ANALYSIS OF FATAL EVENTS IN THE CONSTRUCTION INDUSTRY, 1991-2001: WHAT DO OSHA DATA SHOW?

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INTRODUCTION

Under a contract with OSHA's Directorate of Construction and Office of Statistical Analysis, the Construction Industry Research & Policy Center (CIRPC) at the University of Tennessee analyzed narrative descriptions of fatality investigations (contained in the OSHA Form 170) of all fatal events in construction inspected by OSHA during the 11-year period 1991-2001. The purpose of this analysis was to provide OSHA with sufficient detail in proximal cause to direct the safety community's interest to specific situations where fatalities are known to occur in construction.

DATA AND ANALYSIS

CIRPC used a total of 6,782 fatal events in the construction industry occurring between 1991 and 2001 in the analysis. CIRPC's summary reports for each year are available from either OSHA or CIRPC. Construction industry was defined by Standard Industrial Classification (SIC) code. Fatalities not related to work, such as homicides, suicides, and heart attacks, were removed from the dataset. In addition, 17 fatal events in 2001 could not be classified and were not included in the frequency, rank, and correlation analysis. Fatal events were classified according to a list of 29 mutually-exclusive proximal causes of fatal construction events developed by CIRPC, as shown in Table 1.

Table 2 shows the rank of causes for the years 1991-2001 and the average of the 1991-2001 ranks. Simply, succinctly, and sadly, the data show that falls can kill (particularly falls from/through roofs, from/with structures, and from/with ladders), electricity can electrocute (often during the performance of non-electrical tasks), and heavy equipment can run people over. Crane operations can also be deadly.

Table 2 also shows evidence of stability in the ranks of causes during 1991-2001. This observation is supported by Table 3, which shows the rank of the average ranks, as well as by Table 4, which shows the Spearman correlation coefficients of the ranks between each period and its prior period (e.g., 1993-94 with 1991-92), as well as between each period and the combined prior periods (e.g., 2001 with 1991-2000). None of the period-to-period or period-to-composite-periods correlations was outside the ranges of 0.90-0.95 and 0.89-0.95, respectively, indicating a high degree of autocorrelation.

The data in Tables 2 and 3 also show that the ranks of proximal causes of fatal construction events are very stable over time. The proximal cause "Falls from/through roofs," which has the highest rank in the ranking of average ranks, also ranked first in each of the 9 periods. "Falls from/with structures (other than roofs)," had the second highest average rank, with period ranks of 2-5; "Crushed/run-over of non-operator" had the third highest average rank, with period ranks of 2-4, except in 2000, when it was ranked eighth; "Electric shock by equipment contacting power source" had the fourth highest average rank, with period ranks of 2-7, and "Lifting operations" had the fifth highest average rank, with period ranks of 2-9. These five proximal causes accounted for 40% of fatal construction events inspected by OSHA during 1991-2001.

In addition to the ranks, the percentage of fatal events accounted for by the leading causes remained stable between 1991-2001 as well. Table 5 shows the annual and total mean percentages for the causes. Period ranks and percentages were highly correlated, with the simple correlation coefficient (r) ranging from -0.87 to -0.96. As expected, therefore, there were no apparent trends in the proportion of events related to the combined top five or top ten causes,

which accounted for 37.8-42.9% and 60.1-66.1%, respectively, of fatal events between 1991 and 2001.

DISCUSSION

Why has the rank of fatality causes remained stable? Assume that the rank of a given cause is a function of the riskiness of work associated with that cause and the hours of exposure of all construction workers to that work. For example, the risk of falling from a structure and dying may not be very high for construction workers building high-rise buildings (assuming OSHA regulations are followed), but because such work employs many construction workers who work many hours, falls from structures nonetheless have a high rank. ("Falls from/with structure" is ranked second in Table 3.) Conversely, while the total number of hours per year that the construction workforce works on a roof may be comparatively low, "Fall from/with roof" ranks high (first in Table 3) because the risk of this fatal event occurring during that work is high.

