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Occupational Accidents in an Industrial City: Are Causative Agents' Employee- and Employer-Related?

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Abstract

Background: The causes of occupational accidents have been widely examined from different perspectives; however, little is known about the specifics of such accidents in the Russian industry. Therefore, this study aimed to identify these specifics and compare them with global patterns.

Materials and Methods: This study analysed 165 officially documented cases of severe and fatal occupational accidents that occurred in the utilities, manufacturing, and construction industries in a Russian industrial city between 2018 and 2021. Structural analysis, cross-tabulation analysis, and binary regression models were used to identify potentially high-risk groups, focusing on two main categories of accident causes: employee-related and employer-related. Sociodemographic and accident characteristics were also analysed.

Results: The general distribution of injury mechanisms (collapses, contacts, and falls) and factors associated with accident severity (night and Saturday shifts and occupations in energy provision) were consistent with international patterns. Night and weekend shifts, as well as energy-provision occupations, significantly increased the odds of fatal accidents. Technical causes were statistically associated with fatal accidents in both the industrial sector overall and the manufacturing industry. Workers with ≥15 years of experience had higher odds of employer-related injuries, whereas accidents involving employees aged ≥61 years were more often attributed to employee behaviour.

Conclusions: The findings identify high-risk worker groups and may help improve occupational safety practices in Russian industry. Closer supervision of high-risk groups (core-age workers, night/weekend shifts, and workers with >15 years of experience), mandatory training for new employees, and proactive safety measures for an aging workforce are recommended.

Keywords: Occupational Injuries, Logistic Models, Wounds and Injuries, Industry, Accident Prevention.

Introduction

Currently, a large body of knowledge on the specifics of occupational accidents in almost every industry in most developed and developing countries has been established and accident patterns have been identified. Researchers, applying modern statistical methods, study various aspects of occupational safety in the industrial sector, focusing on causes of accidents. It is important to note that the authors of these studies employ various cause classifications for their analysis.

Carrillo-Castrillo et al. [1] researched the most common causes and mechanisms of accidents in the Spanish manufacturing sector, splitting them into active and latent and applying categorical data analysis. Based on their data, 71% of the identified causes are latent, and as such there is a need for greater efforts in the areas of

organization, safety management, and behaviour. Baby et al. [2] dealt with personal and safety climate factors, but only in a specific industry. They utilized the example of electrical accidents to analyse such factors as self-esteem, job stress, personal stress, social support, and fatigue. As can be observed, the majority of these factors are more closely linked to the psychological state of workers than with their behaviour (actions). Elsewhere, Kazan & Usmen [3] analysed construction equipment accidents in the US. They concluded that inadequate safety training, missing equipment protective system, being a non-union worker, being an equipment operator and being on or around inadequately maintained equipment yielded higher odds for fatality. In this research, the authors did not differentiate the causes into employee- and employer-related factors.

Nwankwo et al. [4] researched the most common causes of catastrophic accidents in the oil and gas industry, considering that the integration of human causal factors with technical and organizational factors provides more objective results concerning the true causes of accidents. Fuentes-Bargues et al. [5] explored the relationship between various factors and industrial accidents in the Spanish metallurgical sector. They classified the factors into four groups: personal, business, material, and time, emphasizing that worker-related characteristics are especially important in production processes and the accident rate. Based on their results, The Monday effect, meal breaks, and being near retirement age are the most important factors affecting the number of serious accidents in the metal sector. As can be observed, all of these are employee-related factors.

While the aforementioned cause classifications are undoubtedly important for a deeper analysis, they do not exactly provide sufficient details in terms of accountability for the incident, which rests with both the employer and the employee. Currently, there is a lack of research examining occupational accidents through the lens of such a classification.

Another research aspect in modern studies of occupational accidents is inspecting the causes of fatalities. Gonzalez-Delgado et al. [6] dealt with this issue using the example of Mexican workers at an economy-wide level. At the industry level, a few works exist. One of them has evaluated disparities in unintentional occupational fatalities occurring in North Carolina [7], while another has explored the causes of fatal and severe accidents in the US electric power industry [8]. Olcay et al. [9] used the example of the construction industry to appraise the relationship between the characteristics of cases and the number of fatalities. This study scrutinized factors such as type of project, geographic zone, accident type, worker's profession, injured body area, construction site, and accident environment. Other authors ascertained the influence of age on the frequency of fatal industrial accidents [10, 11], analysed the accidental deaths caused by jamming or crushing in the manufacturing industry [12], researched the types of events that preceded serious and fatal accidents in surface, underground, and total mining [13]. We did not find any research that utilized employer- and employee-related classification for exploring the causes of fatalities in diverse industries.

