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Machinery-Related Fatalities in the Construction Industry

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The National Traumatic Occupational Fatalities (NTOF) surveillance system identified machinery-related incidents as the fourth leading cause of traumatic occupational fatalities in the U.S. construction industry between 1980 and 1992, resulting in 1,901 deaths and 2.13 deaths per 100,000 workers. Fatality rates declined 50% over the study period. Workers in three occupation divisions—precision production, craft, and repair; transportation and material moving; and handlers, equipment cleaners, helpers, and laborers—had both the highest frequency and rate of fatalities. Cranes, excavating machinery, and tractors were the machines most frequently involved. The most common incident types were: struck by a mobile machine; overturn; and struck by a boom. Further delineation of groups at highest risk for machinery-related injuries is complicated by a lack of data on exposure to machinery. The findings suggest that injury prevention programs should focus not only on machine operators, but on those who work on foot around machines. Am. J. Ind. Med. 32:42–50, 1997. *© 1997 Wiley-Liss, Inc.*†

KEY WORDS: occupational fatalities; construction; machinery; NTOF

INTRODUCTION

Machinery-related incidents were the fourth leading cause of traumatic occupational fatalities in the construction industry between 1980 and 1989, according to the National Traumatic Occupational Fatalities (NTOF) surveillance system of the National Institute for Occupational Safety and Health (NIOSH), accounting for 3.5 deaths per 100,000 workers [Jenkins et al., 1993]. Only falls (6.6 deaths per 100,000 workers), electrocutions (4.0), and motor vehicle incidents (3.7) had higher fatality rates during this period.

Another NTOF analysis identified tractors, forklifts, cranes, excavating machines, and loaders as the machinery types most often associated with machinery-related fatalities across all industry divisions [Pratt et al., 1996]. The authors also reported that between 1980 and 1989, cranes were involved in the greatest number of fatalities within the construction industry, followed by tractors, excavating machinery, loaders, and road grading and surfacing machinery.

Other sources have attributed varying percentages of construction industry deaths to machinery. Interpretation of the literature is complicated by different definitions for machines or machine-related incidents, such as the classification of mobile machines as motor vehicles, or using coding systems other than the International Classification of Diseases, Ninth Revision (ICD-9) to define machinery incidents [World Health Organization, 1977].

A report describing 100 construction industry fatalities in the United Kingdom attributed 21% of the incidents to machinery: 15% to machinery under power, and 6% to machinery not under power [Health and Safety Executive, HM Factory Inspectorate, 1978]. Cranes were involved in 10 of the 21 machinery-related incidents.

An analysis of New Jersey construction industry fatalities from 1983 through 1989 found that nine (5%) of 200 construction fatalities were machinery-related [Sorock et al., 1993]. Results from a Washington State study found that 32% of construction industry fatalities between 1973 and 1983 were due to vehicle accidents at the work site or to being struck by an object or machinery [Buskin and

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Paulozzi, 1987]. It is unclear what proportion of these incidents would be considered machinery-related according to ICD-9 coding rules.

Other research not necessarily limited to the construction industry has identified risks associated with the operation of cranes [Eckhardt, 1994; Hakkinen, 1978], tractors [Purschwitz and Field, 1990; Stoskopf and Venn, 1985; Karlson and Noren, 1979], skid-steer loaders [Centers for Disease Control and Prevention, 1996], forklifts [Larsson and Rechnitzer, 1994; Lifschultz and Donoghue, 1994; Stout-Wiegand, 1987], and heavy equipment such as front end loaders, bulldozers, and backhoes [Bobick et al., 1991; Stanevich, 1986; Hurst and Khalil, 1984; Couch and Fraser, 1981].

Previous studies of machinery-related fatalities in construction have been limited to particular geographic areas, machines, or event types, and have used a variety of classification methods to describe the workers, machinery, and settings involved. This research uses a national surveillance system covering a 13-year period to examine machinery-related fatalities throughout the construction industry, presenting demographic and employment characteristics of decedents as well as specific machinery types and circumstances surrounding the incident. It adds to previous research by providing greater detail with respect to occupation, industry, and event circumstances, leading to development of recommendations for injury prevention that can be targeted to more specific worker populations within the construction industry.

MATERIALS AND METHODS

The NTOF surveillance system is a census of death certificates from the 50 states, the District of Columbia, and New York City that meet the following criteria: persons aged 16 years and older who died from external causes and for whom the certifier noted that the injury was work-related. Data for 1980 through 1992 were available for this analysis. The 1992 NTOF data did not include Connecticut and New York City.

