A Case-Control Study of Forklift and Other Powered Industrial Vehicle Incidents

James W. Collins, PhD,[1*] Gordon S. Smith, MB, ChB, MPH,[2] Susan P. Baker, MPH,[2] Douglas P. Landsittel, PhD,[1] and Margaret Warner, PhD[2]

Background *This study examined risk factors associated with forklift and other powered industrial vehicle (PIV) collision injuries with an emphasis on the design of factory traffic systems, the loading and safety features of PIVs, and the characteristics of the drivers.*
Methods *A case-control study examined risk factors for circumstances of injury-producing PIV incidents at eight automotive manufacturing plants between July 1992 and March 1995. A computerized safety and health surveillance system identified 171 incidents where a PIV (forklift 70%, personnel carriers 15%, other 15%) was involved in a collision incident. Site visits were conducted to collect data regarding the factory environment at the collision site, the PIVs involved in the incidents, and driver characteristics. These data were compared with information collected from a random sample of comparison worksites, PIVs, and PIV drivers who had not been involved in a PIV-related incident in the prior 3 years.*
Results *In half of the cases (86 of 171), an employee (pedestrian) was struck by a PIV or an object being carried by the PIV. The presence of an obstruction that restricted the aisle width increased the odds of a collision incident 1.89 times (95% CI = 1.22, 2.86). The presence of overhead mirrors at intersections and blind corners with limited visibility reduced the odds of a PIV collision incident by a third (OR = 0.33, 95% CI = 0.16, 0.68). When carrying a load, the odds of a PIV being involved in a collision was 1.58 (95% CI = 1.03, 2.41) times greater than an unloaded one.*
Conclusion *Changes in the factory environment, vehicle safety features, and driver and pedestrian training are suggested to reduce the risk of PIV incidents.* Am. J. Ind. Med. 36:522–531, 1999. *Published 1999 Wiley-Liss, Inc.*[†]

KEY WORDS: injury; occupational; manufacturing; automotive; powered industrial vehicles; forklifts; case-control study

INTRODUCTION

Since World War II, manual material handling has been largely replaced by mechanized lifting and transport equipment [Larsson and Rechnitzer, 1994]. The forklift is the single most versatile piece of material handling equipment used in manufacturing. The forklift's freedom of movement combined with its weight and rigid construction creates inherent safety hazards, particularly when operated in close proximity to pedestrians. In a previous study of forklift injuries, Booth [1979] noted, "The need for

[1]National Institute for Occupational Safety and Health, Division of Safety Research, 1095 Willowdale Road, Morgantown, West Virginia
[2]Department of Health Policy and Management, Johns Hopkins University School of Public Health, Center for Injury Research and Policy, Baltimore, Maryland
James W. Collins was a doctoral student at Johns Hopkins University at the time this research was conducted
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*Correspondence to: James W. Collins, National Institute for Occupational Safety and Health, Division of Safety Research, 1095 Willowdale Road, Mail-Stop P-1133, Morgantown, West Virginia 26505-2888. E-mail: joc4@cdc.gov

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planning of the layout of factories and warehouses to minimize risk of transport accidents...'' and that ''...the wealth of knowledge and experience from road safety has not been adequately implemented inside the factory gate.''

Forklifts and other powered industrial vehicles (PIVs) are a common source of occupational injuries. The Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI) indicates that approximately 100 workers die each year in forklift incidents [Helmer, 1994]. An estimated 34,000 work-related injuries involving forklift trucks are treated in U.S. emergency rooms each year [Stout-Wiegand, 1987]. Of the 3,041 forklift injuries reported by the California Department of Industrial Relations in 1980, 31% were cases in which pedestrians were struck by forklift trucks [California Department of Industrial Relations, 1982]. Another 23% were cases where the worker was caught in, under, or between a forklift and another object. Other studies of forklift injuries reported that the most frequent incidents involve workers who are struck by or run over by forklift trucks [Coleman et al., 1978; Ostberg and Svensson, 1973]. In Finland too, of the approximately 1,500 incidents per year involving forklifts, the most common causes of injury are forklifts striking workers and collisions with other vehicles or fixed objects [Hakkinen, 1978]. Because of the high frequency and severity of collisions with pedestrians, fixed objects, and other PIVs [Collins et al., 1999b], the focus of this case-control study was on injury-producing incidents involving moving PIVs.