To the best of our knowledge, no studies to date have specifically analysed occupational accidents in industrial cities or employed data on Russian industrial accidents. This study fills this gap and is the first to explore the interaction between causal categories of occupational accidents in a Russian industrial city. As part of this study, all occupational accidents that took place in the city of Chelyabinsk from 2018 to 2021 were analysed. The analysis period was limited by the availability of data provided by the State Labor Inspectorate. This study was conducted using quantitative data analysis, including structural analysis, cross-tabulation analysis, and binary logistic regression models. The aim of our research has been to identify the relative contribution of employer- and employee-related factors to severe and fatal accidents in Chelyabinsk's industrial sector. The rationale for utilizing an "employee-related vs. employer-related" classification is supported by the following arguments. First, industrial occupational accidents frequently emanate from a combination of inappropriate employee behaviour and personal factors (such as unsafe acts, young age, lack of experience, low education, and health problems) and employer practices (including poor safety management and hazardous environments). Preventing these incidents effectively therefore demands a focus on both sets of factors. Further, analysing the causes of injuries (fatal and severe cases) in the context of employer and worker responsibility allows not only for a deeper understanding of accident root causes but also for taking more effective preventive measures in production management.

Chelyabinsk is an industrial city located in the central part of Russia. In 2024, the total population was 1.18 million, with the average number of employed individuals being 331,439, of whom approximately 35% were recruited in the industrial sector (manufacturing, construction, power generation, water, gas distribution) [14]. This segment of the workforce, predominantly in the metallurgical industry, is employed in potentially hazardous conditions owing to the prevailing association of the industrial sector with the risk of injury. Metallurgical production generates approximately 62% of the region's income. The automative, chemical, and food production industries generate 10%, 11%, and 8% of the region's gross domestic product, respectively.

The highest rate of severe occupational incidence is found in the construction industry (251 per 100,000 employees), followed by the manufacturing industry

(24.5) [14]. It is therefore essential to identify the factors in occupational accidents as well as the groups of the labour force overrepresented in severe and fatal accidents. According to the Russian Labour Code, a fatal occupational accident is an accident when the victim is afflicted by a fatal injury, while a severe accident is an accident when the victim is harmed by an injury classified as severe (injuries resulting in the loss of limbs, hearing, vision or speech, or the loss of labour capacity by 30% or more, category I disability, or loss of reproductive function). We chose these two categories of accidents for analysis as they have the most serious consequences for both the employer and the employee. Most countries have laws and regulations that require employers to inspect and prevent fatal as well as severe occupational accidents. The retrospective analysis of such cases will help employers to comply with these regulations by more accurately appraising injury risks, ameliorating safety measures, and protecting employees from potential hazards.

Materials and Methods

According to the Russian law, it is obligatory for businesses to report occupational accidents, with the information being sent to the State Labour Inspectorate, the Occupational Safety Department, and insurance companies. Therefore, information based on the authors' coding (Table 1) was requested from the State Labour Inspectorate, for severe and fatal accidents in the industrial sector while not including accidents classified as non-occupational (chronic disease such as heart attack or stroke, suicide, murder, etc.). The coding system was developed jointly by the authors based on the literature review and international classifications. The brief content of Table 1 is depicted in Fig. 1, where the "main cause" is the primary factor attributed to accident occurrence, classified based on official investigation records. The "mechanism of injury" refers to the physical manner in which the injury occurred; the "type of occupation" is worker roles grouped according to job responsibilities and hazard profile.

