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MOTOR VEHICLE FATALITIES IN THE UNITED STATES CONSTRUCTION INDUSTRY

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Abstract—A death certificate-based surveillance system was used to identify 2144 work-related motor vehicle fatalities among civilian workers in the United States construction industry over the years 1980–92. Construction workers were twice as likely to be killed by a motor vehicle as the average worker, with an annual crude mortality rate of 2.3/100,000 workers. Injury prevention efforts in construction have had limited effect on motor vehicle-related deaths, with death rates falling by only 11% during the 13-year period, compared with 43% for falls, 54% for electrocutions and 48% for machinery. In all industries combined, motor vehicle fatality rates dropped by 47%. The largest proportion of motor vehicle deaths (40%) occurred among pedestrians, with construction accounting for more than one-fourth of all pedestrian deaths. A minimum of 54 (6%) of these pedestrian fatalities were flaggers or surveyors. Flaggers accounted for half the 34 pedestrian fatalities among women, compared with only 3% among men. Along with previous studies and recent trends in the amount and type of road construction, these results underscore the need for better traffic control management in construction work areas to reduce pedestrian fatalities. As the second leading cause of traumatic death in construction, with an annual average share of 15% of the total deaths, exceeded only by falls, prevention of work-related motor vehicle research should become a greater priority in the construction industry. © 1997 Elsevier Science Ltd.

Keywords—Pedestrians, Construction trucks, Passenger vehicles, Flaggers, Backup

INTRODUCTION

For over 15 years, the construction industry has consistently ranked as the third most hazardous industry in the United States (Jenkins et al., 1993), with a work-related fatal injury rate of two to four times higher than that for all industries combined (Jenkins et al., 1993; Kisner and Fosbroke, 1994). During 1980–92 an average of 6% of the civilian labor force was employed per year in construction [Bureau of Labor Statistics (BLS), 1981–93a], but construction accounted for an average of 18% of 77,675 occupational fatalities identified among civilian workers over the same period [National Institute for Occupational Safety and Health (NIOSH), National Traumatic Occupational Fatalities Surveillance System (NTOF (1980–92)].

Analyses of occupational fatalities in construction have focused on general causes (Buskin and Paulozzi, 1987; Sorock et al., 1993; Kisner and Fosbroke, 1994; Robinson et al., 1995; Ore and Stout, 1996; Pollack et al., 1996), specific external causes, such as machinery (Pratt et al., 1996), trench cave-ins (Suruda et al., 1988), hand tools (Trent and Wyant, 1990), falls (Suruda et al., 1995; Cattledge et al., 1996), electrocutions (Ore and Casini, 1996), and particular occupations, such as laborers (Burkhart et al., 1993; Stern et al., 1995), painters (Suruda, 1992), and operating engineers (Decoufle et al., 1977). Although work-related fatalities resulting from motor vehicle incidents have been researched, motor vehicles as a cause of fatal injury have not received detailed attention in construction, despite being the leading factor in work-related fatalities in the U.S. (Jenkins et al., 1993) and the second leading cause of death for construction workers, exceeded only by falls. This study analyzes motor vehicle deaths in construction from 1980 through 1992 for the purposes of identifying the populations most at risk, prevention opportunities, and areas for further empirical studies.

MATERIALS AND METHODS

Civilian work-related mortality data were taken from the NTOF surveillance system. NTOF data are

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obtained directly from death certificates from all the 50 states, New York City, and the District of Columbia. Case selection criteria were: age 16 years or older, an 'external' cause of death according to the *International Classification of Diseases* (ICD), 9th revision, codes E800–E999 (World Health Organization, 1977), and a positive response to the 'Injury at Work?' item. NTOF includes work-related motor vehicle accidents, but excludes cases which occur while commuting to and from work. Detailed description of the NTOF has been published (Bell et al., 1990; Jenkins et al., 1993). The NTOF classifies each case according to industry and occupation based on the Standard Industrial Classification (SIC) system (Office of Management and Budget, 1987) and the Bureau of the Census occupation codes (BOC, 1982, 1992).

Motor vehicle fatalities in construction were identified according to the external cause of injury E810–E825 (Table 1). For ease of comprehension, the E-codes are presented in four major categories in Tables 3, 5 and 7: traffic collision (E810–E815), traffic noncollision (E816, E818), nontraffic collision (E820–E823), and other/unknown (E819, E825). Years of potential life lost were calculated by subtracting the victim's age at death from the potential retirement age of 65 years (Centers for Disease Control, 1986). Cells with fewer than three deaths were suppressed for confidentiality purposes. The number of deaths identified in 1992 does not include deaths from Connecticut and New York City; the effect of this on the rates presented in the paper are negligible (data from 1990–91 showed fewer than three fatalities in Connecticut and 15 for New York State as a whole).

Table 1. *International Classification of Diseases* (ICD-9) E-codes for motor vehicle accidents

ICD-9 E-Code	Code description
E810	Motor vehicle traffic accident involving collision with train
E811	Motor vehicle traffic accident involving re-entrant collision with another motor vehicle
E812	Other motor vehicle traffic accident involving collision with another motor vehicle
E813	Motor vehicle traffic accident involving collision with other vehicle
E814	Motor vehicle traffic accident involving collision with pedestrian
E815	Other motor vehicle traffic accident involving collision on the highway
E816	Motor vehicle traffic accident due to loss of control, without collision on the highway
E817	Noncollision motor vehicle traffic accident while boarding or alighting
E818	Other noncollision motor vehicle traffic accident
E819	Motor vehicle traffic accident of unspecified nature
E820	Nontraffic accident involving motor-driven snow vehicle
E821	Nontraffic accident involving other off-road motor vehicle
E822	Other motor vehicle nontraffic accident involving collision with moving object
E823	Other motor vehicle nontraffic accident involving collision with stationary object
E824	Other motor vehicle nontraffic accident while boarding and alighting
E825	Other motor vehicle nontraffic accident of other and unspecified nature

Source: World Health Organization (1977).

