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Assessing Construction Accident Costs and Influencing Factors in Eastern Province, Saudi Arabia

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ABSTRACT

The construction sector in Saudi Arabia's Eastern Province is vital for economic growth, yet workplace accidents impose severe human and financial costs. Vision 2030's industrial expansion highlights the need for accurate assessments of accident-related costs to inform effective safety policies. This study aimed to estimate direct, indirect, and total costs of construction accidents from 2016 to 2021, considering sociodemographic, company, project, and accident characteristics. A retrospective cross-sectional design analyzed 348 randomly selected accident cases reported to the General Organization for Social Insurance (GOSI). Data on direct costs were obtained from GOSI records, while indirect costs were collected through surveys and interviews with company personnel. Descriptive statistics and generalized linear models (GLM) with Gamma distribution were employed to identify cost predictors. The indirect costs averaged SAR 4,018.60, surpassing direct costs of SAR 4,855.60, accounting for approximately 67% of total accident costs. Larger companies (>500 employees) and permanent injuries significantly increased both cost types. Work on scaffolding, rooftops, or ladders was associated with higher expenses. The workforce was predominantly South Asian laborers on medium-sized projects. GLM models effectively predicted accident costs, underscoring company size and injury severity as key determinants. The indirect costs constitute a major component of construction accident expenses in the Eastern Province, often overlooked in traditional safety investments. Tailored interventions focusing on large firms and high-risk work environments are essential to reduce financial burdens and enhance worker safety. This localized cost estimation framework supports

evidence-based occupational health and safety policies aligned with Saudi Arabia's Vision 2030 goals.

Keywords: Construction Accident Costs, Occupational Health and Safety, Saudi Arabia Eastern Province, Direct and Indirect Costs, Construction Industry Safety Management.

INTRODUCTION

The construction sector plays a crucial role in economic growth, but accidents in this industry cause significant harm to workers and financial losses. In Saudi Arabia's Eastern Province, Vision 2030 accelerates industrial growth, emphasizing the importance of construction safety and cost management, with accurate accident cost assessments being critical for effective safety policy development [1]. In 2018, Saudi Arabia recorded approximately 31,104 construction-related accidents resulting in injuries or fatalities, according to quarterly data from the General Organization for Social Insurance (GOSI) (GOSI, 2018). From direct compensation statistics, it is estimated that around 1,608 cases of permanent disability and deaths occurred annually in the construction sector. However, recent reports from 2025 indicate a significant surge in construction site accidents, pointing to systemic occupational health and safety challenges in the Saudi construction industry [2]. The construction accidents in Saudi Arabia impose significant financial burdens that extend beyond the immediate physical harm to workers, encompassing both direct and indirect costs [3]. Direct costs typically include occupational hazard allowances, medical treatment expenses, liquidated compensation, and pensions paid to injured or deceased workers. Indirect costs, which are often underestimated, cover overtime expenses, supervisor and manager time lost, investigation and legal costs, training for replacement employees, and equipment damage. Despite the clear presence and impact of these costs, current assessments in Saudi Arabia often underestimate indirect costs and lack context-specific models tailored to the unique regulatory, economic, and labor dynamics of the Saudi construction industry [4, 5].

Analyzing the financial impacts of construction accidents requires considering multiple intertwined factors such as company size, project size, and the specific work environment, which influence the variability of accident costs. Larger companies and bigger projects tend to have more structured safety protocols and allocate more resources to safety, potentially reducing accident-related costs. In contrast, smaller firms often face greater financial vulnerability due to limited safety management capabilities and higher relative costs from accidents, including direct medical, compensation expenses, and indirect losses such as operational downtime and reputational damage [6, 7]. Additionally, the type of accident whether falls, equipment-related injuries, or fatal events affects both the magnitude and nature of costs involved, impacting insurance premiums, legal fees, and productivity losses. For instance, direct costs cover medical bills and compensation payments, while indirect costs include lost work hours, delays, damage to equipment, and increased insurance premiums, which cumulatively strain company profitability and can also affect the national economy [6-8]. Moreover, the complexity of construction sites, including environmental conditions, diverse workforce skills, and equipment used, introduces additional safety challenges that directly influence accident rates and their associated costs [9]. These multifaceted factors underscore the need for a comprehensive approach to estimating financial impacts that informs targeted safety interventions, especially in smaller firms where financial resilience to accidents is lower [7, 9].