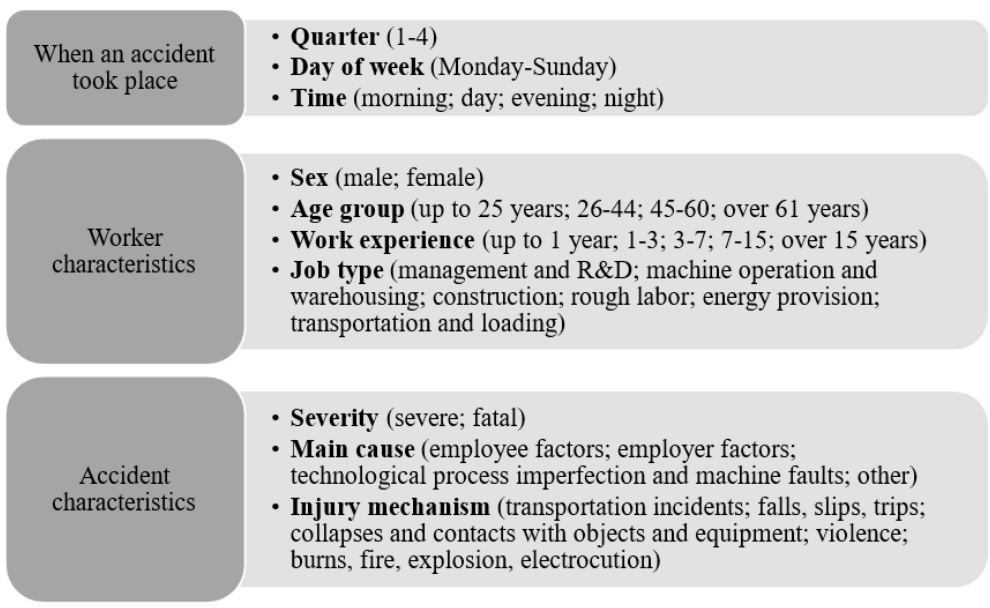

Fig. 1. Overview of study variables employed in coding the initial data

The complete dataset was composed of 165 cases containing coded information about accident date, time, severity, injury mechanism, leading cause according to the investigation, sex, age (at the time of the accident), work experience (at the time of the accident), job type, and company's industrial sector. In this way, the inspectorate shared encoded data without giving access to any personal information of the accident victims. Overall, the dataset includes all severe and fatal accidents that took place in the city from 2018 to 2021. Only data from this period was permitted for transmission and processing.

Typically, there are three main groups of occupational accident causes: organizational, human, and technical [4; 30]. Nevertheless, in this study, according to the causes identified in the official reports, we classified groups of causes under the following categories. First, "Technological process imperfection and machine faults" which coincides with "Technical causes" in the original classification, where it is impossible to identify a direct human error, but it is linked to the faulty machines and equipment. Second, "Employer causes" corresponds to organizational causes, and is utilized when the enterprise has been charged and accused of poor work organization. The instances include lack of supervision, providing insufficient training or having workers operate outside their specialty. "Employee causes" implies causes when workers were at fault and correlates with "Human causes". This category's sub-causes, are fore example violations of technical rules; failure to follow organizational and technical documentation, safety requirements or discipline; failure to utilize protective equipment; alcoholic, narcotic, and other intoxication; personal negligence, etc. The "Other" group captures unfavourable natural conditions, the actions of third parties, and any unidentified reasons.

Accident causes were categorized based on the leading cause identified in the official investigation report. If the documented cause referred to the worker's unsafe actions or violations of rules, the case was classified as employee-related. If it pointed to deficiencies in workplace organization, supervision, equipment, or environment, it was rated as employer-related. The full coding scheme is presented in Table 1.

Table 1. Variable coding table

Variable		Code	Variable		Code
Accident severity	Severe (ref.)	0	Sex	Male (ref.)	1
	Fatal	1		Female	2
Quarter	1 (ref.)	1	Age group (years)	Up to 25 (ref.)	1
	2	2		26-44	2
	3	3		45-60	3
	4	4		Over 61	4
Day	Mon (ref.)	1	Work experience (years)	Up to 1 (ref.)	1
	Tue	2		1-3	2
	Wed	3		3-7	3
	Thu	4		7-15	4
	Fri	5		Over 15	5
	Sat	6	Injury mechanism	Transportation incidents (ref.)	1
	Sun	7		Falls, slips, trips	2
Accident time	Morning (05:00-11:00) (ref.)	1		Collapses and contacts with objects and equipment	3
	Day (11:00-17:00)	2		Violence by persons	4
	Evening (17:00-23:00)	3		Burns, fire, explosion, electrocution	5
	Night (23:00-05:00)	4	Job type	Management and R&D (administrative personnel, engineer, etc.) (ref.)	1
Accident main cause	Employee factors (violation of work processes or traffic rules, violation of organizational and technical documentation rules, safety requirements, discipline; failure to use protective equipment; a state of alcoholic, narcotic and other intoxication; usage of funds for other purposes; personal negligence) (ref.)	0		Machine operation and warehousing (operator, master, tester, inspectors, etc.)	2
	Employer factors (unsatisfactory organization of work; inadequate supervision; lack of medical examination; improper housekeeping; shortcomings in the training of workers in labor protection or lack of safety documentation; workers employed outside their area of expertise)	1		Construction work (concrete worker, welder, mason, roofer, painter, finisher, insulator, etc.)	3
	Technological process imperfection and machine faults (design flaws and insufficient reliability of equipment; operation of faulty equipment; unsatisfactory condition of buildings, structures, territory)	2		Rough labor, equipment adjustment, application of specialized tools (pour man, refractory man, charge maker, smelter, separator, heat-treater, die press coremaker, caster, straightener, processor of surface defects of metal, cutter, carpenter, driller, turner, setup technician, smith, industrial cleaner, support workers, etc.)	4
	Other factors (unfavorable natural conditions; illegal actions of third parties; deterioration of health for unidentified reasons)	3		Energy provision (electrician, etc.)	5
				Transportation and loading (driver- machinery operator, loader, etc.)	6