Injuries have traditionally been classified in terms of the general environment in which they occur (e.g., work, home, or on the highway), the general mechanisms of injury (motor vehicle collisions, falls, drownings, etc.) or the contributing behavioral or human factors. Because of the multiple factors that contribute to most injury causing events, epidemiologic methods offer a useful approach for identifying risk factors that contribute to injuries. While previous investigations of PIV incidents were primarily limited to descriptive studies of forklift incidents, this study utilized an analytical case-control study design that incorporated control groups to make comparisons between injury sites, involved drivers, and PIVs with vehicles, sites, and drivers not involved in powered industrial vehicle incidents.

The human host has been the unit of analysis in most case-control studies [Mittleman et al., 1997] but case-control designs have also been used to provide evidence regarding the contribution of vehicle and environmental factors in motor vehicle incidents. In a study of fatal motor vehicle crashes, the characteristics of crash sites where vehicles struck fixed objects along the roadside were compared to sites which the case vehicles had safely passed one mile prior to the crash site [Wright and Robertson, 1976]. Driver and vehicle factors were assumed to remain constant at the case and comparison sites. The study identified substantial differences between the crash and non-crash sites in the curvature and gradient of the road, as well as the number of fixed objects beside the road between crash and non-crash sites. The study findings suggested that environmental modifications would greatly reduce the severity of fixed-object crashes at sites with the identified characteristics. Subsequent research using this study design found excess involvement of similar road characteristics in off-road rollover fatalities [Wright and Zador, 1980], occupant drowning caused by vehicles running into water [Wintemute et al., 1990], and multiple vehicle crashes at roadway sections other than intersections [Fulgham, 1989]. An investigation of large truck crashes in Washington State used a similar case-control design [Stein and Jones, 1988]. For each large truck involved in a crash, data were collected on three control trucks that were randomly selected from the traffic stream at the crash site one week after the crash. The case-control methodology has proven effective in identifying factors that were over represented in crashes.

Automobile manufacturing is an industry that has experienced rapid change and modernization. Over the last 25 years, the United Auto Workers and auto manufacturers have worked hard to improve the working conditions of auto workers. These efforts include, but are not limited to, establishing joint labor–management health and safety programs, strengthening safety and health contract language, increasing worker education, and sponsoring safety and health research. Despite these efforts, a significant number of auto workers are injured in PIV-related incidents; most frequent are collisions with pedestrians, other PIVs, and obstructions. This study examined the influence of the characteristics of the factory environment, the PIV, and the driver on the risk of PIV-related injuries.

METHODS

This case-control study examined incidents involving PIVs that occurred between July 1992 and March 1995 at eight automobile manufacturing plants. Cases were restricted to incidents which occurred while a PIV was in motion. Incidents that occurred while PIVs were stationary (e.g., worker mounting or dismounting, maintenance) were excluded.

A real-time computerized surveillance system was used to identify cases. A variable in the data base identified potential cases with a variable that asked ''Was a PIV a factor in this incident?'' A subsequent study improved the method of case identification by selecting additional cases through the use of a computerized key word search of the narrative fields in data base [Collins et al., 1999b]. When an injury occurs, information on the injury is required to be entered into the computer data base within 24hr by the worker's supervisor, the Safety Department, and the plant Medical staff. Information was initially provided on PIV-related incidents that occurred between July 1992 and June 1994, and subsequent cases were updated from the computer data base every two weeks until March 1995. For each incident that met the case definition, a site visit was conducted to collect data on the characteristics of the factory environment; questionnaires were administered to PIV drivers to obtain information about the incident and the vehicle. Information on the controls was also gathered.

Data on three types of control groups were obtained separately: (1) comparison sites; (2) comparison vehicles; and (3) comparison drivers. Risk factors examined included the driver's age and experience, the safety features and loading of the PIV, and plant characteristics such as aisle width, volume of vehicle traffic, volume of pedestrian traffic, obstructions in the factory (e.g., poles, parts bins, and storage racks), placement of stop signs, overhead dome mirrors to improve visibility, guardrails/barriers to separate pedestrians from vehicle traffic, and the slope of the floor surface.

