resulted in fatalities; however, there is no statistically significant relationship between two variables based on p-value.

The odds ratios calculated as part of crosstab analyses are presented in ranking order in Figs. 2 and 3, respectively, for aggregate data, and for on-foot workers and operators. In this paper, odds ratios signify the

Table 3
Degree of injury vs. on-foot worker specific variables.

		Degree of injury		Total	p-Value
		Nonfatal	Fatal		
Back-up motion	Not present	257 (32.6%)	380 (48.2%)	637 (80.8%)	*0.003*
	Present	37 (4.7%)	114 (14.5%)	151 (19.2%)	
	Total	294 (37.3%)	494 (62.7%)	788	
Back-up alarm	Not working	14 (1.8%)	61 (7.7%)	75 (9.5%)	*0.002*
	Working	280 (35.5%)	433 (54.9%)	713 (90.5%)	
	Total	294 (37.3%)	494 (62.7%)	788	

Table 4
Degree of injury vs. equipment type when equipment is backing up.

		Degree of injury		Total	p-Value
		Nonfatal	Fatal		
Equipment type	Backhoe	10 (6.6%)	34 (22.5%)	44 (29.1%)	*0.002*
	Bulldozer	9 (6.0%)	39 (25.8%)	48 (31.8%)	
	Excavator	12 (7.9%)	12 (7.9%)	24 (15.9%)	
	Scraper	6 (4.0%)	29 (19.2%)	35 (23.2%)	
Total		37 (24.5%)	114 (75.5%)	151	

Table 5
Degree of injury vs. back-up alarm during back-up motion.

		Degree of injury		Total	p-Value
		Nonfatal	Fatal		
Back-up alarm	Not working	13 (8.6%)	53 (35.1%)	66 (43.7%)	*0.023*
	Working	24 (15.9%)	61 (40.4%)	85 (56.3%)	
Total		37 (24.5%)	114 (75.5%)	151	

Table 6
Degree of injury vs. operator specific variables.

		Degree of injury		Total	p-Value
		Nonfatal	Fatal		
Seat belt	Not present	6 (1.5%)	53 (12.9%)	59 (14.3%)	*0.009*
	Present	91 (22.1%)	262 (63.6%)	353 (85.7%)	
	Total	97 (23.5%)	315 (76.5%)	412	
ROPS	Not present	5 (1.2%)	26 (6.3%)	31 (7.5%)	*0.312*
	Present	92 (22.3%)	289 (70.1%)	381 (92.5%)	
	Total	97 (23.5%)	315 (76.5%)	412	

odds that fatality will be higher than nonfatal injury when a certain variable/factor associated with an accident is considered.

According to the odds ratios given in Fig. 2, the highest odds of fatality are for safety training, followed by equipment protective systems, union status, occupational group, and equipment maintenance. It is found that workers who were not trained according to OSHA regulations are 2.54 times more likely to be the victim of a fatal accident than those who were trained. Importance of safety training has been well acknowledged by various authors (Hinze et al., 2005; McCann, 2006). The fact that odds are measurably increased for fatal accidents when appropriate training is not provided is further validation of this opinion.

The figure also indicates that fatality chances increase 2.38 times when there is some missing protective system installed on equipment. Referring back to Table 2, it is noted that presence of equipment protective systems anomalously increases the number of fatalities. The odds ratio given here corrects this anomaly.

The odds ratio for non-union construction workers indicates that their risk is 2.26 times greater for being involved in a fatal accident than union workers. This finding is supported by a previous study by Gillen et al. (2002), which claimed that union workers in construction were more likely than nonunion workers to perceive that their supervisors care about their safety; to be made aware of dangerous work practices; to have received safety instructions when hired; to have regular job safety meetings; and to perceive that taking risks was not a part of their job. Regarding occupational group, the odds ratio suggests that operators are 1.93 times more likely to experience death in an accident than on-foot workers. It is further noted that when adequate maintenance is not performed, this may lead to using equipment with missing or inoperable safety protective systems. Additional analysis revealed that missing equipment protective systems were associated with maintenance problems in 183 cases. Risk of fatality is increased 1.58 times collectively for on-foot workers and operators when equipment maintenance is substandard.

Odds ratios for on-foot worker specific and for operator specific variables are graphed in Fig. 3 in ranking order for each. The figure shows that an on-foot worker is 2.08 times more likely to be involved in a fatal accident when the equipment is in back-up motion. Also, odds for fatality are 1.6 times greater when an accident involves an equipment in back-up motion and without a well-functioning alarm system. These results are consistent with other research (Hinze & Teizer, 2011; McCann, 2006; Teizer et al., 2010), which emphasizes blind spots located in various areas around equipment that can contribute to such accidents.