Note: (ref.) = reference group for regression models

Table 2. Factors associated with accident severity and causes in the industrial sector and manufacturing industry (OR and CI)

Dependent variable		Severity		Cause	
		Industrial sector	Manufacturing	Industrial sector	Manufacturing
		Model 1	Model 2	Model 3	Model 4
Quarter	Base: 1				
	2	2.588 (0.558-11.99)	0.813 (0.046-14.171)	4.712 (1.117-19.86)	1.764 (0.145-21.36)
	3	1.894 (0.345-10.39)	1.621 (0.027-95.218)	2.919 (0.705-12.08)	0.351 (0.024-5.012)
	4	1.180 (0.255-5.452)	11.03 (0.233-521.089)	9.823 (2.412-39.99)	5.535 (0.512-59.74)
Weekday	Base: Mon				
	Tue	1.177 (0.182-7.580)	17.51 (0.244-.)	0.484 (0.105-2.212)	0.933 (0.076-11.37)
	Wed	1.766 (0.275-11.33)	25.01 (0.296-.)	0.923 (0.240-3.554)	0.779 (0.120-5.025)
	Thu	1.395 (0.160-12.11)	98.02 (0.619-.)	0.966 (0.212-4.397)	0.901 (0.085-9.549)
	Fri	1.111 (0.128-9.591)	0.078 (0.001-5.1)	0.628 (0.128-3.074)	0.339 (0.031-3.670)
	Sat	7.502 (0.762-73.87)	. (2.865-.)	0.134 (0.014-1.260)	0.073 (0.001-3.563)
	Sun	2.144 (0.251-18.30)	90.11 (0.662-.)	0.168 (0.017-1.626)	0.443 (0.016-11.92)
Injury mechanism	Base: Transportation incidents				
	Falls, slips, trips	0.148 (0.013-1.638)	.	19.65 (2.508-154.0)	1.517 (0.042-54.55)
	Collapses & contact with objects	0.471 (0.064-3.439)	.	10.46 (1.511-72.41)	2.190 (0.095-50.11)
	Violence	-	.	-	-
	Burns, fire, explosion, electrocution	0.804 (0.091-7.073)	.	35.15 (3.662-337.4)	5.617 (0.133-236.1)
Accident severity	Base: Severe	-	-		
	Fatal	-	-	0.541 (0.143-2.052)	0.358 (0.024-5.323)
Cause	*Base: Employee factors*			-	-
	Employer factors	0.627 (0.178-2.206)	0.056 (0.001-1.91)	-	-
	Technological process	13.39 (1.919-93.46)	85.40 (0.753-.)	-	-
	Other factors	-	-	-	-
Accident time	Base: morning				
	Day	1.116 (0.305-4.086)	0.540 (0.031-9.242)	0.745 (0.256-2.166)	0.069 (0.007-0.668)
	Evening	0.618 (0.106-3.584)	0.064 (0.000-4.297)	0.834 (0.211-3.285)	0.391 (0.043-3.491)
	Night	7.174 (1.384-37.16)	. (3.423-.)	2.253 (0.434-11.69)	2.052 (0.126-33.18)
Age	Base: Up to 25				
	26-44	7.972 (0.769-82.60)	1.255 (0.011-142.506)	1.354 (0.252-7.263)	0.672 (0.034-12.98)
	45-60	12.94 (0.996-168.2)	1.433 (0.006-295.461)	0.496 (0.072-3.405)	0.069 (0.002-2.007)
	Over 61	12.26 (0.398-377.1)	43.76 (0.053-.)	0.038 (0.001-0.890)	0.001 (0.000-0.717)
Job type	Base: Management and R&D				
	Operators, Warehousing	16.93 (0.594-482.3)	5.239 (0.027-997.327)	8.702 (0.573-132.1)	167.9 (0.705-.)
	Construction work	20.71 (0.535-800.6)	20.36 (0.016-.)	2.111 (0.149-29.72)	-
	Rough labor	3.983 (0.170-93.14)	0.061 (0.000-11.932)	4.859 (0.387-60.93)	16.77 (0.128-.)
	Energy provision	92.83 (2.645-.)	3.951 (0.007-.)	5.812 (0.334-100.9)	22.48 (0.066-.)
	Transportation and loading	11.50 (0.445-297.4)	1.314 (0.003-559.792)	3.652 (0.266-50.14)	24.06 (0.149-.)
Work experience	Base: Up to 1 year				
	1-3	0.613 (0.122-3.059)	0.061 (0.000-3.864)	1.343 (0.372-4.848)	0.565 (0.078-4.098)
	3-7	0.228 (0.036-1.441)	0.032 (0.000-1.586)	0.674 (0.187-2.432)	1.044 (0.155-7.002)
	7-15	0.717 (0.146-3.516)	0.125 (0.003-4.648)	1.386 (0.333-5.773)	0.134 (0.011-1.558)
	Over 15 years	1.385 (0.180-10.64)	51.55 (0.301-.)	24.09 (3.250-178.6)	164.7 (5.104-.)
Number of obs		155	110	140	91