Direct costs in the Saudi construction sector, such as occupational hazard allowances, injury treatment costs, liquidated damages, and pensions owed to injured workers, are generally easier to track and are often documented through worker compensation programs and insurance claims. For instance, the General Organization for Social Insurance (GOSI) in Saudi Arabia reported that in the third quarter of 2018 alone, US$ 13.44 million was paid out for disability and death claims related to construction accidents [10]. However, these direct costs only represent part of the total financial burden of workplace incidents. Indirect costs, which can be much larger, include expenses such as overtime for covering absent workers, time spent by supervisors and managers handling accident issues, costs for investigations and legal proceedings, training replacement workers, and repair or replacement of damaged equipment. These indirect costs are difficult to measure but critically impact project timelines, labor productivity, and organizational efficiency. Studies estimate that indirect costs can be twice or more than direct costs, underscoring the need for their inclusion in comprehensive accident cost evaluations. In Saudi Arabia, a study estimated the average total cost of a construction accident at about US$ 91,940, with indirect costs comprising roughly two-thirds of the total. This significant discrepancy explains why many construction firms underestimate these expenses, leading to insufficient investment in safety and risk management programs [10].

Sociodemographic characteristics of the construction workforce in Saudi Arabia further complicate cost analyses. Worker nationality, age, experience, and skill levels can influence the likelihood and severity of accidents, as well as the associated financial ramifications. The Eastern Province of Saudi Arabia, a major industrial hub, has a diverse labor force including a large expatriate population, each group presenting unique risk profiles and cost implications. Understanding these relationships is essential for developing effective safety interventions tailored to the demographic composition of the workforce. The construction industry in Saudi Arabia employs a majority of non-Saudi workers approximately 87.5% of the construction workforce with Saudis representing only about 12.5%, many of whom are young and require on-the-job training [11, 12]. Additionally, the workforce composition varies significantly by nationality, skill level, and gender, with most female workers being Saudi nationals and expatriate workers filling many unskilled and semi-skilled roles [12]. The urgency of developing a localized, empirically grounded cost estimation framework lies in these complexities. Current methods often rely on generic international benchmarks or assume accident costs as a fixed percentage of project value, which inadequately reflect Saudi Arabia’s specific economic conditions, regulatory environment, and labor market characteristics. A Saudi-specific model would help construction firms, policymakers, and related stakeholders assess the real economic impact of accidents, devise targeted safety strategies, and ensure better resource allocation towards accident prevention and control.

Despite the critical impact of construction accidents in Saudi Arabia, the industry lacks a localized, empirically validated model for estimating the full economic costs, especially indirect costs such as productivity losses and administrative overhead, leading to underestimation and poor safety investment [13-15]. Moreover, existing cost estimation models largely rely on generic international data and fail to consider local factors like project size, company size, and worker demographics, creating a significant knowledge gap in safety management. Therefore, this study aims to estimate the levels of direct, indirect, and total costs of construction accidents in construction projects in the Eastern Province, Saudi Arabia and their relationship with sociodemographic factors, company and project characteristics, and accident attributes, thus supporting evidence-based improvements in occupational health and safety and enabling better resource allocation and regulation in the Saudi construction industry.

METHODS

Study Design, Sampling and Participants

A retrospective cross-sectional study was conducted to analyze construction accident cases and their associated costs in the Eastern Province of Saudi Arabia, a key economic region known for its oil reserves and industrial activities. The study focused on reported workplace accidents within construction companies in this province between January 2016 and January 2021. From a total of 21,520 reported incidents, a sample was drawn randomly based on specific inclusion criteria requiring that cases be workplace accidents reported to the General Organization for Social Insurance (GOSI) within the Eastern Province. Cases outside this region or unreported to GOSI were excluded. The sample size was determined using the OpenEpi online calculator, considering a population of 21,520 incidents, with a 95% confidence level, 5% margin of error, and 80% statistical power. To account for an expected 50% dropout and outlier rate, the final sample size was adjusted to 348 cases. Simple random sampling was then applied to select these incidents, ensuring each eligible case had an equal chance of being included, thereby minimizing bias and enhancing the sample's representativeness and validity.