Fatalities caused by machinery are assigned an external cause of death code (E-code) of E919 according to ICD-9 (Table I) [World Health Organization, 1977]. The E919 code does not, however, capture all events in which a machine is involved. Notable exclusions are events involving: a machine in transport on a highway under its own power (classified as motor vehicle incidents); electric current in connection with machinery; a machine not in operation; powered hand tools or implements; and certain powered industrial carriers used solely within the buildings and premises of commercial and industrial establishments (e.g., coal cars in mines or battery operated airport passenger vehicles). Construction machinery fatalities that occur on public highways are motor vehicle incidents, while similar events occurring on construction sites or off the highway are machinery-related incidents. If a highway is under construction, with only a portion of the road open to traffic, incidents occurring on the open portion are motor vehicle incidents, while those occurring in the construction area are machinery-related incidents.

TABLE I. Incidents Classified as Machinery-Related Under ICD-9 Coding Rules*

Burned by	machinery
Caught in moving parts of	machinery
Collapse of	machinery
Crushed by	machinery
Cut or pierced by	machinery
Drowning or submersion caused by	machinery
Explosion of, on, in	machinery
Fall from or into moving part of	machinery
Fire starting in or on	machinery
Mechanical suffocation caused by	machinery
Object falling from, on, in motion by	machinery
Overturning of	machinery
Pinned under	machinery
Run over by	machinery
Struck by	machinery
Thrown from	machinery
Caught between other object and	machinery

*Source: World Health Organization, ''International Classification of Diseases, Ninth Revision.''

ICD-9 coding allows for assignment of a fourth digit to denote broad machinery categories, e.g., agricultural machines, lifting machines and appliances, and metalworking machines. However, the inclusion in NTOF of the injury description, cause of death, occupation, and industry as narratives provides an opportunity for more detailed examination of machinery-related fatalities through additional coding.

For this analysis, the injury description and cause of death narratives for the 1,901 machinery-related deaths in the construction industry were used to assign source-of-injury codes from the Occupational Injury and Illness Classification Structures (OIICS) of the Bureau of Labor Statistics [1992]. Three-digit OIICS codes were successfully assigned to 1,619 (85%) of the NTOF machinery-related fatalities within the construction industry.

All the cases were further classified according to the nature of the incident, e.g., whether the victim was caught in machinery, struck by machinery, or fell from machinery. Event codes were assigned to 1,807 (95%) of the fatalities. This classification, used in conjunction with the OIICS source code, allowed us to determine what kinds of incidents were most frequently associated with each machine type.

Construction industry fatalities are defined as those assigned to that major industry division according to the

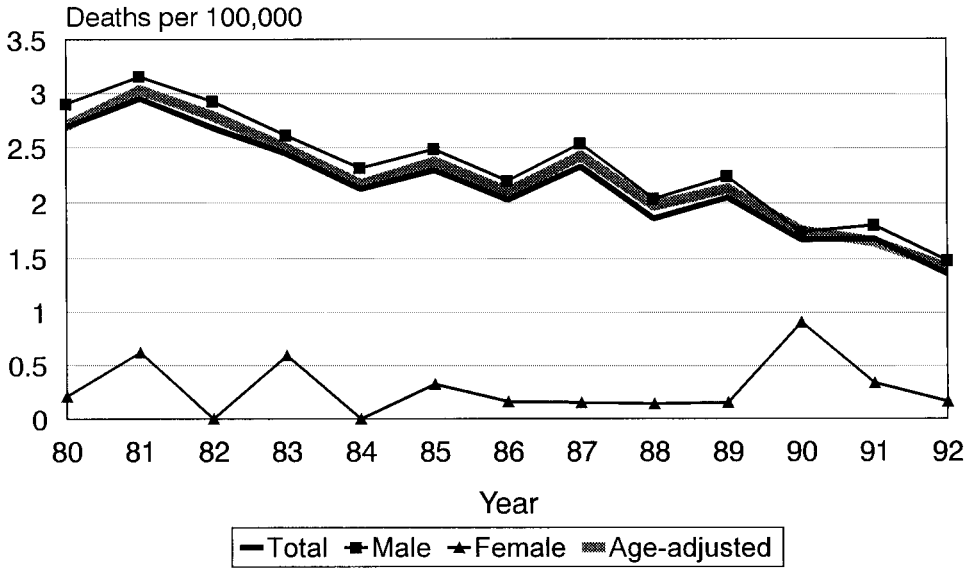

FIGURE 1. Annual rates of machinery-related fatalities in the construction industry, United States, 1980–1992. Source: National Traumatic Occupational Fatalities (NTOF) Surveillance System.