Note: "." = the number is omitted because it is larger than a three-digit number

Initially, the sample structure was analysed to explore the distribution of accident causes by industry. Next, descriptive analysis of occupational accidents was conducted in the form of crosstab representation. This indicated the potentially at-risk groups of workers in relation to employee- and employer-related causes. Thereafter, a logistic regression was applied to identify the factors statistically associated with the occupational accidents in the industrial sector generally, and in the manufacturing industry in particular.

This study employed a binary logistic regression method performed using SPSS 26 to analyse the association between occupational accident severity, accident causes (with a focus on employee- and employer-related causes), and independent factors. A total of four models were utilized (Table 2): Accident severity in the industrial sector (Model 1) and in the manufacturing industry (Model 2); Employee- and employer-related causes of accidents in the industrial sector (Model 3) and in manufacturing industry (Model 4). The sector and dependent variable differ, whereas the independent variables (age, sex, job type, experience, accident date and time, accident main cause, and injury mechanism) were the same in all models. As a dependent variable, The first two models examined factors associated with accident severity (severe vs. fatal) in the industrial sector and the manufacturing industry, while the remaining two models analysed factors related to employee- and employer-related causes of accidents in the same sectors.

The logistic regression models indicated adequate goodness of fit according to the Hosmer–Lemeshow test. The results were $\chi^2 = 13.01$, $p = 0.11$ for accident severity and $\chi^2 = 13.54$, $p = 0.09$ for cause. Since p-value is greater than 0.05, we fail to reject the null hypothesis that the model fits the data well. The pseudo R2 value is modest, ranging between 0.28 and 0.54 depending on the model.

Results

Fig. 2 compares employee- and employer-related causes depending on the injury mechanism. We have presented distributions for only 2 of 4 causes (employee- and employer-related) and only for two sectors: manufacturing and construction (there are not enough cases in the utilities industry to provide distribution diagrams). In the diagrams, “TOTAL” signifies the total number of cases for all 4 injury causes depending on the injury mechanism.

The results indicate more employer-related causes in severe accidents related to "Collapses and contacts with objects and equipment" (3) in both industries. Nevertheless, "Falls, slips, trips" (2) in manufacturing refer to employee-related causes while in construction it mostly relates to employer factors. "Transportation incidents" (1) pertain to employee factors in both industries and both types of accident severity. "Burns, fire, explosion, electrocution" mostly refer to employer-related factors.