Questionnaires were completed by each driver involved in an incident. The drivers were asked about the incident, their training, the safety features and the loading of vehicle involved in the incident and their ideas about reducing the risk of injuries associated with PIVs. Because interviews were conducted as long as two and a half years after their involvement in a collision, and the fact that drivers were selected for interview because they were operating a PIV that struck a pedestrian, another PIV, or a fixed object, the drivers' memory of the incident may not be completely accurate. Because controls were not interviewed and all of the case and control data used for comparison was obtained from routinely recorded personnel records, differential information bias from case and control drivers was not an issue in this study.

To examine risk factors related to the driver, each case driver was matched on occupation to three control workers in the same plant who had not been involved in a PIV incident in the 3 years prior to the incident. Controls were randomly selected from personnel records of hourly workers with the same occupation in the same plant. Injury records were reviewed, and workers who had been involved in a PIV incident in the past three years were eliminated from the list of drivers eligible to be sampled as controls. Data were collected for both cases and controls on age and total length of employment.

For physical environment variables, each plant was divided into functional zones based on the consensus of a group of plant and union representatives. The functional zones involved activities such as door assembly, subassembly, storage, painting, and loading docks. For each case, the functional zone in which the incident occurred was identified and three control sites were then selected from the same functional zone. Using a map of each plant, the location of each PIV-related incident was marked on the map. Locations are specified within each plant with a matrix of numbers and letters based on roof support columns which make up a 40 feet by 40 feet square. The first stage of a two-stage sampling strategy for control sites used a random number table to select an initial location. The second stage of the sampling strategy subdivided the square into sixteen 10 feet by 10 feet sections and used a random number table to select one of the sixteen squares as a comparison site. If an incident had occurred at the control site or if it was not possible for a PIV to travel through the area, then the random number table was used to select another of the 16 sites for data collection. This procedure was repeated three times for each control. Comparisons between incident sites and three control sites for each case were made for 7 plants, at which 129 incidents occurred.

A map of each plant was used to sample control sites at seven of the modern auto plants that each consisted of one rectangular building on a single level. Unlike the modern plants, one older assembly plant consisted of 52 buildings, most of which were 5 stories high. The two-hundred and sixty maps that would have been required for sampling control sites were not available for this facility. No control data were collected on the physical environment at this plant, only data on drivers and vehicles.

Control vehicles selected were the first three PIVs of the same type as the PIV involved in the incident to pass the incident site at approximately the same hour of the day that the incident occurred. The loading of the vehicle and presence of flashing lights mounted on PIVs were assessed for association with collisions.

Site Visits—Data Collection Procedures

A letter was sent to the union and management representatives of the Safety and Health Department notifying them that their plant had been selected as a study site and presenting an overview of the study and the data collection procedures. Site visits began with an opening conference in which the objectives of the study were discussed with safety and union staff, the plant manager, and representatives from the personnel department. The management and union representatives of the safety department were extremely helpful in setting up driver interviews, identifying incident sites, describing training programs, obtaining personnel records, and other aspects of data collection. After the opening conference, each PIV incident was reviewed by union and management representatives from the safety department. When PIV drivers were approached to obtain informed consent to be interviewed, the union representative assured the drivers that this information was being collected confidentially for research purposes only and would not be used by or available to either the corporation or the union.

Data Analysis

Frequencies were computed for each nominal variable such as ''type of PIV'' and for all ordinal variables such as ''aisle width.'' This analysis provided information on: (1) the basic profile of the data, (2) the percentage of missing data for each variable, (3) the number of data points in each stratum and whether it made sense to combine certain strata in further analyses, and (4) data points that were outliers. Certain strata were combined due to very small numbers in a few categories, which led to unstable estimates. Frequency distributions were examined to determine how many observations fell in each category. Although tests of homogeneity were not performed, several regression models were fit using different cut-points to examine what effect combining strata would have. Strata were then combined based on (1) meaningful categories for the given variables, and (2) results of preliminary regression analyses (i.e., what effect did combining the given strata have on regression estimates).

