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Aerial lift fall injuries: A surveillance and evaluation approach for targeting prevention activities

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Abstract

Problem: Work on aerial lift platforms exposes workers to fall hazards. The objective of this study was to identify the most common injury scenarios and determine current research gaps for addressing fall incidents associated with aerial lifts. *Methods:* Three databases were searched: Census of Fatal Occupational Injuries (CFOI), NIOSH Fatality Assessment and Control Evaluation (FACE) reports, and OSHA Incident Investigation Records. *Results:* The majority of falls/collapses/tipovers were within the height-category of 10–29 feet. Tip-overs comprised 44–46% of boom-lift falls and 56–59% of scissor-lift falls. Constructing and repairing activities were most commonly associated with fall/collapse/tipover incidents. *Discussion:* CFOI and OSHA/FACE show convergent data, suggesting similar scenarios for aerial lift tipovers. *Impact on Industry:* The analysis provides the aerial lift industry information to prioritize their efforts on aerial lift design.
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Keywords: Fall incidents; Aerial lifts; Injury surveillance; Equipment failure; Human error

1. Introduction

Aerial lifts consist of vehicle-mounted elevating and rotating aerial platforms (bucket trucks), boom-supported elevating platforms (boom lifts), and elevating work platforms (mostly scissor lifts; Burkart, McCann, & Paine, 2004). Boom lifts can have the platform extending beyond the wheel base of the supporting structure. The platforms can be extended by telescoping booms or articulating booms that have joints. Scissor lifts are elevating platforms that do not extend beyond the wheel base of the structure.

In 1991, the Occupational Safety and Health Administration (OSHA) published a report on 34 fatal incidents involving 35 deaths from 1986–1990 related to bucket trucks (OSHA, 1999a,b). One-third of the cases involved failure of equipment or were material- or facility-related; 40% of the deaths involved falls. A Center to Protect Workers' Rights (CPWR) surveillance study of fatal falls in construction during 1997 found that aerial lifts were involved in 18 (5%) of 364 fall deaths identified from the Census of Fatal Occupational Injuries (CFOI) data (McCann & Chowdhury, 2000). Between 1992 and 1999, CFOI data identified 339 deaths – an average of 42 per year – in construction related to the use of personnel lifts. The personnel lifts most frequently involved in these deaths were aerial lifts (61%). The major causes of death involving aerial lifts were falls from elevation and collapses/tipovers (51%). Major construction trades involved in the personnel

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Table 1
Style of Lift vs Method of Propulsion in Aerial Lift Deaths, 1992–2003

Style of lift	Propulsion			Total
	Manually propelled	Self propelled	Truck mounted	
Scissor	-	75	-	78
Articulated boom	-	-	-	5
Telescoping boom	-	-	19	23
Unspecified boom	-	20	180	200
Total	-	102	201	306

-Data do not meet BLS publication criteria.
Source: U.S. Bureau of Labor Statistics CFOI Research File.

Table 2
Height Information in Fatal Falls Associated with Aerial Lifts, 1992–2003

Lift Type	Boom Lift		Scissor Lift	
Height	of Fall	of Lift	of Fall	of Lift
<10	6	-	-	-
10–19	17	-	15	-
20–29	31	5	21	-
30–39	22	9	8	-
40–49	14	-	-	-
50–59	8	-	-	-
60–69	6	-	-	-
70–79	-	-	-	-
80+	5	-	-	-
Total	111	27	52	5

-Data do not meet BLS publication criteria.
Note: Cases with missing values are excluded from the table.
Source: U.S. Bureau of Labor Statistics CFOI Research File.

lifting deaths were electrical workers, construction laborers, painters, ironworkers, and carpenters (McCann, 2003).

According to the CFOI data, falls from vertical lifts accounted for 28 (44%) of 64 vertical lift deaths, almost all involving scissor lifts (McCann, 2003). Tipovers of scissor lifts mostly occur while the lift is elevated over 15 feet, especially while the lift is moving (McCann). Scissor lifts are available that can reach between 20 and 75 feet. At such heights, the stability of the lift and worker are of great concern. Scissor lifts with wheel bases as narrow as 17 inches to fit through doors increases their instability. The use of rollout platform extensions on the scissor lift platform also decreases stability since the extension extends beyond the wheel base, affecting the center of gravity. Workers performing pulling or pushing activities while the platform is elevated to such heights can exert horizontal forces that the scissor lift is not designed to withstand. This is a concern, especially when the platforms are extended horizontally beyond the base of the scissor lift. The growing popularity of this type of scissor lift in construction could lead to increased numbers of injuries if preventive action is not taken (Lift and Access, 2004, 2005, 2006).