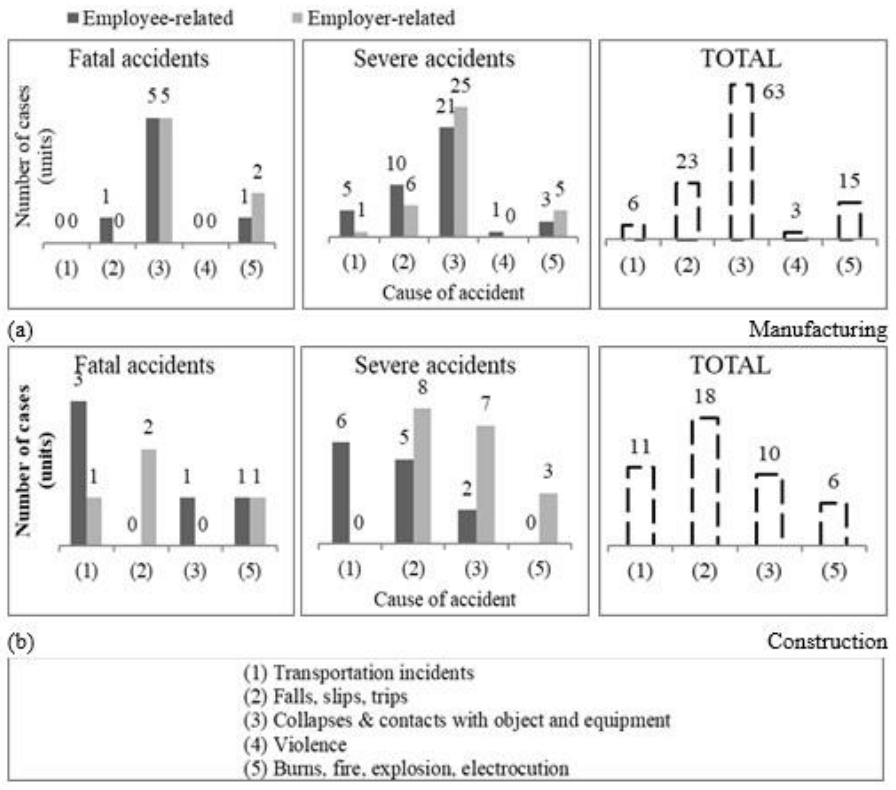

Fig. 2. The distribution of injury mechanisms

The total distribution of injury mechanisms indicates that the manufacturing industry claims the highest rate of "Collapses and contacts with objects and equipment," followed by "Falls, slips, and trips." In construction, the highest rates belong to "Falls, slips, and trips,"

"Transportation incidents," and "Collapses and contacts with objects and equipment."

Matrix analysis: Applying highlighted variables, a comparative table was compiled and analysed in detail below (Table 3-4). The total number of cases in the tables is 140, since only those linked to two types of causes: employee- (70) (Table 3) and employer-related (70) (Table 4) are indicated.

Table 3. Industrial accidents (Employee-related causes)

Accident severity	Gender-Age	Years of experience					Total
		< 1	1-3	3-7	7-15	> 15	
		Employee-related (N=70)					
Severe (56)	M: < 25	3	1	1	1	0	6
	M: 26-44	9	5	7	3	0	24
	M: 45-60	4	3	5	3	1	16
	M: > 61	0	0	0	0	3	3
	W: < 25	0	0	0	0	0	0
	W: 26-44	2	1	1	0	0	4
	W: 45-60	0	0	1	1	1	3
	W: > 61	0	0	0	0	0	0
Subtotal		18	10	15	8	5	56
Fatal (14)	M: < 25	2	0	0	0	0	2
	M: 26-44	2	3	0	2	0	7
	M: 45-60	1	1	1	1	0	4
	M: > 61	0	0	0	0	0	0
	W: < 25	0	0	0	0	0	0
	W: 26-44	0	1	0	0	0	1
	W: 45-60	0	0	0	0	0	0
	W: > 61	0	0	0	0	0	0
Subtotal		5	5	1	3	0	14

Note: M = man, W = woman

The proportion of men and women injured in occupational accidents is 89% and 11%, respectively. Presumably, this proportion can be explained by the labour force distribution in these industries. Based on local statistics [34], the share of employed women in the manufacturing industry is 35%, in utilities 30%, and in construction 18%.

Table 4. Industrial accidents (Employer-related causes)

Accident severity	Gender-Age	Years of experience					Total
		< 1	1-3	3-7	7-15	> 15	
		Employer-related (N=70)					
Severe (58)	M: < 25	2	1	1	0	0	4
	M: 26-44	15	8	6	3	2	34
	M: 45-60	1	1	2	1	7	12
	M: > 61	0	0	0	1	1	2
	W: < 25	0	0	0	0	0	0
	W: 26-44	1	0	0	1	0	2
	W: 45-60	0	0	2	1	1	4
	W: > 61	0	0	0	0	0	0
Subtotal		19	10	11	7	11	58
Fatal (12)	M: < 25	0	0	0	0	0	0
	M: 26-44	3	0	0	2	1	6
	M: 45-60	1	0	0	0	3	4
	M: > 61	0	0	0	0	0	0
	W: < 25	0	0	0	0	0	0
	W: 26-44	0	0	0	1	0	1
	W: 45-60	0	1	0	0	0	1
	W: > 61	0	0	0	0	0	0
Subtotal		4	1	0	3	4	12

Note: M = man, W = woman

The ratio of severe and fatal accidents that occurred in the industrial sector over four years is approximately 4 to 1. In the industrial sector, the total number of employee- and employer-related accidents is distributed equally, whereas there are some differences in the samples associated with employee age and work experience.