Data prior to 1990 were coded using a 1987 computer algorithm accurate only at the industry and occupation division level (Castillo and Jenkins, 1994). Data presented by industry sector and detailed occupations are restricted to NTOF data for 1990–92, which were manually coded for detailed industry and occupation. The coder made the assumption that nonspecific industry/occupation combinations, such as construction laborer, belonged in highway and street construction (SIC 1611). Fifty cases were determined to be coded based on this assumption and eliminated from industry sector analyses.

Age, sex, race and occupation-specific rates were calculated as deaths due to motor vehicles per 100,000 workers. These denominator data were taken from the BLS Current Population Survey (CPS) annual averages for employed civilians 16 years of age and over (BLS, 1981–93a). The CPS, which is collected each month from a probability sample of ca 60,000 households, captures both the employed and the self-employed in its enumerations (BLS, 1992). Annual average, civilian employment estimates were derived from the monthly household surveys.

Rates by geographic region were obtained from State employment estimates published in the BLS *Geographic Profile of Employment and Unemployment* (BLS, 1981–93b). State estimates of the distribution of employed civilians are provided by industry for private nonagricultural wage and salary workers. State-specific construction employment estimates do not include either the self-employed or government workers. To adjust the state estimates for self-employment, government workers and unpaid family members, the annual proportion of the U.S. construction industry comprised of nonprivate industry wage and salary workers was assumed to be consistent from state to state. This proportion was obtained from the CPS (BLS, 1981–93a) and used to adjust the employment estimate for each state.

Occupation-specific employment estimates for 1992 were obtained from published and unpublished data provided by Dr Earl Pollack of the Center to Protect Workers' Rights (Pollack et al., 1996; Pollack, personal communication). These data are based on the summation of monthly estimates of hours worked

from the CPS for the year and division by 2000 hours to obtain an estimate of the number of full-time equivalents employed during the survey year. Since these data are based on the CPS, they include both employed and self-employed workers. Occupation-specific employment for 1990 through 1992 was calculated by tripling the 1992 estimate, assuming relative employment stability over the 3-year period.

Employment estimates for the sector-specific mortality rates were taken from the BLS Current Employment Statistics (CES) (BLS, 1981–93a), because data are not available in the household data by construction industry sector defined by SIC codes. There are differences between the two employment data sets in terms of definitions and coverage, source of information, methods of collection, and estimating procedures. For example, the establishment data cover only wage and salary employees. Because other categories of workers, such as self-employed persons, are excluded from establishment data, the use of establishment data in calculating sector-specific death rates inflates the rate estimates.

Monthly estimates of the amount of both public and private construction work during, 1980–92 presented in Fig. 2 were taken from the BOC *Value of New Construction Put in Place* (Bureau of Economic Analysis) (BEA, 1992). The data, unadjusted for seasonal variation, cover the complete original erection of structures, mechanical installations, additions or alterations to existing buildings and outside construction of fixed structures such as highways, streets, and railroad tracks. The estimates represent the value of construction put in place during a reference period. Seasonally unadjusted household monthly construction employment estimates from the CPS (BLS, 1981–93a) were used to calculate the monthly mortality rates.

RESULTS

From 1980 through 1992, motor vehicle incidents ranked as the second leading cause of occupational fatality among civilian workers in the U.S. construction industry, accounting for 15% or 2144 of the total deaths (Table 2). The number of motor vehicle fatalities in construction remained relatively constant, with an annual average of 165 deaths. Motor vehicle was the leading cause of death in all industries combined (23%), and construction accounted for an annual average of 12% of the deaths involving motor vehicles. The annual average crude motor vehicle mortality rate in construction was 2.3/100,000 workers,