1987 Standard Industrial Classification (SIC) [Office of Management and Budget, 1987]. Occupational categories were grouped according to the classification scheme used by the Bureau of the Census [1982, 1992]. Because of lack of comparability with earlier classification systems (before 1983), fatality rates by occupation were calculated only for the years 1983 through 1992. Occupation division was ascertained for all but 1% of the 1,410 construction industry machinery fatalities for 1983 through 1992. For 1990 through 1992, NTOF contains detailed Bureau of the Census occupation codes as well as detailed SIC codes. These were available for 341 (17.9%) of the 1,901 machinery-related fatalities in the construction industry.

Average annual employment data used to calculate fatality rates by age, gender, industry, and occupation were obtained from *Employment and Earnings*, a publication of the Bureau of Labor Statistics based on the Current Population Survey, a monthly household survey conducted by the Bureau of the Census [1981–1993a].

Rates for census regions were calculated from state employment estimates published in the *Geographic Profile of Employment and Unemployment*, adjusted to account for the self-employed, government workers, and unpaid family workers [Bureau of Labor Statistics, 1981-1993b]. This source provides state estimates of the distribution of employed civilians by industry for private nonagricultural wage and salary workers. In calculating the adjusted estimates, the annual proportion of the construction industry comprised of these workers was assumed to be consistent from state to state. This proportion, obtained from *Employment and Earnings*, was used to inflate the employment estimate for each state [Bureau of Labor Statistics, 1981–1993a].

Annual fatality rates for 1980 through 1992 were age-adjusted to 1986 employment estimates for all industries from the Current Population Survey [Bureau of Labor Statistics, 1987a]. For adjustment of gender-specific fatality rates by occupation division for 1983 through 1992, the female fatality rate was adjusted to the male fatality rate using 1986 construction industry employment estimates [Bureau of Labor Statistics, 1987a].

It should be noted that for all fatality rates presented in this paper, workers included in the denominator were not necessarily exposed to machinery in general or to particular machine types (in the case of the machine-specific rates). That is, the fatality rates presented denote the number of deaths per 100,000 workers employed in the construction industry, not the number of deaths per 100,000 workers exposed to these machines on a regular basis.

RESULTS

Between 1980 and 1992, 1,901 civilian workers in the United States construction industry died in machinery-related incidents, with an average annual fatality rate of 2.13 deaths per 100,000 workers. The number of deaths was highest in 1981 (174), declining to 95 in 1992. Annual rates declined 50% over the 13-year period, dropping from 2.69 in 1980 to 1.35 in 1992 (Fig. 1). The decline in rates accelerated near the end of the period. The decline was 24% for 1980 through 1989, but 34% for 1989 through 1992. Males accounted for 1,879 deaths, 98.8% of the total. The fatality rate for males was nearly eight times that for females: 2.30 compared with .29.

TABLE II. Distribution of Machinery-Related Fatalities in the Construction Industry by Age of Decedent, United States, 1980–1992

Age (years)	n	%	Rate*
16–19	62	3.3	1.67
20–24	227	11.9	1.91
25–34	492	25.9	1.69
35–44	411	21.6	1.98
45–54	312	16.4	2.26
55–64	276	14.5	3.23
65+	121	6.4	7.79
Total	1,901	100.0	2.13

*Per 100,000 workers.

TABLE III. Distribution of Machinery-Related Occupational Fatalities in the Construction Industry by Occupation Division, United States, 1983–1992

Occupation division	n	%	Rate*
Executive/administrative/managerial	97	6.9	1.08
Professional specialty	21	1.5	1.53
Precision production/craft/repair	441	31.5	1.07
Machine operators/assemblers/inspectors	40	2.9	4.08
Transportation and material moving	415	29.7	8.38
Handlers/equipment cleaners/helpers/laborers	368	26.3	4.52
All other**	16	1.1	
Total	1,398	100.0	

*Per 100,000 workers.
**Includes five occupation divisions with fewer than ten fatalities each between 1983 and 1992: technicians and related support; sales; administrative support, including clerical; service; and farming, forestry, and fishing.