Data Collection and Measurement

The direct cost data was collected from the construction accident data sourced from the General Organization for Social Insurance (GOSI). While the indirect cost data was collected using survey among sample of different types and size of construction companies (Based on GOSI databases). The survey consists of 10 items that ask for specific cost data, such as hourly rates for overtime work, supervision costs, accident investigation expenditures, training costs, repair or replacement of equipment, legal and administrative expenses, and any other indirect costs like loss of employee morale or transportation [16]. This comprehensive approach ensures accurate, multi-dimensional capture of accident-related variables to analyze their impact on overall accident costs In addition, the information regarding the sociodemographic characteristics (age, nationality), organizational and project characteristics (company size, project size, type and place of work), and accident specifics (type of accident and injury) was collected from the GOSI. Construction accidents encompass a wide range of incidents as defined by OSHA, including falls, mechanical forces, thermal, electrical, and environmental hazards, with costs divided into direct expenses such as medical treatment, compensation, and property damage covered by insurance and indirect costs like lost productivity, administrative efforts, delays, and wages paid during recovery, which are less visible and typically uninsured.

Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 29 for Microsoft Windows (Chicago, IL, USA). Descriptive statistics, including means, medians, and standard deviations (SD), were used for continuous variables, while frequencies and percentages were used to summarize categorical variables. The Kruskal-Wallis test, Mann-Whitney U test, and Spearman's correlation were employed to compare accident costs (direct, indirect, and total) across variables. For multivariate modeling, Generalized Linear Models (GLM) with a Gamma distribution and log link function were applied, as this approach appropriately models positively skewed cost data. Model fit was assessed using deviance statistics, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and

Pearson chi-square statistics. Interpretation of predictor variables was based on beta coefficients, significance levels, and confidence intervals.

Ethical Approval

The permission for this study was granted by the Committee of the General Organization for Social Insurance (GOSI), Saudi Arabia. Approval was also secured from the management of the participating companies located in the Eastern Province of Saudi Arabia.

RESULTS

Respondents' Features and Demographic Profiles

Table 1 presents the distribution of demographics, company, and accident characteristics among the study population for a sample of 324 individuals. The majority of workers were from India (34.6%), followed by Bangladesh and Egypt (both 13.9%), Nepal (12.7%), and the Philippines (8.3%). Most subjects were employed as construction laborers (69.4%), with the remainder in other types of work (30.6%). Company size varied, with a plurality of workers in firms with 50 to 100 employees (36.7%) and 101 to 500 employees (34%), while smaller and larger companies comprised smaller proportions. Projects were predominantly medium-sized (43.2%), followed by small (38.6%) and large (18.2%). Workers were mainly engaged in areas classified as other places (59%) rather than scaffolding, rooftops, or ladders (41%). The most common accident types involved mechanical forces (54.3%), followed by falls (30.9%), thermal, electrical, and environmental hazards (7.7%), and other causes (7.1%). Regarding injury severity, the majority were temporary injuries (80.6%), with permanent injuries accounting for 19.4%.

Table 1: Distribution of Demographics, Company, and Accident Characteristics

Variables		Frequency	Percent
Nationality	India	112	34.6
	Bangladesh	45	13.9
	Egypt	45	13.9
	Nepal	41	12.7
	Filippino	27	8.3
	Pakistan	22	6.8
	Other	32	9.9
Type work	Construction Laboure	225	69.4
	Other	99	30.6
Company size	Less than 50	46	14.2
	50 to 100	119	36.7
	101 to 500	110	34
	More than 500	49	15.1
Project size	Small	125	38.6
	Medium	140	43.2
	Large	59	18.2
Place work	Scaffolding and Rooftops, Or Ladders	133	41
	Other	191	59
Accident Type	Falls	100	30.9
	Mechanical Forces	176	54.3
	Thermal, Electrical, and Environmental Hazards	25	7.7
	Other Causes	23	7.1