The National Institute for Occupational Safety and Health (NIOSH), in collaboration with the National Safety Council and the CPWR, conducted a surveillance study of aerial platform falls/collapses/tipovers across all industry classifications. This collaborative study's objective was to identify circumstances surrounding fall incidents to establish research priorities for addressing fall incidents associated with aerial lifts. In response to the surveillance findings, NIOSH developed an engineering evaluation project to determine the nature of the physical loadings, environmental and safety factors influencing aerial lift stability, and potential for falls, and also to determine possible design and engineering interventions to reduce fall-hazard incidents. Descriptive statistics from aerial-lift injury surveillance related to case and worker characteristics were used to inform working hypotheses about contributory factors leading to risk of injury, and to formulate the mathematical and simulation models used to further study the factors that could be modified by equipment and task redesign. The purpose of the current study is to model lift and task characteristics that can be redesigned to increase safety margins for workers.

2. Methods

Three databases were used to analyze aerial lift fall incidents: (a) Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI) data (1992–2003); (b) Occupational Safety & Health Administration (OSHA) Incident Investigation Records (1990–2003); (c) and NIOSH Fatality Assessment and Control Evaluation (FACE) reports (1985–2002).

The CFOI program is a multi-source data system that attempts to document all work-related injury deaths nationwide. The database includes both coded and narrative data on each fatally injured person. The coding system used by BLS is the Occupational Injury and Illness Classification System (OIICS), which has categories for nature of injury (e.g., traumatic injury), body part injured (e.g., head), source of injury (e.g., ground), secondary source of injury (e.g., scissor lift), and event or exposure (e.g., fall to lower level, n.e.c.).

Table 3
Aerial Lift Deaths by Manner of Fall and Activity, 1992–2003

Activity	Fall from	Tipover/ Collapse	Ejection	Total
Boom Lifts				
Constructing and repairing	27	38	31	96
Logging, trimming and pruning	18	23	19	60
Vehicular and transportation operations	5	22	16	43
Other activities	8	18	-	29
Boom Lift Total	58	101	69	228
Scissor Lifts				
Constructing and repairing	19	18	-	39
Vehicular and transportation operations	-	17	-	22
Painting and cleaning	7	6	-	13
Other activities	-	-	-	17
Scissor Lift Total	31	44	-	78

-Data do not meet BLS publication criteria.
Source: U.S. Bureau of Labor Statistics CFOI Research File.

Table 4
Style of Aerial Lift vs Method of Propulsion, OSHA/FACE

Style of Lift	Propulsion			Total
	Manually propelled	Self propelled	Truck mounted	
Scissor	1	21	4	26
Articulated boom	0	1	17	18
Telescoping boom	0	0	2	2
Unspecified boom	0	6	37	43
Total	1	28	60	89

Relevant cases were identified in the CFOI database through source of injury codes and key word searches of the CFOI narratives. The source of injury codes used to identify cases involving aerial lifts were the following: 3461 (bucket or basket hoist—truck mounted), 3466 (manlift), 8515 (platform lift truck—high or low lift), and 8516 (reach rider lift truck). The narratives of cases identified by these codes were reviewed to confirm that an aerial lift was involved and not some other kind of equipment. One hundred twenty five cases were identified this way. Key word searches (aerial, lift, scissor, bucket, basket, and boom) identified an additional 64 cases for a total of 189 cases involving aerial lifts. Narrative information in the CFOI files were used to assign codes, such as style of lift, means of propulsion, worker activity, movement of lift prior to injury event, type of surface, and height of fall. Tables 1–8 and Figs. 1–9 are taken from CFOI, OSHA Investigation Reports, and FACE Reports, and are included here to provide characterization of the source of injury, location of incident, age of worker at death, and additional descriptive information related to the incident. This information is of value in establishing environmental and task conditions for modeling hazardous exposures, and for establishing the parameters for human subjects and simulated workstation designs for further study in a laboratory setting.

In addition, we evaluated OSHA worksite investigations from 1990–2003, which occur in response to employer reports of fatal and serious injuries and for purposes of encouraging compliance with OSHA regulations. Key words were used to identify deaths and injuries associated with aerial lifts from information on the OSHA website, and the OSHA Office of Statistics provided records in the form of an Access database file for further analysis and coding.

Table 5
Work Activity by Manner of Fall and Type of Lift, OSHA/FACE Records

Activity	Fall From	Ejection	Tipover	Total
Boom Lifts				
Constructing and repairing	10	13	13	36
Logging, trimming and pruning	7	6	11	24
Vehicular and transportation operations	1	2	10	13
Painting and cleaning	3	1	1	5
Other activities	1	1	3	5
Boom lift total	22	23	38	83
Scissor Lifts				
Constructing, assembling, repairing, etc.	11	0	18	29
Painting and cleaning	7	0	3	10
Vehicular and transportation operations	1	0	5	6
Other activities	3	0	6	9
Scissor lift total	22	0	32	54