Bivariate statistics were then employed to test the hypotheses about the relationship between collision and non-collision outcomes and variables associated with the PIV driver, the safety features of the vehicle, and the environmental characteristics of the factory. For dichotomous variables, odds ratios with 95% confidence intervals were used as the basic measure of association. An association was considered significant if the confidence interval did not include one. For variables with three or more categories, one of the categories was treated as a reference group. The data were then treated as a series of 2 by 2 tables computing the odds ratios and 95% confidence interval for each stratum. Adjacent categories having similar odds ratios were combined to provide more stable estimates of risk.

The data were analyzed using the EGRET package to compute odds ratios for each environmental risk factor [EGRET, 1996]. To examine the simultaneous effect of the various study factors, a conditional logistic regression model was used to estimate the adjusted odds ratio for each of the factors included in the model [Hosmer and LeMeshow, 1990]. Conditional logistic regression was applied to each of the three sets of risk factors separately (environmental characteristics, vehicle characteristics, and driver characteristics) with collision and no collision as the outcome. Logistic regression models were used to compute odds ratios for variables within each of three sets of risk factors adjusted for other factors. The model was determined by finding the best fitting, yet plausible model to describe the relationship between the PIV collisions and the three sets of independent variables.

RESULTS

Descriptive Results

Circumstances

The circumstances of the incidents are presented in Table I. In 86 (50%) cases, an employee was struck by a PIV, an object being carried by a PIV, or indirectly by a rack, bin, or other object that was struck by a PIV. The most common scenario involved employees who were struck while walking through the plant to exit doors, to break areas, time clocks, bathrooms or the cafeteria. Approximately 10% of the pedestrian incidents occurred when a PIV bumped a rack, bin, or table, that subsequently struck an employee in the immediate vicinity of his or her workstation. Another 10% of the pedestrian injuries occurred when the load fell, slipped, or was lowered onto an employee. Of the 86 PIV-related incidents where a pedestrian was injured, a forklift was involved in 67 (78%), personnel carriers and carts were involved in 10 (12%), and other types of PIVs in 9 (10%) incidents. In approximately 30% of the incidents in which a forklift struck a pedestrian, the forklift was traveling backwards.

Thirty-nine PIV drivers were injured when their vehicle struck an obstruction such as a post, rack, bin, guardrail, wall, table, or fixed equipment, and 29 incidents consisted of collisions between two PIVs. There were three cases in which a forklift overturned and two in which a forklift fell between a tractor trailer and the loading dock.

Consequences of the Injuries

Hospital visits and lost work days and restricted days

Seventy-five of the 171 (44%) incidents resulted in days away from work; a total of 3065 lost workdays, an average

TABLE I. Circumstances of Incidents[a] Investigated in the Case–Control Study

Nature of incident	Frequency	Percent
Pedestrian struck by PIV	86	50.3
Collision with obstruction	39	22.8
Collision with other PIV	29	17.0
PIV fell from tractor-trailer	6	3.5
PIV drove over pothole	4	2.3
Passenger fell from PIV or driver jumped off	4	2.3
Rack fell onto driver	1	0.6
Load fell off rear of overloaded cart	1	0.6
Steering wheel knob broke off in employee's hand	1	0.6
Total	171[a]	100.0

[a]Environmental data was collected for only 167 sites, at four sites plant renovations had changed the site.

of 41 days per incident. Of the 75 incidents that resulted in lost workdays, 48 resulted in an additional 460 restricted days, an average of 10 restricted days per lost-workday incident. Of the 171 injured workers, 67 (39%) required a hospital for treatment.

Site visits

Site visits were conducted at eight automobile manufacturing and distribution plants: three stamping plants, three assembly plants, one transmission plant, and one parts depot. Data were collected on the environmental characteristics of 167 of the 171 (97.7%) incident sites. Data were not collected on four sites because plant renovations had completely changed the area and as mentioned earlier, suitable control sites could not be determined at one plant. Of the 171 drivers who were eligible to complete questionnaires, it could not be determined who the driver was in 20 (11%) of the incidents. Of the remaining 151 drivers, 131 (87%) completed and returned questionnaires. Ten drivers were no longer employed, three drivers refused to complete the questionnaire, two were on sick leave, two were on vacation, one driver had been laid off due to disciplinary reasons, and two drivers were still off work because of their injuries.