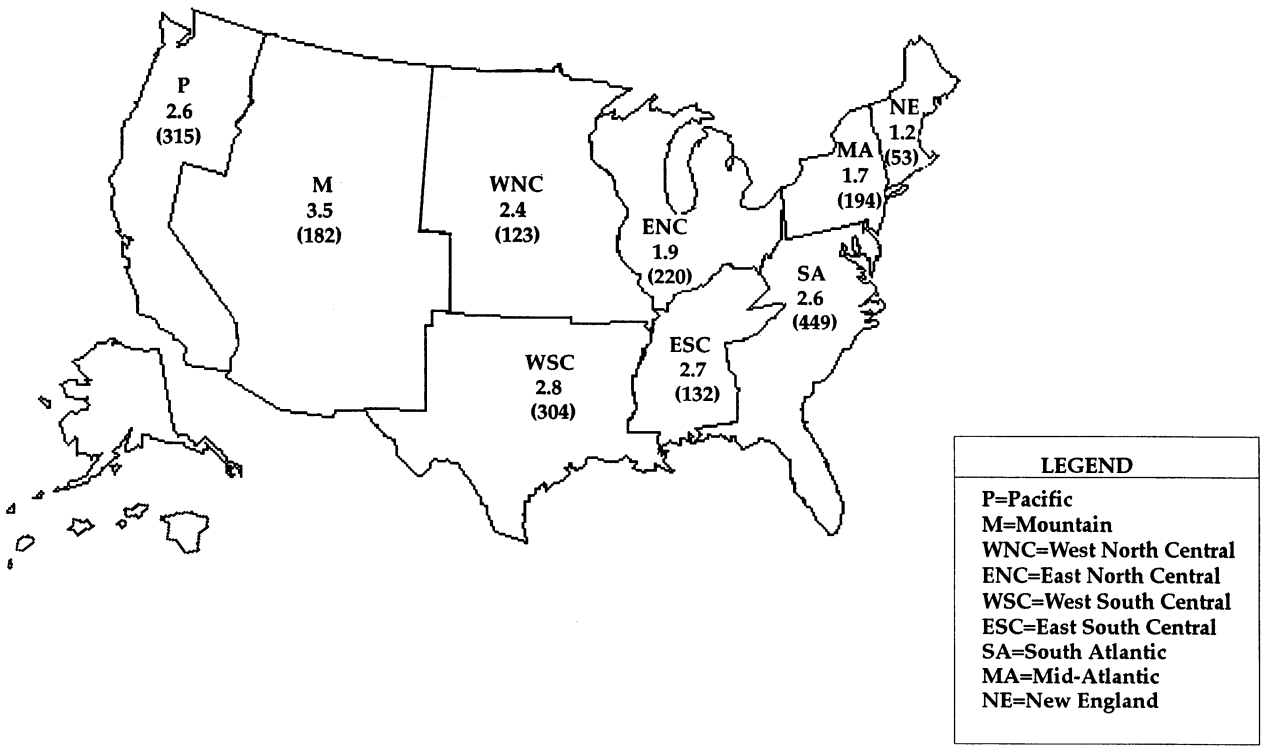


Fig. 1. Number (in parentheses) and rate of civilian occupational fatalities resulting from motor vehicle incidents in the U.S. construction industry by Bureau of Census Geographic Division, 1981–92. Source: NIOSH, National Traumatic Occupational Fatalities Surveillance System and BLS Geographical Profile of Employment and Unemployment and the Current Population Survey. Note: occupational fatalities occurring in Connecticut and New York City are not included in the 1992 data.

Table 2. Rate and number of civilian occupational fatalities related to motor vehicle incidents in the U.S. construction industry and in all U.S. industries combined, 1980–92

	Construction		All industries	
Year	MVF rate/ 100,000 workers	Rate for all causes of fatalities/100,000 workers	MVF rate/ 100,000 workers	Rate for all causes of fatalities/100,000
1980	2.8 (172)*	21.3 (1294)	1.7 (1612)	7.6 (7405)
1981	2.7 (159)	21.0 (1240)	1.5 (1527)	7.2 (7136)
1982	2.0 (118)	19.0 (1091)	1.3 (1309)	6.5 (6459)
1983	2.8 (175)	17.3 (1066)	1.3 (1309)	5.8 (5856)
1984	2.8 (188)	16.1 (1074)	1.4 (1504)	5.9 (6162)
1985	2.2 (155)	16.6 (1160)	1.3 (1405)	5.8 (6250)
1986	2.0 (148)	15.0 (1091)	1.1 (1231)	5.2 (5672)
1987	2.3 (172)	15.9 (1188)	1.2 (1330)	5.2 (5884)
1988	2.4 (179)	14.9 (1130)	1.2 (1401)	5.0 (5751)
1989	2.3 (178)	14.3 (1096)	1.2 (1442)	4.9 (5714)
1990	2.6 (199)	14.0 (1077)	1.1 (1254)	4.6 (5384)
1991	1.8 (129)	12.5 (887)	0.9 (1059)	4.4 (5192)
1992†	2.5 (172)	12.3 (863)	0.9 (1098)	4.1 (4810)
Total	2.3 (2144)	15.9 (14,257)	1.2 (17,481)	5.5 (77,675)

Source: NIOSH, National Traumatic Occupational Fatalities Surveillance System and the BLS Current Population Survey-household data, annual averages.

*Number of motor vehicle deaths in parentheses.

†Occupational fatalities occurring in Connecticut and New York City are not included in the 1992 data.

double the all industry average rate, and these rates fell by only 11%, compared with 47% in all industries. Other leading causes of construction injuries during the 13-year period experienced higher reductions in fatality rates: falls, from 5.3/100,000 workers to 3.0, a decline of 43%; electrocutions, from 3.5 to 1.6, 54%; and machinery, from 2.7 to 1.4, 48%, a combined average decline of 49%. The lack of a decline in motor vehicle deaths in construction during a period when construction fatalities fell 33% resulted in motor vehicles moving from the third leading cause of construction deaths to the second since 1988.

Traffic events accounted for a majority of motor vehicle fatalities in construction (87%) (Table 3). Most (76%) of the 1955 fatalities with known causes resulted from collisions while 24% were noncollisions. Pedestrians accounted for the largest proportion of deaths, 40%, followed by drivers (30%), and passengers (9%). From 1980 to 1992, construction was the industry accounting for the highest share of pedestrian deaths from work-related motor vehicle events, 27%, compared with 25% in transportation, communication and public utilities and 9% in public administration.

The type of vehicle pedestrians were struck by was known for the majority of cases (82% or 709) through the injury description item on the death certificate (Table 4). Trucks were involved in 54% of the pedestrian deaths, passenger vehicles in 22% and machinery 6%. Paucity of detailed information in the surveillance data made it difficult to establish correctly the actual activities being carried out by pedestrians at the time of injury. A minimum of 54 pedestrian decedents (6%) were flaggers or surveyors. Backup deaths among pedestrians were most commonly associated with truck (unspecified) and heavy construction trucks and construction machinery. Exposure to nonconstruction traffic (passenger vehicle, semi-truck and other heavy truck) and work-site traffic (heavy construction trucks and construction machinery) accounted for 31% and 18% of all pedestrian fatalities. There was insufficient information to determine which of these two categories of exposure the remaining 51% of pedestrian deaths fit.

Traffic collision was the leading cause of motor vehicle death in nearly all occupations, ranging from 52% among transportation and material moving workers to 63% among handlers, equipment cleaners, helpers and laborers (Table 5). Although the occupation division that includes laborers represented an annual average of 11% of the construction workforce, they accounted for 41% of the pedestrian fatalities for which the occupation division was known (15 pedestrian deaths were not coded to an occupation division). During 1990–92, transportation and material moving workers, helpers and laborers, and technicians and related support workers had the highest annual average fatality rates, an average of 6.8/100,000 (Table 6). While the precision production, craft and repair occupation division had one of the lowest rates (1.4), two occupations in the division (concrete finishers and structural metal workers) had rates that exceeded the industry average.