For this assumption to account for the apparent stability in rankings, two further assumptions are necessary, as follows:

1. *Constant exposure*: the proportion of hours the construction workforce spent engaged in work associated with a particular cause remained constant over time. For example, suppose that 10% of total annual construction workforce hours were spent on roofs annually throughout 1991-2001.
2. *Constant risk*: the risk of a worker dying from a particular cause while doing work associated with that cause remained constant over time. For example, suppose that the risk to a worker on a roof of dying from falling off the roof was 0.00002 per 2,000 hours of work on the roof annually throughout 1991-2001.

Given the changes in the economy between 1991 and 2001, the first assumption (constant exposure) may not be valid. In any case, it is presumably out of the control of organizations that promote worker safety and health. The second assumption (constant risk) may also not be valid. For example, if construction firms began using the work practices mandated by OSHA's steel erection standard after OSHA proposed the rule in 1998, and these work practices were effective, the risk of a worker dying from a fall from a structure while working on a high-rise building should have changed (decreased) during 1991-2001.

On the other hand, the OSHA standard only directly addresses one aspect of risk. In reality, risk is the combination of three factors: physical, technological/regulatory, and organizational. Which factor predominates affects not only the explanation for the stability of cause rankings, but also the strategies of organizations that promote worker safety and health.

The physical factor is the potential for a mishap or misstep in a work environment to lead to a fatality. For example, workers working at great heights are inherently more likely to die from a fall than workers working on the ground. If the physical factor is the most important aspect of risk, the ranking of causes should remain stable, unless the economy changes. Unfortunately, safety and health organizations are unable to affect this aspect of risk.

The technological/regulatory factor is the degree to which technology and/or regulation can reduce the risk of a given task. For example, trench boxes reduce the risk of dying from a trench collapse while working in a trench. Requiring the use of fall protection reduces the risk of dying from falling from a scaffold while washing windows – assuming that the fall protection actually is used, and used correctly. The stability of causes in the period 1991-2001 suggests that technology and regulation either did not reduce risk at all, or did not affect it substantially enough to change the rankings.

The organizational factor is the degree to which employers and employees accept risk. Risk-seeking employers may reduce short-term expected costs – and incur the risk of much higher long-term costs from serious injury or death – by avoiding costs associated with safety, such as slower work performance in compliance with OSHA standards or investments in safety training and safe equipment. (They also pass this risk on to their employees, regardless of how the employees feel about risk.) In contrast, risk-averse employers increase short-term expected costs by accepting safety-associated costs, but they reduce long-term expected costs by avoiding the risk of costly injuries. As with the technological/regulatory aspect, safety and health organizations should be able to affect this aspect of risk, at least to the degree that employers rationally and correctly assess risk.

Now, assume that the organizational factor is the most important aspect of risk. Further suppose that a few types of work which account for a substantial proportion of total fatalities were characterized by a high proportion of risk-accepting (i.e., unsafe) employers throughout 1991-2001. This may be due, for example, to the high cost in money, effort, or knowledge of safe work practices, especially to small businesses, in those types of work. In that case, the stability of cause rankings might reflect the unsafe behavior of employers in those types of work, while hiding real reductions in risk associated with other types of work.

In possible support for this explanation, the total risk of fatal injury to construction workers has, in fact, declined. According to data published by the Census of Fatal Occupational Injuries at the Bureau of Labor Statistics, the fatality rate in the construction industry declined from 13.9 in 1993 per 100,000 workers to 13.3 in 2001 (and to 12.2 in 2002). The decrease suggests that economic changes and/or changes in the technological, regulatory, and organizational aspects of construction work have occurred. A continued decrease in the

construction fatality rate may depend on a better understanding of the hierarchy of causes, with interventions designed to address the specific risk factors associated with the higher-ranking causes.