Analytical Results

Site characteristics

Data were collected on 378 non-collision sites for comparison with the incident sites and obstructions were identified at half (189) of the comparison sites. Of the 189 comparison sites where obstructions existed, 74 of the obstructions were permanent obstructions, consisting of 42 sites with fixed equipment, 19 roof supporting poles, 9 guardrails, and 4 overhead obstructions. Temporary obstructions were observed at the remaining 115 comparison sites. They consisted of 107 racks, bins, or other parts containers, three parked PIVs, two locations with small parts on the floor, one barrel in the aisle, and two unspecified obstructions. Sixty percent of injury sites had an obstruction either in the aisle or at the edge of the aisle that narrowed the width of the aisle or could have potentially restricted the view of the vehicle operator or a pedestrian (Table II). In contrast, obstructions were identified at only 50% of comparison sites ($P = .004$).

Obstructions included both temporary obstructions such as racks, bins, and parked PIVs and fixed obstructions such as roof-supporting poles, fixed equipment, guardrails, and overhead doorways, pipes and lighting. No obstructions were present to restrict the width of the aisle or overhead clearance of the aisle at 67 of the sites. For the remaining 100 incident sites, 37 of the obstructions were permanent objects such as fixed equipment ($n = 12$), roof supporting poles ($n = 11$), guardrails ($n = 7$), overhead doorways ($n = 4$), tables ($n = 2$), and an overhead scrap chute in the basement below a stamping press ($n = 1$). Fixed equipment was identified because of the potential to obstruct the visibility of the driver, while poles and guardrails were listed as obstructions because they narrowed the width of the aisle. The remaining 63 obstructions were categorized as temporary obstructions that were either partially or completely in the aisle. Fifty-two of these were racks, bins, or other parts containers; the others were powered industrial vehicles parked in the aisle ($n = 3$), boxes ($n = 3$), car carriers ($n = 2$), dies ($n = 2$), and parts on the floor ($n = 1$).

TABLE II. Frequency and Percentage of Permanent and Temporary Obstructions at Incident and Comparison Sites in a Study of PIV Incidents at Automotive Plants

Obstruction	Incident sites frequency (%)	Comparison sites frequency (%)	
Permanent	37 (22%)	74 (20%)	*P*-value = .004
Temporary	63 (38%)	115 (30%)	
No obstructions	67 (40%)	189 (50%)	
Total	167 (100%)	378 (100%)	

Note: No data were collected on four sites that had completely changed since the incident occurred.

Overhead dome mirrors

There were fewer mirrors at incident sites ($P < .001$) when compared to control sites (Table III). Only 8% of the incident sites had an overhead dome mirror within 50 feet of where the incident occurred, whereas 19% of the control sites had an overhead dome mirror within 50 feet of the site. The improved visibility to drivers and pedestrians provided by mirrors at intersections and blind corners was associated with an odds of a PIV collision of one third (OR = 0.33, 95% CI = 0.16, 0.68).

Inclined surfaces

Of the 167 incident sites where data were collected, the PIV was traveling on an inclined floor surface in 7 incidents. Of the 373 comparison sites for which the information was recorded, only 1 had an inclined floor surface. Five of the incidents on inclined floor surfaces were excluded from analysis because they occurred at the one older assembly plant where the sampling strategy could not be followed because of plant design and resulted in no control data being collected. These incidents occurred on a large ramp upon which PIVs frequently traveled from one floor to another in a multi-storied building.

TABLE III. Distribution of Cases and Controls: Characteristics of Environment and Vehicle