Table 6
Height Information Associated with Falls from Aerial Lifts, OSHA/FACE

Height (ft.)	Boom Lifts			Scissor Lifts		
	Of Work Area	Of Bucket/ Basket	Of Fall	Of Work Area	Of Platform	Of Fall
<10	6	7	4	8	9	4
10–19	13	14	16	22	22	23
20–29	16	15	15	21	21	21
30–39	9	9	8	4	3	3
40–49	11	12	12	0	0	0
50–59	11	10	10	0	0	0
60–69	4	4	4	0	0	0
70+	4	3	4	2	1	2
Total reported cases	74	74	73	57	56	53

NIOSH supports in-depth case-based investigations of targeted types of occupational injury deaths, including those associated with machinery, through the FACE program. Investigations are conducted by NIOSH and a number of collaborating state-based FACE programs, which are supported by NIOSH. Each investigation results in a detailed narrative report that is posted on the NIOSH website and publicly disseminated and accessible for research purposes. Keyword searches were used to identify FACE reports involving aerial lifts. Information in the narrative reports was used to assign codes (e.g., work activities, lift movement, surface conditions) for analysis. The FACE and OSHA databases were matched to identify unique cases, and information from both systems was combined.

Policy established by the Bureau of Labor Statistics for working with the CFOI research file prohibit matching it with other databases to prevent identification of decedents through the cross-referencing of established data sources, with the possibility of identifying data that would normally be censored (Letter of Agreement Between Bureau of Labor Statistics and National Safety Council [Agreement #CFOI 95-03a]). To maintain compliance with CFOI data confidentiality requirements, the authors analyzed and presented CFOI and OSHA/FACE databases separately.

3. Results

Analyses and implications of this study are primarily descriptive. Comparative analyses are based on proportions

Table 7
Fall Protection Mentioned, FACE/OSHA Records

Type	Scissor Lifts	Boom Lifts
Guard rails, chains, gates/doors	9	0
Belts, harnesses with or without lanyards	4	30
Total	13	30

Table 8
Surface Condition of Aerial Lift Location (OSHA/FACE)

		Style of Lift		Total
		Scissor	Boom	
Surface Condition	Hole(s)	7	0	7
	Sloped	0	7	7
	Uneven	4	0	4
	Unstable	1	0	1
	Edge	4	1	5
Total		16	8	24

(e.g., between types of aerial lifts), not rates, because denominator information is not known and cannot readily be established for the number of workers using the various lifts (McCann, 2003).

3.1. CFOI

Three hundred and six aerial lift fatalities (228 boom lifts and 78 scissor lifts) occurring between 1992 and 2003 were identified. Twenty-six aerial lift fatalities could not be definitively classified as boom or scissor and therefore were excluded from this analysis. Table 1 shows the lift style/propulsion combinations that could be discerned from the narratives. Thirty-nine percent of boom lift fatalities (n = 89) and 74% of scissor lift fatalities (n = 58) occurred in the construction industry. Ninety-three percent (n = 206) of the 221 boom lift incidents involved only one worker in the boom lift, and 7% (n = 15) involved two workers. Fig. 1 shows the number of boom and scissor lift fatalities by year.

Time with employer was reported in 31% of the boom lift cases and 24% of scissor lift cases. Where reported, 26% of boom lift operators and 37% of scissor lift operators had been working for their employer for one year or less.

All of the CFOI cases involved males. Deaths occurred across all age groups with the greatest number of deaths in the age group 35–44 years for both boom lift cases (81 deaths or 36%) and scissor lift cases (22 deaths or 28%; Fig. 2).

Height of fall or height of lift at time of fall was reported in 61% of boom lift fatalities and 73% of scissor lift fatalities.

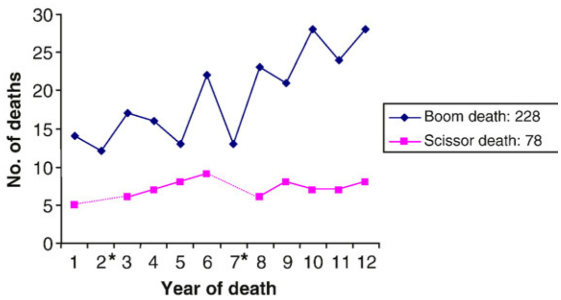

Fig. 1. Aerial lift fatalities by year, 1992–2003. * Data (dash line) do not meet BLS publication criteria. *Source: U.S. Bureau of Labor Statistics CFOI Research File.*

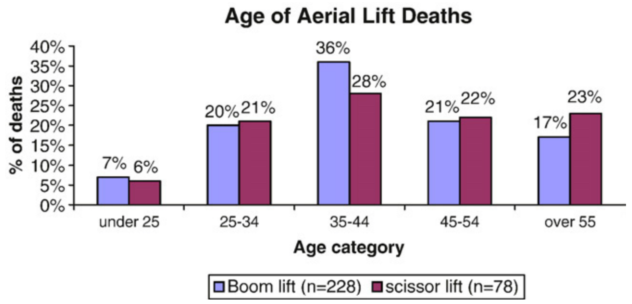

Fig. 2. Age of Aerial Lift Deaths, 1992–2003. *Source: U.S. Bureau of Labor Statistics CFOI Research File.*

A fall or lift height of 10–29 feet was reported for 35% of boom lift cases and 70% of scissor lift cases where height was reported (Table 2).