Table 1. Definitions of Fatality Causes

Event cause	Description
1	Asphyxiation/inhalation of toxic vapor/gas, lack of oxygen (excluding asphyxiation resulting from fire/explosion).
2	Caught in stationary equipment: body or clothing get caught in equipment and pull worker in.
3	Collapse of structure: building or other structure fall on worker (excluding falling ladder, scaffold, aerial lift/ basket, or platform; falling with a structure, or trench or earthen collapse).
4	Crushed/run-over of non-operator by operating construction equipment: non-operator run over or crushed between equipment and ground or another object by an operator-controlled piece of construction equipment.
5	Crushed/run-over/trapped of operator by operating construction equipment: includes rollover and catching of body in equipment or between equipment and ground or other object while operating the equipment (including fatalities resulting from asphyxiation/fire/explosion/ drowning of trapped operators)
6	Crushed/run-over by construction equipment during maintenance/ modification: includes equipment/parts falling on worker while worker assembles or disassembles equipment.
7	Crushed/run-over by highway vehicle: any run-over by non-construction equipment, including trains.
8	Drowning (including with non-lethal fall): resulting from non-lethal falls into water or flooding of containers, trenches, etc.
9	Electrocution by touching exposed wire/source (excluding while installing equipment or using a tool).
10	Electrocution by equipment contacting wire. a. Ladder. b. Scaffold. c. Crane/lifting equipment/boom/dump truck. d. Other: contact while handling materials (gutters, iron rods, painting equipment, etc.).

Table 1. Definitions of Fatality Causes (continued)

11	Electrocution from equipment installation/tool use: includes failure to de-energize equipment, inappropriate energizing, contacting energized part with tool or body, and inadequately-grounded tools or exposed tool wires.
12	Electrocution, other and unknown cause.
13	Elevator: struck/crushed by elevator or counterweights.
14	Fall from/with ladder (including with collapse/fall of ladder).
15	Fall from roof, fall through roof (skylight or other opening).
16	Fall from vehicle/construction equipment while in motion or at rest.
17	Fall from/with scaffold (including with collapse/fall of scaffold).
18	Fall from/with bucket/aerial lift/basket (including with collapse/fall of bucket/aerial lift/ basket).
19	Fall from/with structure (other than roof): fall through opening in the side or through the floor (excluding through opening in the floor), and with the structure in a collapse.
20	Fall from/with platform/catwalk attached to structure (including with collapse/fall of platform/catwalk).
21	Fall through opening (other than roof): falls through stairwells, equipment openings, or other openings in a floor.
22	Fall, other.
23	Fire/explosion/scalding (excluding electrical burns/explosions).
24	Hyperthermia/hypothermia.
25	Lifting operations: failure of equipment, inappropriate lifting, and all loading and unloading by crane operations except electrocution (including objects falling and striking worker during lifting operation).
26	Struck by falling object/projectile (including tip-overs) (excluding collapse of structures, trenches, and earthen walls, and lifting operations).
27	Trench collapse (including earthen walls)
	Unloading/loading equipment/material (except by crane): includes slipping and tipping-over of construction equipment/material while loading and unloading.
29	Lightning.
30	Crushed, other.
31	Unknown cause or other.