	Cases		Controls		
Environmental characteristic	**Number**	**Percent**	**Number**	**Percent**	**P-value**
Mirrors present within 50 feet of the site					
Yes	10	7.9	72	19.2	.001
No	116	92.1	303	80.8	
Total	126				
Obstructions at the site					
Not present	44	34.9	186	49.6	.004
Present	82	65.1	189	50.4	
Total	126				
PIV Carrying a Load					
No	61	48.8	279	59.5	.035
Yes	64	51.2	190	40.5	
Total	125				
Floor surface					
No incline	124	98.4	372	99.7	.098
Incline	2	1.6	1	0.3	
Total	126				
Volume of pedestrian traffic					
$<$40 pedestrians/hr	112	86.9	348	89.9	.327
$\geq$ 40 pedestrians/hr	17	13.2	39	10.1	
Total	129				
Walkways for Pedestrians					
Yes	1	0.8	7	1.9	.404
No	125	99.2	367	98.1	
Total	126				
Guardrails to separate pedestrian and PIV traffic					
Guardrails	2	1.6	4	1.1	.644
No guardrails	124	98.4	370	98.9	
Total	126				
Volume of PIV traffic					
$<$40 PIVs/hr	80	62.0	244	63.1	.833
$\geq$ 40 PIVs	49	38.0	143	36.9	
Total	129				
Stop sign at site					
Yes	15	11.9	46	12.3	.914
No	111	88.1	329	87.7	
Total	126				
Aisle width					
$>$12 feet	52	40.3	157	40.6	.956
$\leq$12 feet	77	59.7	230	59	
Total	129				
Vehicle equipped with flashing light					
Yes	93	78.8	369	79.2	.929
No	25	21.2	97	20.9	
Total	118				

Pedestrian and vehicle traffic

The volume of PIV traffic between case and control sites was not determined to be a statistically significant factor (OR = 1.06, 95% CI 0.65–1.72) in the occurrence of PIV incidents (Table III). A heavy density of pedestrian traffic was suggestive of an increased risk of injury but this finding was not statistically significant (OR = 1.39, 95% CI 0.74, 2.64, *P*-value = .315).

Stop signs

Stop signs were present at 12% of the incident sites and were also present at 12% of the control sites. However, in four of the incidents the driver passed through an intersection without stopping at the posted stop sign.

Aisle width

The width of the aisle was investigated as a potential factor that might increase the risk of injury associated with PIVs. Aisle width was categorized as 12 feet or less vs. wider than 12 feet, based on the aisle width necessary for two PIVs to safely pass. Based on the comparison with control sites where no incidents had occurred, there was no evidence ($P = .956$) to suggest that aisle width was associated with an increased risk of PIV incidents.

Walkways and guardrails

The presence of walkways for pedestrians and/or guardrails to separate pedestrians from PIV traffic was not shown to be a significant factor ($P = .644$) and was rare for both cases and comparison sites (Table III).

Vehicle Characteristics

Data were obtained for 469 comparison PIVs. Three matched control vehicles were obtained for 152 of the incidents. At 15 of the incident sites, fewer than three vehicles passed the site during the data collection period.

Loading of the vehicle

Drivers were asked whether or not their vehicle was carrying a load when the incident occurred. Of the 125 drivers who could recall, 64 (51%) indicated that their vehicle was loaded. Of the 469 comparison vehicles, 41% were carrying a load ($P = .035$).

Warning lights

In general, all of the vehicles in a plant were either equipped with flashing lights or none of the vehicles had flashing lights. Because the comparison vehicles were selected from the same plant as the vehicles involved in the incidents, this study design was unable to detect an effect of warning lights due to the fact that the percentage of case and control vehicles with back-up audible warning signals was the same.

Driver characteristics

Ninety-eight percent of the injuries occurred to workers who were paid hourly and two percent to salaried workers. Control data were available only for the hourly workers ($n = 405$). Data were obtained from personnel records on 441 of 513 possible comparison drivers. No comparison drivers were selected for the incidents where the driver could not be identified. However, there were four incidents for which a driver questionnaire was not obtained but case and control data were obtained from personnel records. Differences in the age distribution of cases and controls were not statistically significant (Figure 1, $P = .07$). Workers aged 45–54 years were the lowest risk group and were selected as the reference group. Relative to the reference group, the odds of a worker in the 21–34 year old group being injured was 2.08 (95% CI = 0.90, 2.08), in the 35–44 year old age group the odds were 1.77 (95% CI = 0.50, 2.77), and in the 55 and older age group, the odds were 1.48 (95% CI = 0.55, 3.57).