Decedents ranged in age from 16 to 90 years, with a mean age of 40.5 years and a median age of 38 years. Over one-fourth were aged 25 to 34 years. Workers aged 55 to 64 years and 65 years and older accounted for fewer deaths, but experienced higher fatality rates (Table II). Age-adjusted annual rates were very similar to overall rates (Fig. 1).

The distribution of decedents by race and ethnicity was 83.6% white, 8.3% black, 6.9% Hispanic, 0.4% Native American, 0.2% Asian or Pacific Islander, 0.1% other race, and 0.4% unknown.

More than two-thirds of the fatalities (68.7%) occurred during the months of April through October. Eighty-nine percent occurred between normal daytime working hours of 8 a.m. to 5 p.m.

Detailed SIC codes were available for 330 (96.8%) of the 341 fatalities that occurred between 1990 and 1992. Of these, 204 (61.8%) were classified as Major Group 16, Heavy Construction Other Than Building Construction—Contractors; 100 (30.3%) as Major Group 17, Construction—Special Trade Contractors; and the remaining 26 (7.9%) as Major Group 15, Building Construction—General Contractors and Operative Builders. Within Major Group 16, the majority of fatalities were in SIC 1611, Highway and Street Construction, Except Elevated Highways (101 deaths); and SIC 1629, Heavy Construction, n.e.c. (91 deaths).

Workers in three occupation divisions—precision production, craft, and repair; transportation and material moving; and handlers, equipment cleaners, helpers, and laborers—accounted for 87.6% of fatalities between 1983 and 1992 for which occupation division could be ascertained. Workers in transportation and material moving occupations had by far the highest fatality rate during the 10-year period (Table III).

The three occupation divisions with the highest numbers of fatalities overall accounted for 16 of the 18 (88.9%) fatalities among females between 1983 and 1992. Fatality rates for females in these occupational groups were 0.45 per 100,000 workers in precision production, craft, and repair, 2.01 among handlers, equipment cleaners, helpers, and laborers, and 15.38 among transportation and material moving workers (1.9 times the rate observed among males). The occupation-adjusted fatality rate for females for 1983 through 1992 was 1.68 per 100,000 workers, 5.8 times the unadjusted rate for 1980 through 1992.

Examination of detailed occupation codes for 1990 through 1992 revealed that nearly half the deaths occurred among two occupations: construction laborers (80, or 23.5%) and operating engineers (77, or 22.6%). Other occupations with ten or more fatalities during the 3-year period were construction supervisors, n.e.c. (23); carpenters (14); managers and administrators, n.e.c. (10); and electricians (10). Decedents working in a supervisory capacity comprised 14.1% of fatalities; some were employed in executive, administrative, and managerial occupations, the remainder in precision production, craft, and repair occupations.

The machines most often involved in construction industry fatalities were cranes, excavating machines, and tractors (Table IV). Trends in the annual number and rate of fatalities varied by machine type. In general, rates declined over the period, although not steadily, with fluctuations from year to year. The number and rate of fatalities related to cranes, tractors, loaders, and paving machinery showed sustained declines near the end of the 13-year period, while fatalities due to excavating machinery and forklifts showed smaller declines (Fig. 2). Declines in fatality rates due to tractors (71%) and cranes (67%) were particularly striking, while excavating machine fatalities declined only 12%.

The greatest number of fatalities occurred in the South census region (860), followed by the Midwest (426), West (390), and Northeast (220). Fatality rates for 1981 through 1992 were 2.37 per 100,000 workers in the South, 2.28 in the Midwest, 2.05 in the West, and 1.29 in the Northeast. Fatality rates for specific machine types also varied by

TABLE IV. Distribution of Machinery-Related Occupational Fatalities in the Construction Industry by Machine Type, United States, 1980–1992

Machine	n	%	Rate*
Crane	306	16.1	0.34
Excavating machine	288	15.1	0.32
Tractor	284	14.9	0.32
Loader	130	6.8	0.15
Paving machine	127	6.7	0.14
Forklift	109	5.7	0.12
Elevator	76	4.0	0.09
Other specified construction machine	41	2.2	0.05
All other	258	13.6	
Unknown	282	14.8	
Total	1,901	100.0	

*Per 100,000 workers.

census region (Table V). Crane and tractor fatality rates were comparatively higher in the South, with loader fatality rates higher in the Midwest and forklift rates higher in the West. With the exception of excavating machines, the Northeast had the lowest rates associated with most major machine types. Excavating machine rates were consistent across census regions.