Table 2. Period Event Rank 1991-2001 and Average Event Rank 1991-2001

EVENT CAUSE	DESCRIPTION	YEAR									AVE. 1991 - 2001
		1991 - 1992	1993 - 1994	1995	1996	1997	1998	1999	2000	2001	
1	Asphyxiation/inhalation of toxic vapor	25	24	22	25	21	22	24	24	20	23
2	Caught in stationary equipment	25	26	24	24	24	21	24	23	26	24
3	Crushed from collapse of structure	9	9	9	8	9	14	9	10	15	10
4	Crushed/run over of non-operator by operating con equipment	3	2	4	3	3	4	2	8	3	3
5	Crushed/run over/trapped of operator by operating con equipment	5	6	8	6	11	9	5	4	10	7
6	Crushed/run over by construction equipment during maint/mod	17	17	16	20	19	22	17	17	21	18
7	Crushed/run over by highway vehicle	13	10	10	9	12	11	4	13	14	11
8	Drown, non-lethal fall	25	21	24	27	27	26	21	24	28	25
9	Electric shock by touching exposed wire	7	7	5	10	12	12	17	14	11	10
10	Electric shock by equipment contacting power source	2	3	2	4	4	3	7	3	7	4
11	Electric shock from equipment installation/tool use	21	11	5	11	7	5	10	7	4	10
12	Electric shock, other	15	24	23	25	27	29	29	28	29	24
13	Elevator	28	28	28	28	27	27	26	27	24	27
14	Fall from/with ladder	11	13	13	12	6	7	14	10	6	11
15	Fall from/through roof	1	1	1	1	1	1	1	1	1	1
16	Fall from highway vehicle/con equipment	27	24	27	22	24	24	26	21	26	25
17	Fall from/with scaffold	12	18	20	13	9	13	8	9	13	13
18	Fall from/with bucket	20	19	17	15	23	19	15	19	16	18
19	Fall from/with non-roof structure	4	4	3	5	2	2	3	2	2	3
20	Fall from/with platform/catwalk	19	15	10	15	15	17	20	21	18	17
21	Fall through non-roof opening	16	20	15	17	15	16	13	15	12	16
22	Fall, other	23	28	28	23	22	27	28	28	22	26
23	Fire/explosion/scalding	17	14	19	17	18	18	16	17	19	17
24	Hyperthermia/hypothermia	29	27	26	28	29	24	23	26	25	27
25	Lifting operation	8	5	7	2	5	7	6	4	9	6
26	Struck by falling object/projectile/tip-over	9	15	12	14	14	6	11	12	5	11
27	Trench collapse	6	8	13	7	8	10	12	6	8	8
28	Crushed while loading/unloading equipment/material	21	21	20	20	19	19	22	15	17	20
29	Lightning	13	12	17	20	17	14	19	19	23	16

Table 3. Rank of 1991-2001 Average Ranks of Proximal Causes

Rank of average rank	Event cause	Description
1	15	Fall from/through roof
2	19	Fall from/with structure (other than roof)
3	4	Crushed/run-over of non-operator by operating construction equipment
4	10	Electric shock by equipment contacting power source
5	25	Lifting operation
6	5	Crushed/run-over/trapped of operator by operating construction equipment
7	27	Crushed/suffocation from trench collapse
8	9	Electric shock by touching exposed wire
9	3	Crushed from collapse of structure
10	11	Electric shock from equipment installation/tool use
11	14	Fall from/with ladder: includes collapse/fall of ladder
12	7	Crushed/run-over by highway vehicle
13	26	Struck by falling object/projectile (including tip-overs)
14	17	Fall from/with scaffold
15	21	Fall through opening (other than roof)
16	29	Shock/burn from lightning
17	20	Fall from/with platform or catwalk
18	23	Fire/explosion/scalding
19	6	Crushed/run-over by construction equipment during maintenance/modification
20	18	Fall from/with bucket (aerial lift/basket)
21	28	Crushed while unloading/loading equipment/material (except by crane)
22	1	Asphyxiation/inhalation of toxic vapor
23	2	Caught in stationary equipment
24	12	Electric shock, other
25	8	Drown, non-lethal fall
26	16	Fall from highway vehicle/construction equipment
27	22	Fall, other
28	24	Hyperthermia/hypothermia
29	13	Elevator (struck/crushed by elevator or counterweights)

Table 4. Fatality Reports Summary 1991-2001[1]

Year(s)	Number Of Events[a]	Spearman R: Y_n-v-Y_{n-1}	Spearman R: Y_n-v-$Y_{1 \text{ to } Yn-1}$
1991-92	1,198	NA[b]	NA[b]
1993-94	1,138	0.90	0.90
1995	587	0.95	0.92
1996	570	0.91	0.95
1997	604	0.94	0.93
1998	624	0.94	0.92
1999	705	0.90	0.89
2000	637	0.92	0.94
2001	719	0.90	0.90

[1]In 2001, seventeen fatal events could not be classified. These events are not included in the frequency, rank, or correlation information.

[a]Non-job-related fatalities, such as homicides, suicides, and heart attacks, were removed from the data.

[b]NA – not applicable.