The comparison drivers had significantly more years of total work experience with the corporation; 67% had been employed by the corporation for more than 20 years, compared to 44% of the cases ($P<.001$). The drivers with at least 15 years of work experience with the corporation had the lowest risk of being involved in a PIV collision and were used as the reference group. Relative to the reference group, the odds of a driver who had been employed by the corporation for more than five years but less than 15 years was 4.67 (95% CI = 2.2, 9.8). The odds of employees with 1–5 years of total employment was 1.98 (95% CI = 0.59,

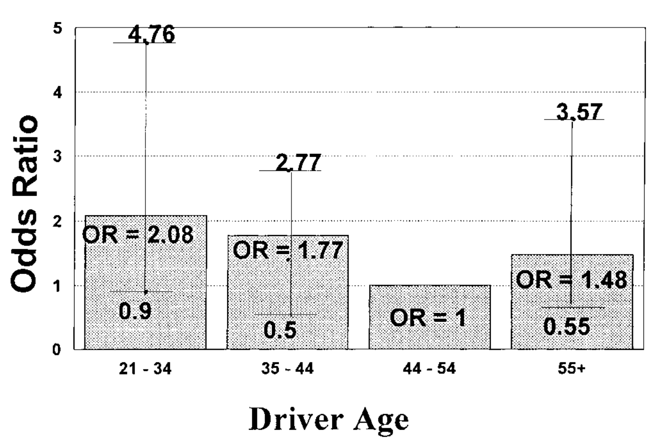

FIGURE 1. Odds Ratios for Forklift Injuries by Driver Age

6.54) and the odds for employees with less than one year of employment with the corporation was 1.34 (95% CI = 0.52, 3.41). The finding that drivers who had worked for the corporation for 5–15 years were at the greatest risk can be partially explained by the amount of time these workers were in their job class. Of the 26 operators who had worked for the corporation for 5–15 years, 10 (38%) had been in their job class for less than one year, and 7 (26%) for less than one month.

Over one-third of the injuries (36%) involved employees with less than one year of experience in their job class. Of particular note, one-fifth of the injuries occurred to employees with less than one month of experience in their job class. Of the workers injured during their first year in a job class, 61% were injured during the first month. Data on time in job class were not available for the control groups.

Multi-variable analysis

Conditional logistic regression was applied to select the models that best describe the estimated risk associated with the three sets of risk factors for the environmental characteristics, vehicle characteristics, and driver characteristics separately. Table IV presents the odds ratios and confidence intervals for each of the environmental and vehicle risk factors.

The variables with bivariate P-values less than .3 were forwarded into the initial multivariate model. The multivariate model for the environmental characteristics included the presence of mirrors, the presence of obstructions, and whether or not the floor surface was inclined or flat at the incident and control sites. The coefficients for mirror and obstruction do not change when floor slope is added to the model. When the interaction between the presence of a mirror and the presence of an obstruction was added to the model, large confidence intervals resulted for all the variables in the model. Even though the interaction between mirror and obstructions was marginally significant, the final model for the characteristics of the physical environment includes mirror (OR = 0.032) and obstruction (OR = 1.92), with the interaction term dropped from the model. The only significant vehicle characteristic was the loading of the vehicle (P =.035). With regard to the characteristics of the PIV driver, only years of experience with the corporation is significant (P<.001).

DISCUSSION

This study is the first to use a case–control methodology to examine the characteristics of the operator, the environment, and the vehicle that were involved in PIV-related incidents relative to control groups. The findings of this study provide evidence that the etiology of collisions involving PIVs is multifactorial, i.e., characteristics of the operator, the vehicle, and the factory environment can each increase risk.

This study provides evidence that the presence of obstructions in the aisle contributes to PIV-related incidents. Obstructions were present at 100 of the 167 (60%) incident sites, two-thirds of which were temporary obstructions and one-third of which were permanent/fixed obstructions. The data suggest that when setting up new workstations or redesigning old workstations, permanent/fixed obstructions such as control panels and other fixed equipment/machinery should be installed as far away from the aisle as possible, particularly at intersections where the installation of fixed equipment and control panels are more likely to create blind corners. In general, fixed equipment/machinery did not restrict the width of the aisle but was more likely to obstruct the visibility of PIV driver and pedestrians due to close proximity to the aisle and intersections. Roof supporting poles and guardrails that were struck by PIVs were generally at the edge of the aisle.