As also seen in Fig. 3, operators riding earthmoving equipment with a missing or defective seat belt are 3.07 times more likely to die in an accident, compared with cases where a seat belt is present in the equipment. When the odds ratio was calculated for seat belt use by operators, even though it was nonsignificant, it was found that not using seat belts when available increases the odds of fatality, but only by 1.1 times. In further analysis confined to rollover and overturn accidents, the odds ratio was increased to 3.27 with a p-value showing statistically significant association. McCann (2006) disclosed that fastening seat belts might have prevented at least one-quarter of operator deaths in rollover accidents; this finding compares well with our results. By fastening seatbelts, operators reduce the odds of being a victim to a fatal accident during a rollover and overturning accident and avoid being thrown off of the equipment.

Table 7
Degree of injury vs. seat belt use.

		Degree of injury		Total	p-Value
		Nonfatal	Fatal		
Seat belt	Not used	25 (7.1%)	77 (21.8%)	102 (28.9%)	*0.7281*
	Used	66 (18.7%)	185 (52.4%)	251 (71.1%)	
Total		91 (25.8%)	262 (74.2%)	353	

5. Conclusions

This study extended the existing knowledgebase on factors affecting construction equipment accidents in two ways: (a) through further analysis on the variables that were incorporated in previous studies, encompassing 7 additional years of new data (2007–2014); (b) by constructing new variables pertinent to earthwork equipment injuries and performing similar analysis on them. As a result, we were able to improve our understanding of the factors involved specifically in earthmoving equipment accidents and introduced new knowledge by characterizing injury severity. In addition, the differences between accident exposures and impacts for on-foot workers and equipment operators were examined, while establishing associations between multiple variables at a more detailed level than what was achieved in past research.

The findings presented in this paper are based on data drawn from the OSHA IMIS database, which contains construction cases that have led to OSHA investigations and reports. Any accidents that were not recordable and thus not included in this database were not covered in our study. Overall, our findings are in general agreement with those of previous researchers, while we have been able to extend the existing knowledge by calculating odds ratio for each significant factor and ranking them, we were able to identify how each contributing factor increases the odds of fatality and by how much. Knowing what the odds are reveals important information that can be used to develop strategy for fatal accident reduction.

Based on the analysis of the available historical data, it is possible to list our conclusions in two categories; equipment-related and worker-related:

Equipment-related conclusions:

- A majority of the earthmoving equipment related accidents results in fatality.
- Accidents and fatalities show the highest frequency with backhoes and bulldozers.
- Struck-by accidents exhibit the highest accident and fatality frequencies.
- Material handling equipment and methods are responsible for the largest percentage of accidents and fatalities.
- Equipment maintenance has an important effect on the occurrence and severity of accidents. Inadequately maintained equipment has an increasing effect on the odds of fatality.
- For the types of equipment and accidents studied, fatalities show higher frequencies than nonfatal injuries while workers are carrying on their regularly assigned tasks. Site-specific and refresher training should improve safety even for experienced workers.
- Wearable personal protective equipment, while important to worker safety, do not prevent earthmoving equipment accidents in many cases; neither do they reduce injury severity.
- Missing equipment protective systems (missing or defective seatbelts, inoperable backup alarms) increase the odds of fatality for on-foot workers and operators (by 2.38). For operators only, this factor increases the fatality odds by 3.07.

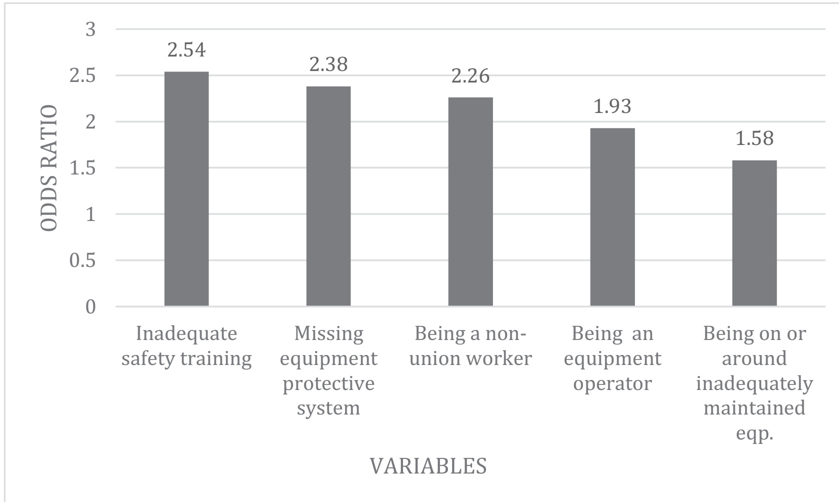

Fig. 2. Ranking of odds ratios – aggregate data.