Older construction workers were at increased

Table 3. Number of civilian occupational deaths resulting from motor vehicle incidents in the U.S. construction industry by cause and type of fatally injured person, 1980–92

Cause	Fatally injured person				
	Driver*	Passenger*	Pedestrian	Other†	Total‡
Traffic collision (E810–E815)	381	79	674	151	1285
Motor vehicle (E812)	249	60	6	111	426
Pedestrian (E814)	-	-	667	-	669
Other motor vehicle Collision (E815)	80	15	-	14	110
Other	51	4	-	25	80
Traffic noncollision (E816–E818)	228	83	9	153	473
Loss of control (E816)	206	37	-	92	336
Other noncollision (E818)	22	46	8	61	137
Nontraffic collision (E820–E823)	10	3	170	14	197§
Other/unknown	31	20	8	130	189
Traffic other/unspecified (E819)	18	11	0	85	114
Nontraffic other/unspecified (E825)	13	9	8	45	75
Total	650	185	861	448	2144

Source: NIOSH, National Traumatic Occupational Fatalities Surveillance System.
*Of motor vehicle other than motor cycle.
†Include motor cyclists, passengers on motor cycle, occupants of street car, rider of animal and pedal cyclists.
‡Occupational fatalities occurring in Connecticut and New York City are not included in the 1992 data.
§179 of 197 were E822, other motor vehicle nontraffic accident involving collision of a moving object.

Table 4. Number of civilian occupational fatalities among pedestrians in the U.S. construction industry by type of motor vehicle and other characteristics, 1980–92

Motor vehicle group (MVG)	Backup incidents	Flagger/surveyor* as occupation	Total No. of deaths associated with MVG
Heavy construction truck†	26	7	120
Other heavy truck‡	<3	0	19
Semi truck§	<3	4	63
Light truck¶	<3	4	20
Truck, unspecified	52	13	246
Construction machinery**	3	<3	36
Other machinery††	<3	<3	17
Passenger vehicle‡‡	<3	13	188
Other vehicles, unknown	4	10	152
Total	94	54	861

Source: NIOSH, National Traumatic Occupational Fatalities Surveillance System.
*45 Flaggers, nine surveyors.
†Dump truck, oil/water/asphalt truck, excavator truck and air compressor.
‡Wrecker, fire truck, sanitation truck and garbage truck.
§Tractor trailer/semi trailer.
¶Pickup truck.
**Bulldozer, grader, roller, earth moving equipment, front end loader, drag pan, road scrapper and back hoe.
††Tractor, forklift, street sweeper and skidder.
‡‡Car/automobile, van, motor cycle and passenger vehicles.

risk for fatal motor vehicle accidents (Table 7). The age-specific fatality rates per 100,000 workers ranged from 1.8 for age group 25–34 years to 6.9 for those aged 65 years and older. Nine of the 82 fatalities identified among the youngest age group (<20 years) occurred to 16–17 year olds. The median age at death was 38 years and a median of 27 years of potential life (to age 65) were lost per decedent. Traffic collision was the most common cause of motor vehicle fatalities for all age groups, ranging from 55% among age group 16–19 years to 66% among age group 55–64 years. Five of the 28 pedestrian fatalities among 16–19 year olds were flaggers, the highest proportion of all age groups.

Table 5. Number of civilian occupational deaths resulting from motor vehicle incidents in the U.S. construction industry by cause and occupation, 1980–92

Occupation	Cause				Total
	Traffic collision (E810-E815)	Traffic noncollision on (E816-E818)	Nontraffic collision (E820-E823)	Other/unknown (E819-E825)	
Precision production, craft and repair occupations	424	142	49	67	682
Handlers, equipment cleaners, helpers and laborers	405	122	68	52	647
Transportation and material moving occupations	269	154	44	47	514
Executive, administrative and managerial occupations	93	27	24	12	156
Other/unknown*	94	28	12	11	145
Total†	1285	473	197	189	2144

Source: NIOSH, National Traumatic Occupational Fatalities Surveillance System.
*Thirty cases were not coded to an occupation division.
†Occupational fatalities occurring in Connecticut and New York City are not included in the 1992 data.

Table 6. Number and rate of civilian occupational deaths resulting from motor vehicle incidents in the U.S. construction industry by occupation, 1990–92

Occupation	Number of deaths	Death rate/ 100,000 workers
Precision production, craft and repair occupations	178	1.4
Carpenters	17	0.6
Plumbers and pipe fitters	13	1.6
Electricians and apprentices	14	1.3
Painters	8	0.8
Roofers	7	1.6
Concrete finishers	5	3.4
Welders and cutters	4	1.7
Brickmasons	4	1.0
Structural metal workers	3	2.9
Other	103	-
Handlers, equipment cleaners, helpers and laborers	142	6.0
Construction laborers	139	8.6
Other	3	-
Transportation and material moving occupations	123	8.2
Truck drivers*	68	15.4
Operating engineers	44	11.8
Excavating and loading machine operators	4	1.8
Grader, bulldozer and scraper operators	3	1.6
Other	4	-
Executive, administrative and managerial occupations	31	1.1
Professional specialty occupations	8	1.9
Technicians and related support occupations	9	4.9
Machine operators, assemblers and inspectors	8	2.6
Administrative support occupations including clerical	<3	-
Total†	500	2.3

Source: NIOSH, National Traumatic Occupational Fatalities Surveillance System and BLS Current Population Survey [derived from Pollack et al. (1996) and Pollack Personal Communication, 1996].
*Includes 'truck driver, heavy' only for 1990 and 1991 and 'truck drivers' for 1992 data due to change in Bureau of the Census occupation codes
†Occupational fatalities in Connecticut and New York City are not included in the 1992 data.

Nonwhites had a higher crude death rate per 100,000 workers than their white counterparts, 5.4 compared with 2.1. The death rate also varied with gender, with men experiencing a rate of 2.6 and women 0.8. Pedestrians accounted for over half (57%) of all motor vehicle fatalities ($N=60$) among women,

Table 7. Number and rate of civilian occupational fatalities resulting from motor vehicle incidents in the U.S. construction industry by cause and age group, 1980–92

Age group	Cause				Total number of MV deaths	MVF rate/ 100,000 workers
	Traffic collision (E810–E815)	Traffic noncollision (E816–E818)	Nontraffic collision (E820–E823)	Traffic and nontraffic unknown (E819, E825)		
16–19	45	25	6	6	82*	2.2
20–24	153	68	22	28	271	2.3
25–34	329	119	42	47	537	1.8
35–44	255	84	40	37	416	2.0
45–54	228	98	41	39	406	2.9
55–64	214	62	25	23	324	3.8
65+	60	16	21	9	106	6.9
Total†	1284	472	197	189	2141‡	2.4

Source: NIOSH, National Traumatic Occupational Fatalities Surveillance System and BLS Current Population Survey unpublished data.
*Of the 82 fatalities nine occurred among 16–17 year olds.
†Occupational fatalities occurring in Connecticut and New York City are not included in the 1992 data.
‡Three cases were not coded to an age group.

compared with 40% among men. The proportion of pedestrian deaths among women flaggers was also considerably higher than for men, 50% ($N=34$) compared with only 3% ($N=827$). Four of the 94 backup pedestrian fatalities were women. Men were 2.5 times as likely to be killed in motor vehicle accidents involving pedestrians as women, with fatality rates of 1.0 and 0.4, respectively.