The nature of injury and part of body analyses indicated that most of the fatal injuries involved the head or multiple internal injuries. The initial event was most often the fall itself. The most frequently reported source of injury was the ground for boom lifts (46%) and floor of building for scissor lifts (41%; Fig. 3). CFOI defines the secondary source of injury as the object that generated the source of injury or contributed to the event. For both boom and scissor lifts, the most common secondary source of injury was the lift itself.

Location of the incident was most commonly construction sites (41%) and industrial setting (31%) for scissor lifts, and a street or highway (30%), followed by industrial settings (15%) for boom lifts (Fig. 4).

Three types of falls are considered in this analysis: fall *from* basket/bucket/platform, ejection, and tipover/collapse. For both scissor lifts and boom lifts, tipover/collapse was the most common event, 56% and 44% respectively (Table 3).

For boom lifts, the most common groups of construction work activities were “constructing and repairing” (42%), and “logging, trimming and pruning” (26%). For scissor lifts, it was “constructing and repairing” (50%) and “vehicular and transportation operations” (28%; Table 3). The construction industry is the leading sector across all industrial sectors for contribution to aerial lift fatalities (Figs. 5, 6); the construction industry was responsible for the highest percentage of both boom and scissor lift fatal injuries (45% and 72%, respectively).

Major contributing factors for boom lift deaths were mechanical failure, movement of the boom lift, struck by objects, failure to use a belt or harness to tie off, and surface conditions (Fig. 7). Mechanical failure was mentioned in 72 of the 221 (33%) boom lift events. Of these 72 fatal boom lift events, 48 (67%) involved failures of the lift structure (including control cables).

Forward or backward movement of the boom lift was mentioned or could be inferred in 22 (10%) of the 221 boom lift events. Raising or lowering of the lift was mentioned or inferred in 21 (9%) of the boom lift cases.

Failure to use a harness or belt and lanyard to tie off while performing tasks was reported in 42 of the 228 (18%) boom

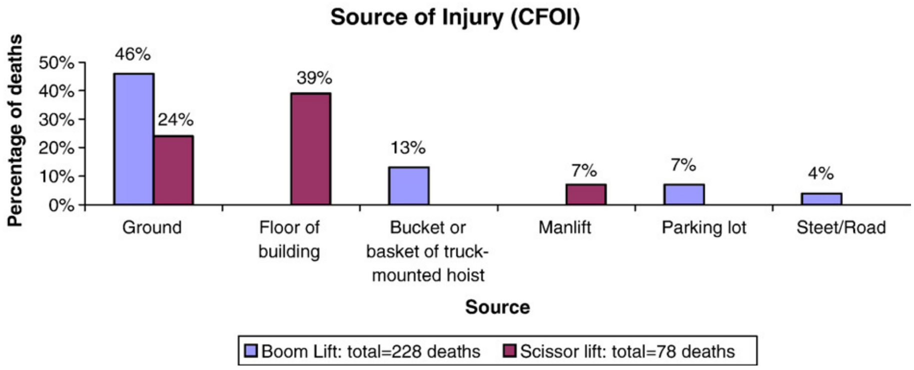

Fig. 3. Source of injury in aerial lift deaths, 1992-20. *Source: U.S. Bureau of Labor Statistics CFOI Research File*.

lift fatalities. In five instances (5% of 101 tipover events), the worker was tied off. In five cases, outriggers were not set.

In 25 deaths involving 23 boom lift ejection or collapse/tipover events (14% of 169 such events), the lift was struck by a vehicle, train or crane. In nine boom lift ejections (13% of 70 ejections), the worker or lift was struck by a falling tree or branch.

In 12 deaths involving nine boom lift collapse/tipover events (9% of 96 such events), the ground was sloped or uneven. Other contributing causes in boom lift deaths included open platform doors or defective latches (8 of 57 fatal falls, 14%). In 6 of 164 (4%) collapse/tipovers and ejection events, the boom lift was lifting a telephone pole or other weight, which caused the hoisting rope to break.

Major contributing factors for scissor lift falls included surface conditions and scissor lift motion. In six tipover events (14% of 44 scissor lift tipovers), uneven or sloped ground or driving on/off a flatbed truck was a factor, and in seven tipover events (16%), driving into holes or over a sidewalk or similar edge was a factor. Forward or backward movement of scissor lifts was mentioned or could be inferred in 18 of 78 (23%) scissor lift deaths.