Type of injury	Temporary	261	80.6
	Permeant	63	19.4

Distribution of Direct and Indirect Costs of Construction Accident

Table 2 presents a detailed analysis of construction accident direct and indirect costs. Direct costs include Occupational Hazard Allowances, Costs of Injury, and Liquidated Compensation & Pensions, with totals ranging from zero to a maximum of SAR 228,826.70 and an average direct cost of SAR 4,855.60 with a standard deviation of SAR 17,479.40. Indirect costs encompass Overtime, Supervisor/Manager Time, Investigation, Training for Replacement Workers, Equipment Damage, Legal/Administrative, and Other Costs, fluctuating between SAR 804.7 and SAR 16,162.10, averaging SAR 4,018.60 with a standard deviation of SAR 3,419.40. The highest direct cost category is the Costs of Injury, which shows a wide range from zero up to SAR 227,580.10, reflecting the potential severity and financial impact of workplace injuries. With a mean cost of SAR 3,728.10 and a substantial standard deviation of SAR 16,001.80, this category dominates the direct expenses. While the highest direct cost category is the Costs of Injury, which shows a wide range from zero up to SAR 227,580.10, reflecting the potential severity and financial impact of workplace injuries. With a mean cost of SAR 3,728.10 and a substantial standard deviation of SAR 16,001.80. The indirect costs constitute a higher proportion (67.41%) of total costs compared to direct costs, which account for 32.59%, highlighting the significant financial impact of indirect factors in workplace-related expenses.

Table 2: Descriptive of Direct and Indirect Costs of Construction Accidents

Cost Indicator	**Min**	**Max**	**Mean**	**SD**
Direct Costs				
Occupational Hazard Allowances	0	21,073.10	699.8	1,754.00
Costs of Injury	0	227,580.10	3,728.10	16,001.80
Liquidated Compensation & Pensions	0	30,128	427.8	2,858.50
Total Direct Cost	**0**	**228,826.70**	**4,855.60**	**17,479.40**
Indirect Costs				
Overtime Costs	96.4	6,720	956.8	1,306.00
Supervisor/Manager Time Costs	47.6	444.6	134.7	75.9
Investigation Costs	129.7	157.3	145.5	10.3
Training Costs for Replacement Workers	0	4,981.80	880.8	1,081.20
Equipment Damage Costs	0	5,450	1,209.70	2,192.40
Legal/Administrative Costs	100.5	138	117.3	13.1
Other Costs	405.6	702.9	573.9	140.4
Total Indirect Cost	**804.7**	**16,162.10**	**4,018.60**	**3,419.40**
Direct Cost Percentage of Total	**32.59%**			
Indirect Cost Percentage of Total	**67.41%**			

Min = Minimum value; Max = Maximum value; SD = Standard Deviation.

Comparison Between Direct and Indirect Cost

Table 3 presents a comparison between direct and indirect costs of construction accidents, showing that the average indirect cost per accident was SAR 4,018.62 (SD = 189.97), while the average direct cost was higher at SAR 4,855.60 but with much greater variability (SD = 17,479.40). The Wilcoxon signed-rank test confirmed a statistically significant difference between these costs ($Z = 6.554$, $p < 0.001$), indicating that indirect costs consistently exceeded direct costs across the sample, with indirect costs amounting to approximately 2.24 times the direct costs per accident.

Table 3: Comparision between direct and indirect costs

	Total indirect	Total Direct	Z value	P value
	Mean (SD)	**Mean (SD)**		
Cost (SAR)	4018.62 (189.97)	4855.6 (17479.4)	6.554	<0.001

Association of Sociodemographic, Company, Project, Work, and Accident Characteristics with Construction Accident Costs