The most significant number of accidents took place among the core of the labour force: the 26–44 age group (Fig. 3a). This might be explained by the age structure of the employed population. This age category covers 55% of employed in the city. In the sample, within this age category, more than half of the accidents occurred through employer-related causes (54%). The 45–60 age group reverses this accident distribution. The number of severe cases linked to employee-related causes (19) outnumbered employer-related cases (16). Based on Rosstat, the average share of employed in age groups up to 25 and over 61 are almost equal (7%), which could explain the low injury rates in these groups.

Overall, older workers are fatally injured less often (employee-related causes). For employer-related causes, the two most at risk age groups for severe injury are up to 25 and over 61. Nonetheless, the general distribution (including the other two causes) reveals a growing share of fatal accidents with employee age. This might suggest that other, less obvious, causes are involved in accidents (see Section 3.3).

Fig. 3. Distribution of occupational accidents in groups of employee age and work experience with correspondence to injury severity and two main causes

The most significant number of accidents was observed in the group of employees with experience of less than a year (Fig. 3b). Accident occurrences generally diminish with increasing years of experience [16], while the total distribution of employed is ascending (where the share of workers with less than a year of experience is up to 10% and more than 10 years is 40%).

A similar distribution is observed between employee- and employer-related causes of accidents in the group with the least experience. The number of industrial accidents with workers in work experience groups 1–3 years, 3–7 years, and 7–15 years, classified as having employee-related causes (42), is 31% higher than that of the same group related to employer-related causes (32). Nevertheless, workers with over 15 years of experience had three times as many accidents due to employer-related causes in absolute terms. The experience of employees can keep them from mistakes resulting in accidents; the least experienced employees could be injured owing to a lack of practice. This is supported by the finding that experienced workers (over 15 years of experience) suffer less often than other groups from employee-related accidents (7%).

In general, if we assume that experience usually accumulates for at least 7 years of working in one area, then it can be concluded that inexperienced (up to 3 years of experience) and insufficiently experienced workers (up to 7 years) are injured through their fault (77% of all cases). Inexperienced and insufficiently experienced workers suffer through employer-related causes less frequently (65% of all cases).

Binary regression analysis: The detailed results of the odds ratio (OR) and the corresponding confidence interval (CI) are reported in Table 2. This section focuses on the significant results (p-value < 0.05) from the table, highlighting factors pertained to accident severity in the industrial sector (Model 1), in the manufacturing industry (Model 2) as well as Employee-

and employer-related causes of accidents in the industrial sector (Model 3) and in manufacturing industry (Model 4).

In the industrial sector (Model 1), fatal accidents were significantly more likely to take place along night shifts, in the energy provision occupations, and when attributable to technological process imperfections or machine faults ($p < 0.05$). In the manufacturing sector (Model 2), fatalities were associated with working at night and on Saturdays.

Factors pertained to employer-related causes of accidents in the industrial sector (Model 3) included working in the second and fourth quarters of the year, injury mechanisms such as "Falls, slips, trips", "Collapses and contacts with object and equipment" and "Burns, fire, explosion, electrocution", and over 15 years of work experience. The only factor correlated with employee-related severe injury or death is age of 61 or older. In the manufacturing industry (Model 4), also age over 61 years and working along the daytime elevated the risk of employee-related causes of accidents, whereas work experience over 15 years was the factors associated with employer-related accidents.

Discussion

To our knowledge, this is the first Russian retrospective study to focus on occupational accidents that occurred in an industrial city and explore the relative contribution of employer- and employee-related factors to severe and fatal accidents in different industries. Importantly, the aim of the discussion section is to compare accident patterns in Chelyabinsk with those observed globally. It is critical to safely adopt successful global practices for mitigating occupational accidents.

The largest number of accidents among industrial companies was connected with “Collapses and contacts with objects and equipment” in manufacturing, followed by “Falls, slips, trips” in the construction industry which correspond to international findings [17-21]. This aligns with [9, 15] in their findings that the incidence of occupational injury remains high in construction.