3.2. OSHA/FACE

One hundred and seventy-three OSHA incident investigations occurring between 1990 and 2003, and 12 FACE cases occurring between 1985 and 2002, were identified and coded. One hundred and three were identified as boom lifts (60%) and 68 as scissor lifts (40%), for a total of 171 incidents. Another 14 aerial lifts could not be classified and were not included in the analysis. The manner of propulsion could be determined in 52% of the cases. Of the cases where propulsion could be determined, 67% were truck mounted, 31% were self-propelled, and 1% were manual. Table 4 shows the lift style/propulsion combinations that could be discerned from the narratives. Both the style and propulsion could be determined in only 48% of the cases.

The number of workers on the lift was mentioned in 166 (97%) of the cases. Where mentioned, there was one worker in 136 (80%) of the events (83 boom lifts and 53 scissor lifts) and two workers in 29 (17%) of the events (17 boom lifts and 12 scissor lifts). Age of the workers was reported in only 12 FACE cases, and is not reported for OSHA incident investigation reports. The reported age range for the available cases was between 25 and 64 years old.

General work activity and type of fall were identified and coded in about 80% of the cases (Table 5). For boom lifts, the most common groups of work activities were "constructing and repairing" (43%), and "logging, trimming and pruning" (29%). For scissor lifts, it was "constructing and repairing" (54%) and "painting and cleaning" (19%). Construction trade/industry is the leading sector for both boom and scissor lifts (Fig. 8). Occupations generally were not mentioned. More than 100 different specific job activities were mentioned in the narratives.

Height information is summarized in Table 6. Fall height was reported in 88% of boom cases and all of the scissor lift cases. The fall height was 10–29 feet for 42% of boom lifts and 83% of scissor lifts.

Major contributing factors for boom lift falls included mechanical failure, motion of the lift, type of surface, and worker action (Fig. 9). Of the 39 boom lift cases (47%), 31 (79%) of the failures were of the lift structure (including control cables).

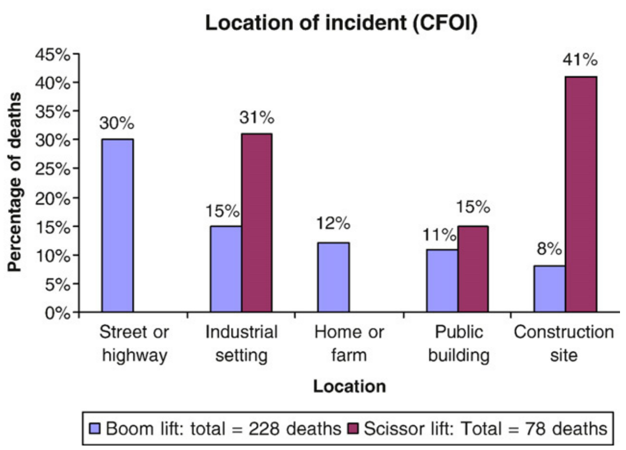

Fig. 4. Location of incident in aerial lift deaths, 1992–2003. *Source: U.S. Bureau of Labor Statistics CFOI Research File*.

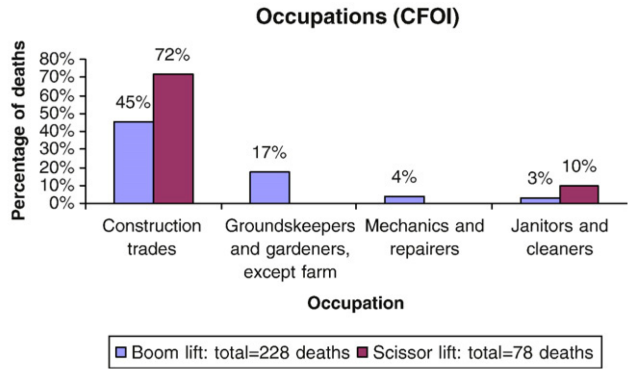

Fig. 5. Occupations in aerial lift deaths, 1992–2003. *Source: U.S. Bureau of Labor Statistics CFOI Research File.*

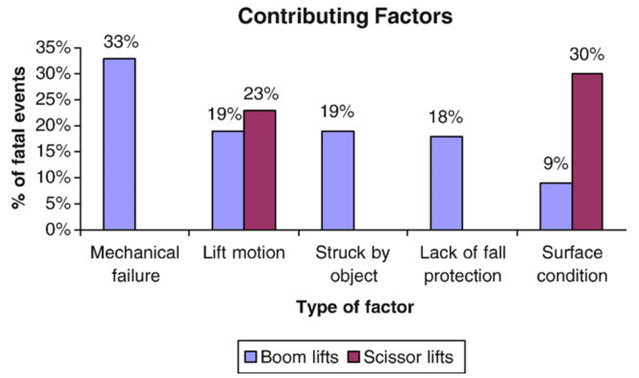

Fig. 7. Contributing factors in aerial lift deaths in construction, 1992–2003. *Source: U.S. Bureau of Labor Statistics CFOI Research File.*

Forward or backward movement of the lift was mentioned or could be inferred in 14 (16%) of the 89 boom lift FACE/OSHA cases (6 forward, 3 backward, 5 unknown, 3 turning). Where motion of the lift was mentioned at all, the specific speed was not. Raising or lowering of the lift was mentioned or inferred in 22 (25%) of the total cases. The cases were about equally divided between upward and downward movements.