TABLE IV. Adjusted and Unadjusted Odds Ratios for Forklift Injuries for Risk Factors Studied

Adjusted variable	Crude odds ratio	95% Confidence interval	Adjusted odds ratio	95% Confidence interval
Interval environmental characteristics				
Mirror	0.33	(0.16, 0.68)	0.32	(0.15, 0.68)
Obstruction	1.89	(1.22, 2.86)	1.92	(1.23, 2.94)
Volume of pedestrian traffic	1.39	(0.74, 2.64)		
Presence of stop signs	1.06	(0.56, 2.00)		
Aisle widths	1.01	(0.66, 1.56)		
Volume of PIV traffic	1.06	(0.65, 1.72)		
Vehicle characteristics				
PIV loaded	1.58	(1.03, 2.41)		

The prevalence of racks and bins in the aisle indicates that a significant number of workstations do not have adequate space to store more than one rack or bin of parts awaiting assembly. This is particularly true in plants that have implemented just-in-time manufacturing practices where the objective is to have just enough inventory arriving at a workstation just-in-time to replace the inventory that was just used. When a new just-in-time plant is constructed, adequate areas for the storage of racks and bins are incorporated at each workstation. However, with older plants, the implementation of the just-in-time inventory concept can cause space utilization problems. Some of the sites where incidents occurred were congested with bins, racks, and PIV and pedestrian traffic.

This study provides evidence that dome mirrors that are mounted overhead at intersections, and other cross aisles with limited visibility, are associated with a reduction in the risk of incidents, presumably by improving the visibility of both PIV operators and pedestrians for oncoming hazards at intersections and other areas with limited visibility. Dome mirrors should be installed at intersections with blind corners and other areas in the plant with limited visibility, and cleaned on a regular basis.

The finding that drivers involved in injury incidents were less experienced suggests a need for more comprehensive training for new PIV operators. Although video and written training programs for PIVs are comprehensive in their coverage of safety hazards, drivers revealed in their replies to questionnaires that they felt more supervised operation should be required of newly trained drivers. A few of the forklift truck operators indicated that when they were first allowed to drive in production areas, they were uncomfortable with their ability to safely operate the vehicle.

Training should also be provided to operators of powered industrial vehicles other than forklifts. Personnel carriers contribute to a significant portion of the incidents involving PIVs and there is currently no standardized training or licensure requirement for operators of personnel carriers.

Training on the hazards of working near PIVs should be provided to all employees. The most common injury scenario involving pedestrians occurs when a forklift or other powered industrial vehicle either directly or indirectly strikes an employee. Many drivers who had been involved in an incident stated that pedestrians were not aware of the hazards associated with working near PIVs.

In the eight plants in this study, there was little attempt to segregate pedestrians from forklifts and other PIV traffic. Pedestrian traffic flow is at a peak during shift changes, meal breaks, and other employee breaks. PIV traffic should be limited during times of peak pedestrian flow. Traffic planning should take into consideration the path and ultimate destination of the pedestrian flow (i.e., time clocks, plant exits, cafeterias, etc.). Consideration should be given to limiting some aisles to either pedestrian or PIV traffic and to restricting the use of forklifts and other powered industrial vehicles near time clocks, exits, and other areas, when there are large numbers of pedestrians, such as at the end of a shift or during breaks.

The findings in this study provide evidence that a PIV is at greater risk of being involved in a collision when transporting a load. It is suspected that the loading of a PIV affects the driver's visibility, the braking distance of the PIV, the driver's posture, the direction of travel, and the overall handling and stability of the PIV. Secondarily, loads are not typically secured on the forks of the trucks and sudden stops or change of direction can affect the stability of the load and the vehicle. Only stable and securely arranged loads should be handled.

One of the most common injury scenarios occurred in the main aisle where forklifts and other powered industrial vehicles travel at high speeds and pedestrians enter the aisle at random spots. Although we were not able to include this in our study, the use of flashing lights and audible warning devices may be a viable means of alerting pedestrians and other operators when a moving PIV is in the area. Every effort should be made to alert employees when a PIV is in close proximity.

It is hoped that this study provides information that will help safety professionals, forklift operators, supervisors, training personnel, union personnel and workstation designers to reduce the risk of PIV incidents. Reducing risk will require well maintained PIVs equipped with the appropriate safety devices, a safe work environment, comprehensive training of operators of all types of PIVs, and implementing and enforcing systematic traffic management.

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