Differences in motor vehicle fatality rates in construction by Bureau of the Census geographic divisions during 1981–92 ranged from 1.2 in New England to 3.5 in the Mountain states (Fig. 1). The South Atlantic states, which accounted for the largest share of the deaths (22.8%), had the fourth highest rate at 2.6. The death rates were based on the states in which the death occurred, which may not always reflect the state where the fatal motor vehicle incident occurred.

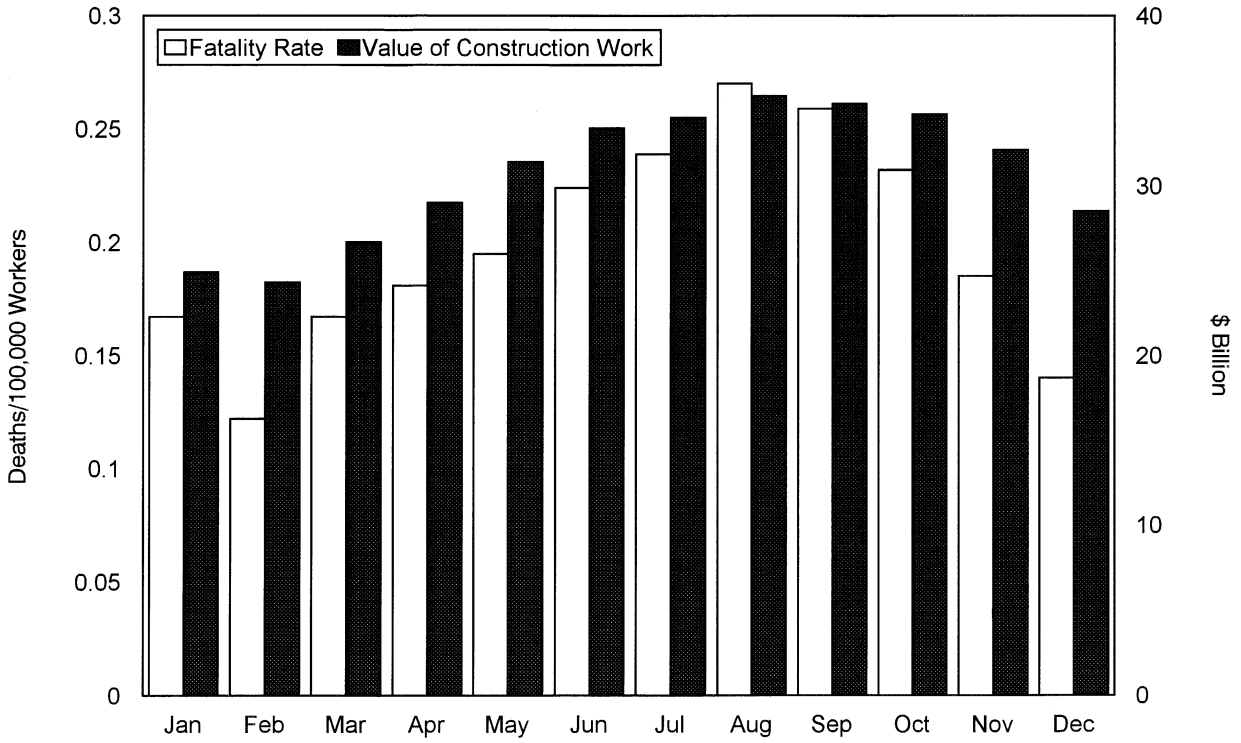
The pattern of seasonal variations in the crude motor vehicle fatality rates in construction during 1980–92 were observed to be similar to the pattern of fluctuations in levels of economic activity in the industry (Fig. 2). In general, months with high average mortality rates also tended to have a high average value of new construction work put in place. The Spearman's rank correlation coefficient between the annualized average monthly fatality rates and the annualized average monthly value of construction work was 0.91.

Most (74%) of the motor vehicle fatalities during 1980–92 occurred on the road, 9% on construction sites, and the remaining 17% happened in other locations, such as home and residential institutions. The industry sector was known for 417 or 83% of 500 motor vehicle deaths from 1990 through 1992, with heavy construction accounting for the largest share (59%), compared with 29% in special trade and 12% in building. Of the 185 pedestrian deaths identified over the 3-year period for which the industry sector was known, 80% were in heavy construction, 13% in special trade, and 7% in building construction. Heavy construction (excluding the 50 cases) also had the highest motor vehicle mortality rate at 10.4, compared with 1.4 each in special trade and building.

The time of injury was known for 91% or 1954 of the fatalities, with a majority (84%) occurring between 6 A.M. and 6 P.M. The hourly distribution was bimodal, with peaks at 11 A.M. and 4 P.M. Similar peaks were observed for traffic, nontraffic and pedestrian deaths. However, for nonpedestrians, the first peak occurred at 8 A.M., and the second at 4 P.M.