Fatal accidents were more common at night, on weekends, and in high-production quarters, consistent with prior international findings [5, 22, 23]. This may be linked to there being fewer staff during such shifts, placing a dual burden on them. Not surprisingly, severe and fatal accidents in the 2nd and 4th quarters were associated with employer-related causes as these timeframes are critical to complete mid-year and annual plans which may create pressure resulting in employer negligence and overworked staff.

Organizational and human factors remain the dominant causes of occupational accidents, with lack of supervision, poor organization, noncompliance with safety regulations, as well as violations of operating rules repeatedly identified in the literature [1, 19-21, 24–27]. Consistent with Eskandari et al. [28], our results confirmed that employee-related causes prevailed in manufacturing and utilities, whereas employer-related causes dominated in construction. Technical causes were less frequent but strongly linked to fatalities, as noted in earlier research [3, 4, 21, 27]. Works mentioning technical factors are new and this heightened attention might be because of accelerating technological progress and its influence on the industrial production.

The key result of the study is that the severity of accidents considerably falls with age for employee-related causes, which is in line with Refs. [5, 29-32], but contradicts Peng and Chan [33], who found that the occurrence of severe/fatal accidents among older workers is twice that of younger workers. This discrepancy may be owing to differences in labour composition or research methods; while Peng and Chan relied on a literature review, our study utilized a sample. Workers up to 25 and over 61 years were not involved in any fatal accidents with employer-related causes. Nevertheless, technical causes hold a key role in accident severity mostly for older workers.

Considering work experience, we find that workers with over 15 years of experience are at a higher risk than other groups for employer-related causes, which to some extent contradicts Refs. [6, 29]. They found less experienced workers (with up to 10 years of experience) to be more likely to be injured regardless of the cause. Once again, this contradiction is common in existing literature and is often explained by occupational and measurement factors linked to accidents [33].

Overall, we recommend closer supervision of high-risk groups (core-age workers, night/weekend shifts, and those with >15 years’ experience), mandatory mentoring for new employees, as well as proactive safety measures for an aging workforce.

Note that this study had the following limitations. First, the factors connected with the causes of accidents were defined along the accident investigation. Despite the investigation process involving at least ten professionals and having been developed to eliminate subjectivity, a subjective component could remain in identifying the cause in every case.

Further, this study was limited by the relatively small number of observed cases and the wide variety of independent factors in the regression model. In general practice, one independent variable in the model should correspond to a sample of at least 10 observations per variable. As a result, the estimation of the factor effect would be more accurate with more observations. We intentionally did not focus on the size of the coefficients and confidence intervals as they may underestimate or overestimate the actual effects. Our primary aim was merely to demonstrate the associations between potentially high-risk groups and types of occupational

accident causes. Thus, our results should be interpreted with caution.

Finally, we analysed a standard set of factors (age, work experience, sex, job type, etc.). If accessible, endogeneity factors such as mood, relations in the family, job stress, job dissatisfaction, job responsibility, work performance, living habits, etc. could be surveyed, and an instrumental variable analysis might be applied.

Conclusion

The most at-risk groups of workers were identified as industrial workers with over 15 years of experience, who were strongly linked to employer-related accident causes; working in the 2nd and 4th quarters and certain injury mechanisms (falls, slips, trips; collapses and contacts with objects and equipment; burns, fire, explosion, electrocution). "Technological process imperfection and machine faults", working nightshifts, and jobs in "Energy provision" were mostly associated with fatal accidents in the industrial sector. Matrix analysis revealed the highest incidence among adults aged 26–44 years and workers with less than one year of experience, indicating the dominant structure of the labour force. Overall, city employees with more than 15 years of experience were disproportionately affected by employer-related incidents, suggesting that system or organizational factors increasingly contribute to risk as experience accumulates. This analysis provided valuable insights for industrial enterprises that could result in improved occupational safety.

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Conflict of interest

None declared.

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Ethical Considerations

This study was based on encoded secondary data provided by the Chelyabinsk State Labor Inspectorate. No personally identifiable information was available to the authors; therefore, individual informed consent was not required. The authors confirm that this study was conducted in accordance with accepted ethical standards for research using secondary, de‑identified data.

Authors' Contributions

Irina Pylaeva: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Visualization, Resources, Writing – original draft. Mariya Podshivalova: Formal analysis, Resources, Supervision, Writing – review & editing. All authors read and approved the final manuscript.

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