The most frequent types of fatal incidents were: struck, pinned, crushed, or run over by a mobile machine; injured during the overturn of a mobile machine; and struck by a boom, bucket, or lift arm (Table VI). Fatalities related to cranes were most frequently associated with being struck, pinned, crushed, or run over by the crane itself or by the boom. In 86 (28.1%) of the 306 fatalities, the worker was struck by a boom. In another 99 cases (32.4%), the description specified only that the worker was struck by a crane. Crane-related incidents accounted for 60.6% of all fatalities which involved a worker being struck by a boom.

Fatalities involving excavating machines most often were incidents in which the worker was struck, pinned, crushed, or run over (127 deaths, or 44.1%); overturns (53 deaths, or 18.4%); and incidents in which the worker was compressed between two machines or between a machine and a fixed object such as a wall or loading dock (27 deaths, or 9.4%).

Among tractor fatalities, overturns predominated (135 deaths, or 47.5%), followed by incidents in which the worker was struck, crushed, pinned, or run over (79 deaths, or 27.8%). Tractor incidents comprised 41.8% of all overturns.

Calculation of fatality rates by age group and machine type revealed the greatest differences in rate ratios in the case of tractor-related incidents (Fig. 3). Tractor fatality rates were 3.93 for those aged 65 years and older, .70 for those aged 55 to 64 years, and .26 for workers aged 45 to 54 years. The rate among the oldest workers was 5.6 times that of the next youngest age group. For excavating machines, the fatality rate among workers aged 65 years and older was 1.22, 2.3 times the rate among workers in the next youngest age group. For cranes, however, the fatality rate was lowest among workers aged 65 years and older (.19 per 100,000, compared with a rate of .44 among workers aged 35 to 44 years).

Within every age group, the most common type of fatal event was one in which the worker was struck, pinned, crushed, or run over by a machine. Overturns comprised greater proportions of fatalities among workers aged 55 years and older than among younger workers: 23.9% compared with 15.2%. Compared with workers aged 20 years or older, those aged 16 to 19 years had proportionally more fall-related fatalities (16.1% vs. 9.6%) and fatalities that involved being caught in running machinery (11.3% vs. 4.2%).

The types of machines associated with fatal incidents varied by occupation division. Among those in transportation and material moving occupations and in executive, administrative and managerial occupations, more fatalities were associated with excavating machines than with any other machine type. Within precision production, craft, and repair occupations, tractor and crane fatalities predominated. Cranes were associated with the greatest proportion of machine fatalities among handlers, equipment cleaners, helpers, and laborers (Table VII).

DISCUSSION

NTOF data for 1980 through 1992 showed that machinery-related fatalities were the fourth leading cause of death in the construction industry, and the second leading cause of death overall. Within construction, all but 22 of the 1,901 decedents were male, and males had eight times the fatality rate observed among females. The small number and rate of fatalities among women may be attributed to both their small numbers in the workforce and their underrepresentation in occupations that may have especially high levels of exposure to machinery. It is important to note that much of the difference between males and females disappears when rates are adjusted for the differences in occupational distribution by gender within construction.

The decline in the rate of machinery-related fatalities in the construction industry, 50% for the entire period, was most pronounced between 1989 and 1992. Another NTOF study, using different employment data for calculation of rates, reported a 15% decline in machinery-related fatalities in construction between 1980 and 1989, and a 25% decline in the industry's fatality rate due to all causes over the same 10-year period [Stout et al., 1996].

Limitations of the use of death certificates in ascertainment of work-relatedness and as a source of occupational