Table 4 shows the association between sociodemographic, company, project, work, and accident characteristics with construction accident costs, focusing on mean direct and indirect costs with standard deviations. Age was positively correlated with mean total direct cost ($r = 0.172$, $p = 0.002$) but not significantly with indirect cost ($r = 0.075$, $p = 0.180$). Nationality showed no significant differences in mean direct or indirect costs across groups, with means ranging from SAR 1,837.7 (Filipino direct) to SAR 10,318.8 (Pakistani direct) and SAR 3,440.6 (Nepal indirect) to SAR 5,058.9 (Pakistan indirect). Company size was significantly related to costs ($p < 0.001$), with the largest companies (>500 employees) reporting the highest mean indirect costs (SAR 6,096.0 ± 3,957.0) and direct costs (SAR 18,961.0 ± 40,591.6). Project size also showed significant differences ($p < 0.001$), with large projects having higher mean indirect (SAR 5,005.6 ± 3,931.5) and direct costs (SAR 10,185.3 ± 24,066.4). Work location impacted costs, where scaffolding/rooftops/ladders had higher meaning indirect (SAR 4,584.8 ± 3,816.3) and direct costs (SAR 7,005.3 ± 21,907.9) than other places. Construction laborers incurred higher mean direct costs (SAR 6,153.6 ± 20,709.8) compared to other roles (SAR 1,905.8 ± 3,742.6), although indirect costs were similar. Accident type did not significantly affect mean costs, but injury severity was strongly associated with costs ($p < 0.001$), where permanent injuries showed substantially higher mean indirect (SAR 8,981.8 ± 2,501.5) and direct costs (SAR 13,946.6 ± 35,847.0) than temporary injuries (SAR 2,820.6 ± 2,371.4 indirect; SAR 2,661.3 ± 6,948.2 direct).

Table 4: Bivariate analysis on relationship between accident cost (direct and indirect) with sociodemographic, company and accident characteristics

Characteristic	Category	Indirect Cost			Direct Cost		
		Mean (SD)	**Z/χ^2**	**P-value**	**Mean (SD)**	**Z/χ^2**	**P-value**
Age	–	r = 0.075	–	0.180	r = 0.172**	–	0.002*
Nationality			4.641[a]	0.591		4.501[a]	0.609
India	(n=112)	3931.8 (3539.1)			4509.4 (10231.0)		
Bangladesh	(n=45)	3919.9 (3144.5)			3565.4 (8582.4)		
Egypt	(n=45)	4415.7 (3178.2)			2743.5 (4402.3)		
Nepal	(n=41)	3440.6 (3225.8)			10617.9 (36585.9)		
Filipino	(n=27)	3915.0 (3559.2)			1837.7 (3083.1)		
Pakistan	(n=27)	5058.9 (3927.0)			10318.8 (35139.3)		
Other	(n=22)	4015.6 (3552.2)			2259.4 (3962.0)		
Company Size			43.042[a]	<0.001*		70.331[a]	<0.001*
<50	(n=46)	3697.2 (2676.6)			860.1 (1920.6)		
50-100	(n=119)	2976.4 (2794.4)			1749.6 (3898.9)		
101-500	(n=110)	4355.2 (3613.5)			3603.3 (7315.7)		
>500	(n=49)	6096.0 (3957.0)			18961.0 (40591.6)		
Project Size			18.603[a]	<0.001*		32.245[a]	<0.001*
Small	(n=125)	3102.1 (2648.6)			1591.3 (3531.6)		
Medium	(n=140)	4421.0 (3623.6)			5524.3 (20858.5)		

Large	(n=59)	5005.6 (3931.5)			10185.3 (24066.4)		
Place of Work			-2.503b	0.012*		-4.372b	<0.001*
Scaffolding/Rooftops /Ladders	(n=133)	4584.8 (3816.3)			7005.3 (21907.9)		
Other	(n=191)	3624.4 (3062.3)			3358.8 (13433.9)		
Type of Work			1.053 b	0.292		2.746 b	0.006*
Construction Labourers	(n=225)	4067.3 (3498.2)			6153.6 (20709.8)		
Other	(n=99)	3908.0 (3247.9)			1905.8 (3742.6)		
Type of Injury			11.342 b	<0.001*		7.017 b	<0.001*
Temporary	(n=261)	2820.6 (2371.4)			2661.3 (6948.2)		
Permanent	(n=63)	8981.8 (2501.5)			13946.6 (35847.0)		

For age, Spearman's rank correlation coefficient. a =Z values denote Mann-Whitney U tests, b= χ^2 values denote Kruskal-Wallis tests. *p < 0.05 significance level; ** Correlation is significant at the 0.01 level (2-tailed).