DISCUSSION

Death certificates are the only single source of occupational fatality data that potentially includes all workers (Stout and Bell, 1991), and have been used for studying occupational motor vehicle-related deaths in other studies (Loomis, 1991). However, several limitations have been associated with death certificates, particularly with regard to motor vehicles (Karlson and Baker, 1978). State studies comparing case ascertainment using various data sources indicate that death certificates identify between 56 and 73% of motor vehicle deaths, compared with 57–88% for all deaths (Russell and Conroy, 1991). During 1985 and 1986 in Oklahoma, only 60% of work-related traffic motor vehicle fatalities among men were identified through death certificates. Some industries and high-risk occupations were shown to be more often under-identified through death certificates. Using death certificates alone, Russell and Conroy (1991) found that construction had an annual death rate of 30.4/100,000 workers, compared with 33.2/100,000 workers when three additional data sources, including medical examiner reports and workers' compensation



Source: NIOSH Traumatic Occupational Fatalities Surveillance System, BLS Current Population Survey, BEA (1992), and BOC Current Construction Reports, C30 series, Value of New Construction Put in Place. Note: Occupational fatalities occurring in Connecticut and New York City are not included in the 1992 data.

Fig. 2. Relationship between annualized average monthly value of new construction work put in place and annualized monthly average fatality rates due to motor vehicle incidents in the U.S. construction industry, 1980–92.

reports, were used. It was also reported that 57% of the deaths missed by death certificates were in the four highest risk occupations, including helpers and laborers, and transportation and material moving workers. Therefore, the number and rates of motor vehicle fatalities presented in this paper should be considered minimum values.

Injury prevention efforts in the construction industry since 1980 have achieved better results for other leading causes of work-related death than for motor vehicles. More construction workers died in motor vehicle incidents in the last 6 years of 1980–91 than in the first 6 years of the period (1005 compared with 967). The reverse was true for all causes of fatal injury in construction, with the number of deaths falling from 6925 to 6469, and for motor vehicles in all industries combined, from 8666 to 7717. In the general population, the number of traffic motor vehicle fatalities fell by 23% to 39,250 over 1980–92, while the death rate per 100,000 population dropped by 32% to 15.4 [National Highway Traffic Safety Administration (NHTSA, 1995)].

It is also apparent that the construction industry is making slower progress in reducing the rate of fatal injuries involving motor vehicles than other industries. While Table 2 shows a 36% decline in the construction motor vehicle fatality rate between 1980 and 1991, the decline was 47% when all industries are considered together. These results confirm the analysis of trends by industry division reported by Stout et al. (1996) where the decline in the construction motor vehicle-related fatality rate during the 1980s was lower than the decline for all industries.

Although the results presented here identify a slower pace of reduction in motor vehicle fatalities than for other causes of death in the construction industry, possible factors underlying this slower change cannot be ascertained with precision. Because the NTOF surveillance system is based solely on death certificates, it is limited for exploring causality or the potential of preventive approaches. Limited detail in the injury description impedes analysis of important motor vehicle safety issues such as weather and road surface conditions; make, model, configuration, and condition of motor vehicles; initiating and contributory events (e.g. running off edge of road, temporary blindness due to bright light); worker fatigue, health, and substance abuse; company size or motor vehicle policies; seatbelt and other protective equipment use; or the task being conducted at the

time of the fatal event. Use of multiple data sources could result in better surveillance of motor vehicle fatalities among construction workers.

The fatality rates (for both the construction industry as a whole and for motor vehicle-related deaths in construction) presented here are lower than those reported in prior studies based on the NTOF surveillance system (Stout et al., 1996; Kisner and Fosbroke, 1994). This is primarily because prior studies have used establishment-based estimates of construction employment in rate calculation. In 1995, 19% of the 7.7 million workers in the construction industry were self-employed (BLS, 1996). An additional difference between this study and previous NTOF analyses is the definition of motor vehicle-related. This study excluded 'other road vehicle accidents' (E826–E829) from the study population definition.

The construction industry is unique for having the largest proportion of work-related motor vehicle fatalities involving pedestrians (40%, see Table 3). Using data from the BLS *Census of Fatal Occupational Injuries*, Pollack et al. (1996) reported that pedestrians accounted for 35% of transportation-related deaths among workers in 'traditional construction trades and related occupations'. In contrast, the analysis by Armstrong et al. (1991) of 644 work-related motor vehicle fatalities, identified from medical examiner reports in North Carolina during 1979–88, found that pedestrians accounted for only 8% of the deaths, where most victims were working as motor vehicle operators at the time of the fatal event. Even in the general population, pedestrian deaths are less prominent, accounting for an annual average of only 15% of traffic motor vehicle deaths during 1975–94, never exceeding 17% (NHTSA, 1995).

Exposure to heavy trucks and machinery on construction sites may partially explain the high incidence of pedestrian fatalities among construction workers. The NTOF surveillance system is limited for exploring the nature of this exposure, and warrants further studies. Of the 20 pedestrian fatalities known in the New Jersey construction industry during 1983–89, nine were associated with dump trucks, bulldozers and backhoes, while ten were related to cars and tractor trailers. Six of these pedestrians were struck by backing dump trucks and bulldozers (Sorock et al., 1993). Of the 861 pedestrian fatalities reported in the NTOF data, 170 were coded as nontraffic collision, the E-code used when a victim is struck by, or run over by a vehicle that is not on a roadway. Eighteen percent of all pedestrian victims were struck by construction trucks and construction machinery, while 11% were killed when they were backed over by a vehicle. Measures, such as, "better driver warning systems and increased buffer zones between work areas and the roadway", have been suggested for reducing these types of fatalities (Wight et al., 1995). Machine design may be needed to improve the visibility of operators working in proximity to spotters, flaggers and other construction workers. Given the high levels of noise in construction work zones, redesigning audible backup alarms to be more noticeable should also be considered. A case-control study of noise and visibility-related factors would be useful.

The proximity of construction work to passing motorists is another hazard. Though death certificates provide limited information regarding these hazards, occupation narratives specifying flaggers and surveyors, and injury descriptions specifying tractor trailer and automobile involvement allude to the need for improved work zone safety. The data presented in Tables 3 and 4 also suggest the gravity of work zone safety issues. Nearly 80% of the fatal injuries to pedestrians in construction from 1980 through 1992 were coded as motor vehicle traffic accident involving collision with a pedestrian (E-814). Exposure to nonconstruction traffic accounted for at least 31% of these pedestrian fatalities. Flaggers accounted for over half of the deceased female pedestrians and five of the 28 deceased pedestrians aged 16 to 19 years old.