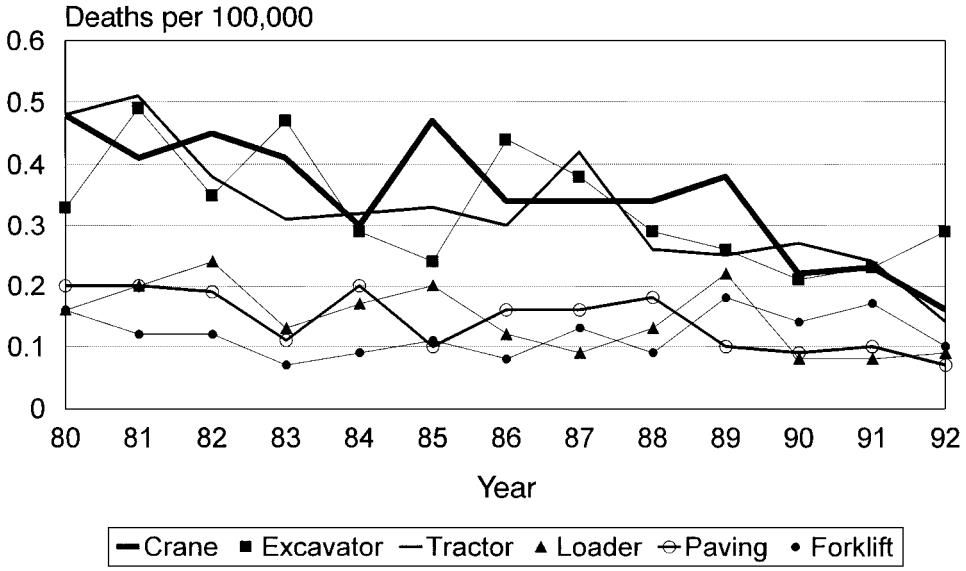

FIGURE 2. Annual rates of machinery-related fatalities for selected machines in the construction industry, United States, 1980–1992. Source: National Traumatic Occupational Fatalities (NTOF) Surveillance System.

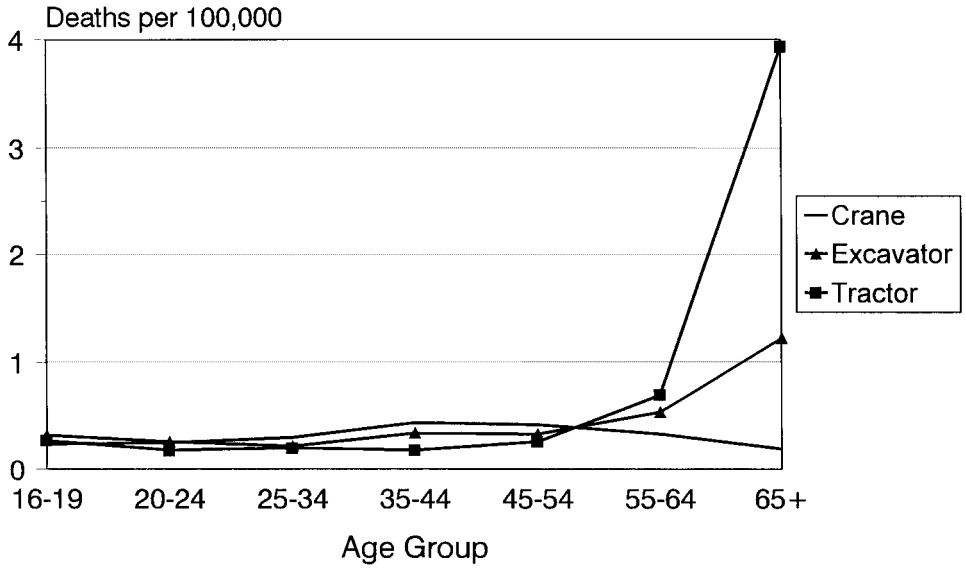

FIGURE 3. Fatality rates by age group for selected machines in the construction industry, United States, 1980–1992. Source: National Traumatic Occupational Fatalities (NTOF) Surveillance System.

fatality data have been described previously [Russell and Conroy, 1991; Stout and Bell, 1991; Bell et al., 1990; Stout-Wiegand, 1984]. Among the limitations are a lack of specific employment information on the death certificate, the customary use of occupation and industry as they appear on the death certificate as proxies for the worker's occupation and industry at the time of injury, and, at the time these NTOF data were collected, the absence of national guidelines for completion of the "injury at work?" item on the death certificate. Despite these limitations, it has been demonstrated that death certificates identify, on the average, 80% of work-related fatalities nationally, more than any other single source [Stout and Bell, 1991]. Thus, it is possible that NTOF did not fully capture the population of machinery-related fatalities occurring in the construction industry during the study period.

The finding that tractor fatalities among construction industry workers increased dramatically with age, while rates for other machine types showed either declines or smaller increases, was difficult to explain. Additional analy-

TABLE V. Fatality Rates* by Census Region for Selected Machine Types, Construction Industry, United States, 1981–1992

	Census region			
Machine	**Midwest**	**Northeast**	**South**	**West**
Crane	.31	.23	.44	.25
Excavating machine	.32	.31	.34	.30
Tractor	.35	.14	.41	.21
Loader	.21	.12	.12	.14
Paving machine	.14	.04	.18	.16
Forklift	.08	.06	.12	.20

*Per 100,000 workers.