Worker-related conclusions:

- Misjudgment of hazard leads all other human factors in fatal and nonfatal accidents.
- In cases of rollover accidents, the odds of fatality are relatively high (2.07) when seatbelts are not used by operators.
- When equipment is in reverse motion, and it does not have an operating alarm system, the odds of fatality are high for on-foot workers. An accident during reverse motion is twice more likely to result in fatality.
- On-foot workers experience a higher number of accidents than operators; however, odds of fatality are higher for operators than on-foot workers (1.98 times).
- Safety training is important for accident prevention; yet, accidents and fatalities can occur even when workers are given OSHA compliant training. On the other hand, fatality odds are 2.54 times higher for all workers (on-foot workers and operators combined) who are involved in equipment-related accidents when OSHA compliant safety training is not provided.

Although having some limitations, the OSHA IMIS database can allow future researchers to examine other dependent and independent variables to uncover new safety-related information and knowledge through a process similar to the one presented in this paper. For instance, the data can be filtered by using a SIC code to focus on a specific trade, or on certain types of accidents (e.g., rollover), or specific hazards like the OSHA Focus Four (Kazan, 2013). Such studies can also include logistic regression modeling, decision tree analysis, neural networks, and other methodologies to model multivariate associations. Separately, effects of human factors, environmental factors, and behavioral safety approaches in preventing earthmoving equipment accidents can also be further investigated using the same database.

6. Practical applications

The findings of this study are expected to help construction project managers and safety professionals to better identify and understand the equipment- and worker-related safety hazards and risks to devise countermeasures and intervention strategies for improving safety. For example, specific attention could be directed to selecting the type of equipment for a given operation according to the risks involved. As a countermeasure, safety monitors could be used for site operations involving reverse motions to reduce fatalities and injuries. Further, deficient maintenance and inspection programs, including checklists, could

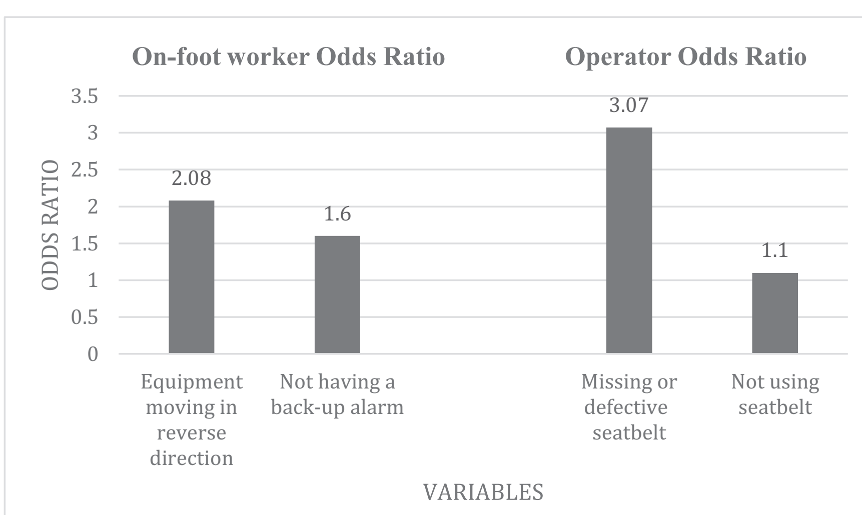

Fig. 3. Ranking of odds ratios based on occupational function.

be improved to ensure proper functioning of seatbelts and backup alarms to create a safer workplace.

The conclusions presented in this paper should also be valuable in planning and managing company and site-specific training programs effectively. For example, the content of the training program could focus on the higher-risk equipment, such as backhoes and bulldozers as appropriate to the project. The different hazard exposures highlighted in this study for on-foot workers and operators could be considered in delivering focused training to these two worker groups. Another example may be site design for avoiding frequently injury-causing situations, such as workers getting struck-by overhead moving objects or by equipment attachments, or caught in or between events.

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