Fall protection was specifically mentioned in 55 (66%) of the 83 boom lift cases. Where mentioned, fall protection was not in use in 82% of the cases. The types of fall protection mentioned are summarized in Table 7.

The surface on which the lift was placed was mentioned in 31 (35%) of the boom lift cases. Where mentioned, the surface was the floor of a building, platform, ramp, sidewalk, or street (14 cases or 45%), or ground/soil (13 cases or 42%). In the 8 cases (26%) where the surface condition was mentioned, 7 cases were sloped, and 1 had an edge (Table 8).

Worker action was mentioned as a contributory cause in 20 boom lift cases (22%). Errors in maintenance or lack of maintenance were mentioned in 6 cases (7%).

Contributing factors for scissor lift falls included surface condition, worker action, and lift motion. In the 16 cases (55%) where the surface condition was mentioned, 7 cases involved holes, 4 were uneven, 4 had an edge, and 1 was unstable (Table 8). The surface on which the lift was placed was mentioned in 29 (54%) of the scissor lift cases and included the floor of a building, platform, ramp, sidewalk, or street (25 cases or 86%) or ground/soil (4 cases or 14%).

Worker action was mentioned as a contributory factor in 25 scissor lift cases (46%). Errors in maintenance were mentioned in two cases (4%).

Forward or backward movement was mentioned or could be inferred in 18 (33%) of the 54 scissor lift cases. Forward movement was mentioned in 14 cases, backward movement in 1 case, and movement in an unspecified direction in 3 cases. A turning maneuver was mentioned or could be inferred in one (2%) of the cases. Raising or lowering of the lift was mentioned or inferred in four (7%) of the total cases, three cases being upward movements.

Fall protection was specifically mentioned in 13 (24%) of the 54 scissor lift cases. The types of fall protection mentioned are summarized in Table 7. Mechanical failure was mentioned in only two of the scissor lift cases (4%).

Materials, supplies, and tools in use on the platform or in the bucket/basket of the lift were mentioned in only 1 out of

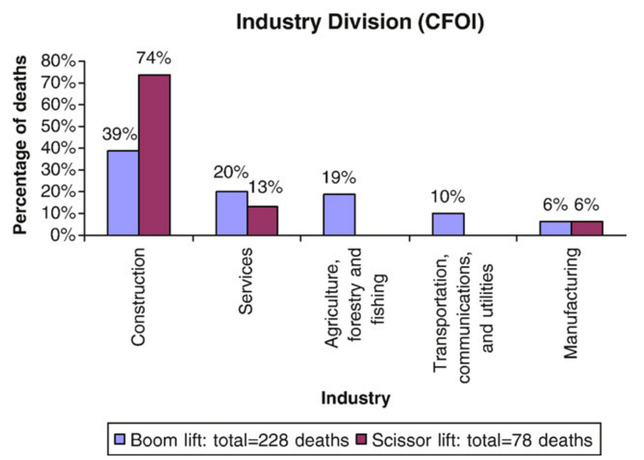

Fig. 6. Industry division in aerial lift deaths, 1992–2003. *Source: U.S. Bureau of Labor Statistics CFOI Research File.*

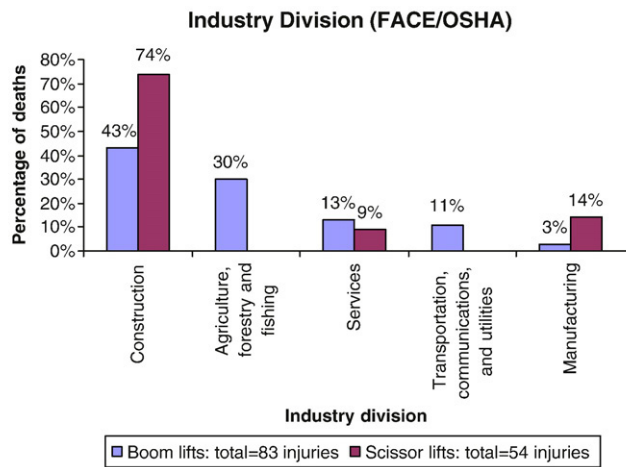

Fig. 8. Industry divisions in aerial lift deaths (OSHA/FACE).