TABLE VI. Distribution of Machinery-Related Occupational Fatalities in the Construction Industry by Event Type, United States, 1980–1992

Event	**n**	**%**
Struck, pinned, crushed, or run over		
By mobile machine	569	29.9
By boom, bucket, or arm	142	7.5
By other machine	91	4.8
Struck by falling object	128	6.7
Overturn	323	17.0
Entangled/caught in running machinery	84	4.4
Compressed between equipment or between equipment and object	130	6.8
Fall-related incidents		
Fall from machinery	78	4.1
Fall into machinery	25	1.3
Fall from machinery or unspecified fall, then struck by machinery	50	2.6
Fall, n.e.c. or unspecified	33	1.7
Mobile machinery incident, n.e.c. and unspecified	130	6.8
Machinery incident, nature undetermined	94	4.9
Total	1,901	100.0

sis of the 121 tractor-related deaths among workers aged 55 years and older was undertaken to confirm that these fatalities occurred during construction activity. On each of these death certificates, the occupation and industry narratives did state that the decedent's usual occupation and industry were construction-related. Examination of the 121 death certificates revealed that in 74 (61.2%) of the 121 cases, the fatality occurred on a farm and did not appear to be associated with construction work. In six additional cases (5.0%), the death was not related to construction work but occurred at another location (in four cases, the decedent's residence). Thus, only about 34% of the tractor-related deaths in this age group attributed to the construction industry actually appeared to involve construction activity.

TABLE VII. Leading Causes of Machinery-Related Fatalities in the Construction Industry for Selected Occupation Divisions, United States, 1980–1992

	n	**%**
Executive/administrative/managerial occupations (n = 97)		
Excavating machine	20	20.6
Tractor	17	17.5
Crane	13	13.4
Loader	11	11.3
Precision production/craft/repair occupations (n = 441)		
Tractor	80	18.1
Crane	73	16.6
Excavating machine	42	9.5
Elevator	36	8.2
Transportation and material moving occupations (n = 415)		
Excavating machine	97	23.4
Crane	65	15.7
Tractor	56	13.5
Paving machine	45	10.9
Handlers/equipment cleaners/helpers/laborers (n = 368)		
Crane	64	17.4
Excavating machine	49	13.3
Tractor	39	10.6
Forklift	26	7.1

The proportion unrelated to construction was only slightly higher among workers 65 years and older than among workers aged 55 to 64 years (63.9% vs. 58.3%). Re-calculation of the rates of work-related fatality due to tractors, with the agricultural and non-work-related cases removed, showed greater consistency across the age groups. The rate for workers aged 55 to 64 years becomes .28 per 100,000, and for workers aged 65 years and older, 1.09. This rate ratio of 3.9 is consistent with previous research on machinery-related deaths and other causes of death such as falls, for which similar risk differentials between younger and older workers have been noted [Kisner and Pratt, 1997; Agnew and Suruda, 1993].

The finding that a high proportion of the tractor-related fatalities among older workers classified to the construction industry occurred on farms underscores a limitation of death certificates in surveillance of work-related fatalities. Use of the usual occupation and industry as reported on the death certificate as a proxy for occupation and industry associated with the fatality is clearly problematic in the case of older workers, who frequently continue to farm after retirement from another lifetime industry and occupation. The ''usual'' occupation and industry provided on the death certificate may not necessarily agree with the decedent's activity found in the injury description, even if that activity was indeed work-related. For NTOF or any surveillance system, there is the potential for misclassification of cases: e.g., erroneous

assignment to the construction industry, to the population of machinery-related fatalities, or to specific machinery or events.

It is far less likely that the misclassification noted among tractor fatalities in older workers exists with respect to most other machinery considered in this analysis. For example, it is unlikely that a crane fatality reported as work-related and classified to the construction industry would have in fact occurred in a non-occupational or agricultural setting.

The high incidence and rate of fatalities related to tractors and other machinery among older workers in agriculture has been well-documented in the literature [Kisner and Pratt, 1997; Pratt et al., 1996; Myers and Hard, 1995; Purschwitz and Field, 1990]. The number and rate of machinery-related deaths among older workers in agriculture may actually be considerably higher than that reported by these and similar studies based on death certificates. It is possible that a number of tractor fatalities among older workers in other industries such as transportation, communications, and public utilities; wholesale trade; and manufacturing were in fact associated with agricultural activity.