The issue of work zone safety has been a concern since at least the mid-1960s when California studied fatal crashes in work zones (Anderson, 1990a). A study of 2651 fatal work zone crashes in 1990 indicated that $>80\%$ occurred in construction work zones (versus utility and maintenance work zones), with 29% of work zone fatal crashes occurring on interstate highways, 25% on State highways, and 18% on U.S. routes (National Transportation Safety Board (NTSB, 1992). Several researchers have shown that motor vehicle travel through roadway construction areas increases the risk of a crash (Doege and Levy, 1977; Pigman and Agent, 1990; Sorock et al., 1996). These studies do not report the number of deaths among construction workers versus among drivers traveling through work zones. However, Frisbie (1991) and Anderson (1990b) describe five deaths to Caltrans workers in 1990. Anderson (1990b) further notes that from 1972 through 1990, 47 Caltrans workers died at work and that 25 of those deaths were due to 'errant motorists'.

Recent research suggests that motor vehicle crashes in work zones are on the rise. Using automobile insurance claims files from 1990 through 1993, Sorock et al. (1996) found that the number of motor vehicle crashes in roadway construction areas in the U.S. rose from 648 to 1065, and the crash rate per

10,000 personal insured vehicles increased from 2.1 to 3.6. Sorock et al. (1996) suggest that this increased exposure is related to increases in federal funding for roadway construction in 1991. If this assertion is correct, then this hazard continues to grow, as the value of new highway and street construction grew 22% in constant dollars from 1990 to 1994 (BOC, 1996). When total spending on highway construction increased from ca U.S.$32 billion (actual dollar figure) in 1982 to ca U.S.$52 billion in 1988 (NTSB, 1992) the number of fatalities that occurred in highway work zones also rose from 489 to 780. Recent years have also seen a shift in the type of highway construction from initial construction to repair, maintenance, and renovation work. A report by the NTSB (1992) suggests that this shift in construction activity might also raise the exposure of both construction workers and the motoring public to work zone hazards. Previous studies, the number of pedestrian deaths among construction workers resulting from being struck by passenger vehicles and tractor trailer trucks, and recent trends in the amount and type of road construction all point to the need for better traffic control management in construction work areas to reduce pedestrian fatalities. The type of traffic control used should be dictated by "the nature, location and duration of work, type of roadway, traffic volume and speed, and potential hazard" (West Virginia Department of Highways, 1985).

Development of an effective traffic control plan during the early stages of a road construction project and strict compliance with the plan during construction is critical to work zone safety (Jacks, 1987). Reduction of fatalities depends on a variety of strategies aimed at reducing the opportunity for collision, potential for driver confusion, and the severity of incidents that do occur. For example, strategies for alleviating traffic disruptions through public relations and through improvements to alternative routes (Jacks, 1987) can reduce the traffic flow through a construction zone during construction activity. Physical separation of opposing traffic flow through the use of barriers is more effective at reducing the chance of head-on collisions than is separation of traffic through barrels or markers (Doege and Levy, 1977; NTSB, 1992; Smith, 1993). Likewise, the use of barriers can protect construction workers from being hit by errant motorists (Jacks, 1987; Merwin, 1988; Smith, 1993). It is also important to avoid confusing drivers entering work zones. Lane markings should be easily understood, with conflicting lane markings erased (NTSB, 1992; Smith, 1993). Signs should be placed so that they are not obscured (Smith, 1993) and so that they provide the driver adequate time to interpret the information. The effectiveness of traffic control devices and speed restrictions are compromised when they remain in place after the work is completed (Merwin, 1988; Frisbie, 1991; Smith, 1993). Several reports suggest that speed restrictions may be more effective with the presence of uniformed police officers (Jacks, 1987; Merwin, 1988; Frisbie, 1991; NTSB, 1992; Smith, 1993). Crash attenuating devices can be installed on fixed objects, such as bridge abutments (Doege and Levy, 1976) or on construction vehicles (Jacks, 1987; NTSB, 1992; Smith, 1993), to reduce the impact of collisions. When preventive measures fail, post-incident measures, such as first aid and emergency medical response, need to be in place (Haddon, 1972; Waller, 1973).

Adequate protection of flaggers or surveyors is critical to construction zone safety planning. The Occupational Safety and Health Administration (OSHA) and Federal Highway Administration (FHWA) have regulations aimed at protecting flaggers from being struck by motor vehicles. OSHA *Standard 29 Code of Federal Regulations* (CFR) 1926.201(a) requires that "flagmen shall be provided with and shall wear a red or orange warning garment while flagging. Warning garments worn at night shall be of reflectorized material" (U.S. Department of Labor, 1995). FHWA (1993) specifies a wider range of colors for both daytime and nighttime work, and flaggers to be visible at a minimum distance of 1000 feet at night. FHWA (1993) also specifies retro reflective material, rather than reflective material, designed "to identify clearly the wearer as a person and be visible through the full range of body motions". It has been suggested that construction workers exposed to traffic should also wear highly visible clothing similar to that of flaggers. These regulations are similar to those in operation in construction work zones in the Ontario province of Canada, where protection of traffic control persons from hazards is mandatory, and includes personal protective equipment and devices to guard against traffic hazards (Construction Safety Association of Ontario, 1992).

Highway agencies require flagger stations to be located far enough ahead of the work zone to give drivers time to reduce their speed (FHWA, 1993), and on the pavement shoulder, or in closed lanes, adequately marked with warning signs [American Society for Concrete Construction (ASCC, 1995)]. When sight distance is limited, sites should be manned by more than one flagger (ASCC, 1995). When flagging, flaggers should stand alone, focusing on the oncoming traffic, and have designated chief flagger when two flaggers are controlling alternate one-way traffic (ASCC, 1995). A flagger should only stand in

the lane being used by moving traffic after traffic has stopped, and the flagger needs to be visible to traffic at all times. Therefore, coworkers should be discouraged from congregating around flaggers (West Virginia Department of Highways, 1985). It may be useful for flaggers to have an escape route ready in case a motorist fails to see them or disregards signals (Construction Safety Association of Ontario, 1992). Adequacy of these flagging procedures should be evaluated.