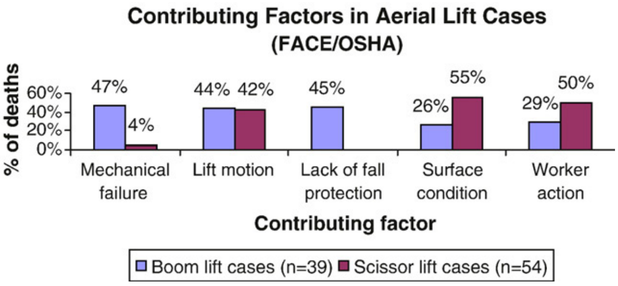

Fig. 9. Contributing factors in aerial lift deaths in construction.

10 cases. Ergonomic contributing factors such as tool/task interaction, reach, and postural factors were mentioned in very few cases. Platform extensions or attachments were rarely mentioned, in only 9 cases.

4. Discussion and recommendations

The strength of the CFOI data set is in the comprehensive nature of its data acquisition; CFOI attempts to identify the circumstances of all work-related injury fatalities using multiple sources, including OSHA, death certificates, workers' compensation reports, newspaper reports, and so forth. However, there is limited narrative information to identify specific fatal circumstances. Therefore, CFOI provides conservative estimates of the numbers of aerial lift-related fatalities and specific injury scenarios since case identification and coding would require detailed information in the CFOI database. The CFOI narratives are restricted in length and usually include only a brief, factual description of the incident. CFOI does not investigate the incidents and instead develops its findings based on a third-party report and at least a single confirmatory report of the incident. Because of the lack of findings by an investigatory agency, the ability to identify causes of fatal injury is very limited, and is predicated solely on information reported from external sources. Nevertheless, the CFOI narratives are more useful than other population-based data bases. In contrast, OSHA/FACE provides more detailed circumstance information than CFOI. The limitations of the OSHA/FACE data are that investigations are not conducted on all deaths and injuries, but only on a sample of selected cases. Thus, data may not be generalizable to all aerial lift fall incidents. However, examination of the various case-based and surveillance narratives was purposeful in providing a sense of common scenarios and events leading to elevated risk of injury and tipover events, and for establishing a general sense of the interface and environment that was obtained at the time of the injury event.

4.1. Incident comparisons from the results of CFOI and OSHA/FACE

A review of CFOI and OSHA/FACE data for manner of fall (Tables 3 and 5) identified that tipovers were the most frequent manner of fall-incident category associated with scissor lifts. Of the 78 scissor-lift fall deaths in the CFOI database, 44 (56%) involved tipovers, and of the 54 incidents in the combined OSHA/FACE reports, 32 (59%) involved tipovers.

For boom lifts, the comparable percentages of tipovers were 44% for CFOI data and 46% for OSHA/FACE reports. Constructing, assembling, repairing, and maintaining activities, including disassembling and dismantling activities, were the most common applications associated with falls on aerial lifts.

Although analyzed separately, the data sets of CFOI and OSHA/FACE support each other, leading to a generalizable set of similar scenarios for aerial lift tipovers. Knoll (2002) reported a similar finding regarding the tipover incidents. Regardless of the height of the work area, these findings indicated that the extended height of the lift, or the height of the fall, for 72% of the scissor lift cases in CFOI and 83% of cases investigated by OSHA/FACE involved falls/collapses/tipovers within the height categories of 10–19 feet and 20–29 feet. For boom lifts, about 40% of falls/collapses/tipovers occurred at these heights.

Contributing factors were similar in CFOI and OSHA/FACE studies, as might be expected. For boom lifts, mechanical failure was a factor in 33% of CFOI boom lift events and 47% of OSHA/FACE studies. For scissor lifts, surface condition, worker action, and lift motion were factors in 55%, 50% and 42% of scissor lift events.

4.2. Recommendations

Findings from this study have application for the identification of descriptive characteristics of the incidents, which are useful from the perspective of an injury epidemiology characterization, and additionally have application for informing a discussion of intervention strategies and analyses. These findings can be used to establish realistic and detailed characteristics of the aerial lift associated with the injury event, which can be further utilized in establishing data-rich mathematical models of the lift structure for modification through engineering design and fabrication. Information on age is of significance for issues related to the relevance of age-related loss of compensatory reaction capability and subsequent decremented ability to maintain postural stability by workers within the aerial lift platform. Unfortunately, these data did not allow us to say anything about age-related risk, but the data do document that lift fatalities occur across all age groups. Subsequent research will simulate physiological and biomechanical requirements to maintain stability under impact conditions, and the distribution of worker ages is significant for modeling input parameters.

Additionally, these findings can be used to establish the human-machine interface variables and task and position variables that are associated with the injury incident event. These variables can be analyzed for their contribution to a potential injury event through human subject tests and dynamic simulations in a laboratory setting. The objective of these laboratory studies is to develop safe work strategies and practices, and to explore the development of more effective interventions related to aerial lift technology.