In general, machine-specific fatality rates showed both temporal and geographic variation. Declines in fatality rates due to cranes and tractors were greater than the overall 50% decline in machinery-related deaths during the 13-year study period. In contrast, fatality rates for excavating machinery stayed nearly level over the same period, and also showed very little variation across census regions. In the Northeast and West regions, where rates due to most machines were quite low, rates for excavating machinery were as high as in the Midwest and South, both of which had considerably higher rates overall. The reasons for this finding are unclear. Presumably, any changes in regulation, training, and safety awareness that may have contributed to overall declines in machinery-related death rates in the construction industry would have affected workers exposed to excavating machinery to the same degree as workers exposed to other types of machinery.

Nearly 62% of all machinery-related fatalities in the construction industry occurred among workers in SIC Major Group 16 (Heavy Construction Other Than Buildings—Contractors). This result is not surprising given that workers in this industry sector may have more consistent exposure to heavy construction machinery. Residential construction workers and some of those employed in special construction trades such as painting, paperhanging, and tile setting, may have less exposure to machinery in general. When they do work around machinery, it may be more likely to involve powered hand tools (excluded from this study), which may cause less severe injuries, rather than heavy machinery such as graders or cranes to which workers in SIC Major Group 16 are more likely to be exposed.

Analysis of fatalities by occupation division showed that, between 1983 and 1992 (the years for which consistent classification of occupation was possible), nearly 88% of all machine-related deaths in construction occurred among precision production, craft, and repair occupations (e.g., electricians, roofers, carpenters, mechanics, and painters), transportation and material moving occupations (e.g., operating engineers, and operators of cranes, excavators, loaders, graders, bulldozers, scrapers, and forklifts); and handlers, equipment cleaners, helpers, and laborers (e.g., construction helpers and freight, stock, or material handlers). Transportation and material moving occupations had by far the highest rates, possibly because most construction industry employees classified in this division have high levels of exposure to machinery. In contrast, the other two divisions contain a broader range of occupations, some of which may have limited exposure to heavy machinery (e.g., carpet and drywall installers, office machinery repairers, service station attendants, hand packers, and paperhangers).

The absence of denominator data that take exposure to machinery into account is a significant impediment to further progress in research on machinery-related fatalities. It is easy to assume that high levels of exposure to machinery would result in increased risk of injury or fatality, but this is not necessarily the case. Workers who are expected to routinely work on or around heavy machinery may receive higher levels of training and may be more familiar with machinery by virtue of more frequent exposure. On the other hand, the worker who is typically engaged in a construction occupation and who may be considered at lower risk of injury may on occasion be placed in an extremely hazardous situation by being asked to operate or work near a machine with which he or she is unfamiliar. Data on exposure to machinery among workers in various construction trades are essential to understanding the relationship between exposure and injury risk.

Analysis by detailed occupation for 1990 through 1992 found that 46% of the decedents were either operating engineers or construction laborers. An additional 14% comprised workers employed in some sort of supervisory capacity. These findings suggest that prevention efforts need to address hazards associated with machine operation, as well as those associated with working on foot around machines. Appropriate training and monitoring of machine operators is particularly important because unsafe actions by operators can jeopardize their own safety and the safety of workers in the area. Practicing safe operating procedures such as avoiding overly rough or sloping terrain, using operator restraints, and working within the machine's recommended load or lift capacity will reduce the risk of injuries due to overturns. The exposure of employees on foot to the hazards associated with movement of heavy machinery can be reduced by institution and enforcement of appropriate traffic control in work areas and ensuring that warning devices such as backup alarms are always operational. Risks can be further reduced through increased compliance with the existing safety and health regulations addressing these

hazards and by the adoption of more easily understood ''plain English'' regulatory language.

Given the seasonality of construction work, the tendency of construction workers to change employers frequently, pressures imposed by contract deadlines, and the constant changes in work environment, workers and employers are constantly challenged to adapt to new work situations, each presenting its own potential hazards [Wolford, 1996; Ringen et al., 1995; Snashall, 1990]. Employers, through provision of appropriate training and encouragement and rewarding of safe work practices, and workers, through adoption and adherence to these practices, can further reduce the risks associated with work around machinery in the construction industry.

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