Table 5 Period percentage and total average percentage of fatal event causes, 1991-2001

EVENT CAUSE	DESCRIPTION	YEAR									AVE
		1991-1992	1993-1994	1995	1996	1997	1998	1999	2000	2001	1991-2001
1	Asphyxiation/inhalation of toxic vapor	1.1	1.0	1.2	0.7	1.7	1.1	0.7	0.8	1.6	1.1
2	Caught in stationary equipmt	1.1	0.9	0.7	1.4	0.7	1.3	0.7	1.1	0.6	0.9
3	Crushed from collapse of structure	4.0	5.1	4.8	4.7	4.0	2.7	5.0	4.1	2.7	4.2
4	Crushed/run over of non-operator by operating con equipmt	7.8	8.3	6.8	6.3	8.1	8.5	9.2	5.2	7.8	7.7
5	Crushed/run over/trapped of operator by operating con equipmt	6.0	5.5	5.6	5.6	3.8	4.0	5.8	5.8	4.3	5.3
6	Crushed/run over by con equipmt during maint/mod	2.2	2.3	2.4	1.9	2.0	1.1	2.0	2.2	1.4	2.0
7	Crushed/run over by highway vehicle	3.2	4.4	4.1	4.4	3.3	3.5	6.1	3.8	2.8	3.9
8	Drown, non-lethal fall	1.1	1.6	0.7	0.4	0.5	0.6	1.4	0.8	0.4	0.9
9	Electric shock by touching exposed wire	4.8	5.3	6.1	4.2	3.3	3.2	2.0	3.1	4.0	4.1
10	Electric shock by equipmt contacting power source	9.8	8.0	8.3	6.1	7.6	9.3	5.2	6.1	5.1	7.5
11	Electric shock from equipmt installation/tool use	1.7	3.7	6.1	4.0	4.3	7.2	4.7	5.5	6.8	4.6
12	Electric shock, other	2.4	1.0	0.9	0.7	0.5	0.0	0.1	0.0	0.0	0.8
13	Elevator	0.5	0.5	0.2	0.2	0.5	0.3	0.4	0.3	0.9	0.4
14	Fall from/with ladder	3.7	3.3	3.7	3.7	5.3	4.3	3.5	4.1	5.4	4.0
15	Fall from/through roof	10.9	10.2	11.1	14.2	11.9	10.6	10.6	11.8	12.3	11.3
16	Fall from highway vehicle/con equipmt	0.6	1.0	0.3	1.8	0.7	0.8	0.4	1.9	0.6	0.9
17	Fall from/with scaffold	3.5	2.2	1.4	3.3	4.0	3.0	5.1	4.7	3.3	3.3
18	Fall from/with bucket	1.9	1.8	2.0	2.5	1.0	2.1	2.6	2.0	2.6	2.0
19	Fall from/with non-roof structure	6.9	6.7	7.7	6.0	9.1	10.3	8.1	8.9	11.0	8.1
20	Fall from/with platform/catwalk	2.1	2.7	4.1	2.5	3.0	2.4	1.7	1.9	1.9	2.4
21	Fall through non-roof opening	2.3	1.7	2.6	2.3	3.0	2.6	4.0	2.8	3.4	2.6
22	Fall, other	1.2	0.5	0.2	1.6	1.3	0.3	0.3	0.0	1.1	0.7
23	Fire/explosion/scalding	2.2	2.9	1.7	2.3	2.6	2.2	2.4	2.2	1.7	2.3
24	Hyperthermia/hypothermia	0.5	0.7	0.5	0.2	0.3	0.8	0.9	0.6	0.7	0.6
25	Lifting operation	4.7	6.1	5.8	6.5	5.5	4.3	5.4	5.8	4.4	5.4
26	Struck by falling object/projectile/tip over	4.0	2.7	3.9	3.3	3.1	4.6	4.4	3.9	5.7	3.9
27	Trench collapse	5.1	5.2	3.7	5.4	4.1	3.8	4.1	5.7	4.6	4.7
28	Crushed while loading/unloading equipmt/material	1.7	1.6	1.4	1.9	2.0	2.1	1.3	2.8	2.0	1.8
29	Lightning	3.2	3.4	2.0	1.9	2.8	2.7	1.8	2.0	1.0	2.5
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0