Training all construction workers to work next to traffic in a way that reduces their vulnerability may reduce risk. Training in traffic control techniques, device usage and placement should be provided to workers who have specific traffic control responsibilities. Effective use of audible warning devices could help flaggers alert coworkers to approaching danger (NTSB, 1992; FHWA, 1993). Previous publications suggest that changes in driver behavior, vehicle structures (Haight and Olsen, 1981), bumper and hood design (Robertson and Baker, 1976) and improved traffic control techniques (Jacks, 1987; Merwin, 1988; Smith, 1993) should also be considered as methods of reducing pedestrian fatalities.

The crash frequency of motor vehicles traveling through roadway construction work zones varies with the level of construction activity, increasing in April and falling off in October (Sorock et al., 1996). Fatal motor vehicle incidents among construction workers are also related to construction activity. In peak work seasons, with high value of new construction work put in place, exposure to motor vehicles could be higher than in low seasons, hence a higher risk of motor vehicle-related deaths. Labor turnover rates are high in construction (Business Roundtable, 1982) and construction employment levels are seasonal (Myers and Swerdloff, 1967). Many of the workers hired during peak periods to offset labor shortages may be inexperienced (Foster and Strauss, 1972; Helander, 1980) and may be at a higher risk to injury (Helander, 1980). Seasonal fluctuations in work-related fatalities in construction are not unique to motor vehicle events. Ore and Casini (1996) noted a similar pattern for electrocutions between 1980 and 1991. Annual fluctuations in motor vehicle fatality rates (see Table 2) could also be related to variations in construction activity. Further empirical studies are required to unravel the dynamics of the interaction between changes in economic activity and the risk for motor vehicle-related deaths among construction workers.

Regional variations in work-related motor vehicle mortality rates in construction are similar to the pattern for the general public (Baker et al., 1987) and for work-related motor vehicle fatalities in all industries (Jenkins et al., 1993). Factors associated with regional differences in motor vehicle death rates in the general population include variations in economic conditions, population density and road safety policies (Baker et al., 1987; Haight and Olsen, 1981; Zlatoper, 1991), age composition of the workforce and weather (Chang and Graham, 1993), degree of urbanization (Haight and Olsen, 1981), travel speeds (FHWA, 1982), and enforcement of pedestrian protection laws (Haight and Olsen, 1981). Special prevention efforts for motor vehicle fatalities in construction are warranted in the high-risk Mountain, West South Central, and East South Central states. Studies of factors (e.g. union density, topography, legal measures and managerial practices) associated with regional and state differences in motor vehicle fatality rates in the construction industry are needed.

The occupation-specific mortality rates are also broadly consistent with other studies. In the New Jersey construction industry, helpers and laborers were observed to be more frequently involved in motor vehicle deaths than other construction occupations, while heavy truck drivers had the fourth highest death rate (27.2/100,000 workers) from all causes, nearly twice the industry average (Sorock et al., 1993). Across all North Carolina industries, motor vehicle operators experienced the highest age-adjusted motor vehicle death rate at 18.8/100,000 person years (Armstrong et al., 1991). Two occupations that had relatively high motor vehicle fatality rates in both the North Carolina study of all industries and this study of the U.S. construction industry were transportation and material moving operators, helpers and laborers. Transportation accidents (a category that includes motor vehicle-related fatalities) accounted for at least one-third of work-related fatal injuries among truck drivers, equipment operators (excavating machine, grader, dozer and scraper operators) and operating engineers in the U.S. construction industry in 1992 and 1993 (Pollack et al., 1996). Decoufle et al. (1977) calculated proportionate mortality ratios for operating engineers and estimated an excess proportion of deaths due to motor vehicle-related incidents of 41%. Along with these studies, the present investigation points to the need to focus prevention of fatal motor vehicle incidents in construction on construction laborers, truck drivers and operating engineers.

Notwithstanding data limitations, intersectoral differences in motor vehicle fatality rates in the U.S. construction industry are consistent with results of the Washington State construction industry study. During 1973–83, the heavy construction sector in the Washington State had the highest rate of fatalities

from motor vehicles at 17.0/100,000 workers, compared with 3.1 in building construction, 2.3 in special trade construction, and 5.8 in the industry as a whole (Buskin and Paulozzi, 1987). Heavy construction, particularly highway and street construction, should be better targeted, and availability of more detailed surveillance data will be critical to this exercise.

Existing prevention measures in the general population, such as seat belt use and prohibition of alcohol use, while useful, are not sufficient to reduce the number of construction workers killed by motor vehicles. This is partly because "workplace deaths are often distinct from deaths from the same cause outside the workplace" (Stout et al., 1996). In the case of fatal motor vehicle incidents, younger persons tend to experience higher age-specific motor vehicle mortality rates in the general population than older persons (NHTSA, 1995). As shown in Table 7 and in the study of construction fatalities in Washington State (Buskin and Paulozzi, 1987), the reverse was true in construction. Another example is the proportion of pedestrians killed in motor vehicle events presented earlier. These important differences underscore the need for workplace-based prevention programs for motor vehicles that are specific to the construction industry.

CONCLUSION

This study shows that there has been limited success in controlling work-related motor vehicle deaths in construction, and points to leading causes and high-risk regions and demographic groups where prevention efforts should be directed. Better surveillance and prevention will require on site observation in case-control studies and the linkage of death certificates with other data sources, such as the National Highway Traffic Safety Administration's Fatal Accident Reporting System, medical examiner reports, Occupational Safety and Health Administration fatality reports, workers' compensation reports, and insurance claims accident narrative data. Improved safety requires the co-operative efforts of construction contractors, the motoring public, enforcement agencies, highway agencies, occupational safety researchers and the road construction workers themselves. As the second leading cause of traumatic death in construction, exceeded only by falls, work-related motor vehicle injury research and preventive efforts should become a greater priority.

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