Another interesting finding of this study relates to the human operators' stability and the related workstation-design issues for aerial lifts. Workers typically position the aerial lift platform to perform work tasks directly adjacent to the platform, at an equal height, as opposed to positioning the platform beneath a work location and working overhead (Ellis, 2001). This worker-preferred task location is extremely important to consider in the design of lifts and work practices, in that common tasks—which frequently involve pulling, stretching, over-reaching, and leaning over the edge or guardrail—place the operator at increased risk of falls from the platform to a lower level. Also, as indicated in Table 7, the use of fall protection systems (e.g., harness and lanyard) will generate significant issues in ergonomic-design considerations, since the platform/bucket is a very confined working area and operators need to perform tasks using limited working postures (Kroemer & Grandjean, 1997; The Eastman Kodak Co., 2004). When these awkward-postural issues are combined with the application of significant task-related side force in the horizontal direction, hazards associated with ejection and tripping incidents, as well as overexertion, are significantly increased (Pan & Chiou, 1999). Improvement in control over operators' whole body stability within the platform/bucket will be critical to prevent such fall/trip/ejection incidents (Pan et al., 2005).

The use of fall protection equipment on aerial lifts is generally recognized by aerial lift safety experts as one of the most effective safety control practices to reduce fall-risk exposure for operators (Burkart et al., 2004). However, results from this study indicated that for a significant percentage (82% for OSHA/FACE data) of fall-from-elevation incidents, safety controls did not protect workers because existing fall protection systems (e.g., guard rails, chains, gates/doors, belts, harnesses with or without lanyards) were not in use at the time of the incident. Only 4 out of 13 scissor lift injury/fatality cases from OSHA/FACE reports showed the use of additional safety protection systems (i.e., belts and harnesses). Findings from a field observation study additionally found significant nonusage of existing fall-protection systems and indicated that the majority of operators (16 out of 18) of boom lifts conducted tasks without using personal fall protection systems (Weeks, 2004). This finding significantly supports data analysis of this study that found that 45% (18 of 39) of those fatalities recorded in OSHA/FACE Reports as boom-lift related involved nonuse of fall protection systems. This finding is also extremely significant, since fall-protection-system deployment and use are, as noted, required safety controls under OSHA regulations (OSHA, 1999a,b), with the further requirement that the lanyard must be attached to the boom or basket (1926.453(b) (2) (v)). However, there is no body of scientific knowledge that establishes the efficacy of this control for use on scissor lifts. This represents a serious issue for the industry.

OSHA regulations (1926.451 (g) (1) (vii)) mandate the use of guardrails or personal protection systems as primary safety controls for scissor lifts, which are designated as mobile scaffolds under the applicable regulation. Expert opinion indicates that this designation may not fully capture the hazardous exposures of this equipment, which is generally operated at heights, conditions, and work tasks that do not represent similar conditions for scaffolding moved under manual power (Burkart et al., 2004). This suggests an additional research knowledge gap for the differing requirements of the aerial lift in comparison with manually powered mobile scaffolds.

5. Conclusions

The construction industry has the highest nonfatal lost workday incidence rate of any sector and costruction work also is one of the leading fatal occupations (Bureau of Labor Statistics [BLS], 2006). This study described the risk characteristics of fatal and non-fatal injuries associated with an increasingly popular item of construction equipment – aerial lifts. Falls are one of the leading causes of fatal and non-fatal injuries in the construction industry (BLS, 2006; National Institute for Occupational Safety and Health [NIOSH], 2000; Pan & Chiou, 1999). For boom lifts, about 44% of what BLS classifies as falls include tipover or collapse of the lift; for scissor lifts it is 56%. Mechanical failure, lift motion, surface condition, fall protection, and worker action are the major contributing factors in falls and tipovers.

6. Impact on the construction industry

Aerial lifts are used in a number of industries; their use is increasing as new designs and applications are developed within the construction industry (7,583,000 employment), landscape services (705,900 employment), telecommunications (705,800 employment), warehousing and storage (595,700 employment), electric power transmission and generation (162,300 employment), and other industries (BLS, 2006). Aerial lifts are becoming a very common tool, especially in the construction and scaffolding industries, to perform work at elevation. They are complex systems, subject to failure from both mechanical problems and operator errors. Little systematic study has been done on their failure modes and limitations. This study was formulated to address some of the potential mechanical failures and operational errors frequently discussed at consensus standard committee meetings (ANSI A10.29 and A92). This study attempts to build upon the limited injury data (i.e., three injury databases) recorded for the industry by adding research hypotheses on the mechanical problems and operational errors imposed by workers, tasks, and activities. After potential modes of equipment failure and human error leading to fall incidents have been identified, corresponding evaluations and interventions can be proposed and tested. This study incorporates multidisciplinary information into the analysis of a multi-factorial fall-incident hazard; the integration of this information to develop a reliable method for hazard identification represents an opportunity to apply these study findings to a range of aerial lifts used in construction, warehousing and storage, landscape services, telecommunications, electric power transmission and generation, and other industries (BLS, 2006).

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