Estimation Model for Direct and Indirect Cost

A Generalized Linear Model (GLM) with Gamma distribution and log link function was applied to estimate predictors of indirect and direct costs in construction accident cases in a multivariate model. For indirect cost, the model showed strong fit (χ^2 = 90.072, p < .001; deviance = 165.659, p = 1.000; Pearson χ^2 = 188.732, p = 1) and better AIC/BIC than the null model, with no severe multicollinearity. Significant predictors included company size of 50 to 100 employees (β = –0.367, SE = 0.143, t = –2.556, p = .011, 95% CI [–0.65, –0.091]) associated with lower indirect costs, and permanent injuries (β = 1.141, SE = 0.116, t = 9.875, p < .001, 95% CI [0.914, 1.376]) linked to higher indirect costs; age, project size, workplace location, and accident type were not significant. For direct cost, the GLM improved over the null model (χ^2 = 453.625, p < .001), although deviance and Pearson χ^2 indicated poor absolute fit. Despite this, relative fit was better (lower AIC/BIC) and multicollinearity was low.

Table 5: Generalized Linear Model Coefficients for Predicting indirect and direct Costs (Multivariate analysis)

	Indirect Costs						Direct Cost					
	Coefficients	SE	T value	P value	95 % CI		Coefficients	SE	T value	P value	95 % CI	
					Lower Bound	Upper Bound					Lower Bound	Upper Bound
(Intercept)	8.059	0.229	35.269	< .001	7.617	8.508	5.791	0.64	9.049	< .001	4.536	7.073
Age	0.004	0.005	-0.097	0.922	-0.009	0.009	0.015	0.012	1.212	0.226	-0.008	0.039
Company size (50 to 100)	-0.367	0.143	-2.556	0.011	-0.65	-0.091	0.978	0.387	2.527	0.012	0.153	1.753
Company size (101 to 500)	-0.245	0.181	-1.36	0.175	-0.59	0.094	1.607	0.486	3.309	0.001	0.565	2.617
Company size (More than 500)	-0.061	0.211	-0.291	0.771	-0.463	0.339	2.851	0.569	5.01	< .001	1.66	4.032
Project size (Medium)	0.134	0.128	1.046	0.296	-0.109	0.378	-0.539	0.348	-1.546	0.123	-1.274	0.21
Project size (Large)	0.031	0.173	0.178	0.859	-0.294	0.36	-0.33	0.468	-0.707	0.48	-1.301	0.669
Type Injury (Permanent)	1.141	0.116	9.875	< .001	0.914	1.376	0.926	0.311	2.978	0.003	0.321	1.587
Place of work (Other)	0.104	0.091	1.143	0.254	-0.077	0.283	-0.844	0.309	-2.734	0.007	-1.477	-0.235

Note. Reference categories: Company size (less than 50), Project Size = Small, Type of injury : Temporary, Place of Work = Scaffolding/Rooftops/Ladders, Type of Work = Other roles, Accident Type = Falls. β = Unstandardized regression coefficient.

Significant predictors included company sizes 50–100 employees (β = 0.978, SE = 0.387, t = 2.527, p = .012, 95% CI [0.153, 1.753]), 101–500 employees (β = 1.607, SE = 0.486, t = 3.309, p = .001, 95% CI [0.565, 2.617]), and more than 500 employees (β = 2.851, SE = 0.569, t = 5.01, p < .001, 95% CI [1.66, 4.032]), all linked to higher direct costs; permanent injuries (β = 0.926, SE = 0.311, t = 2.978, p = .003, 95% CI [0.321, 1.587]); workplace location other than scaffolding/rooftops/ladders showed lower costs (β = –0.844, SE = 0.309, t = –2.734, p = .007, 95% CI [−1.477, −0.235]); and accident types mechanical forces (β = 0.660, SE = 0.327, t = 2.016, p = .045, 95% CI [0.014, 1.307]) and other causes (β = 1.115, SE = 0.529, t = 2.105, p = .036, 95% CI [0.093, 2.285]) were significant. Age, project size, and type of work were not significant predictors.

DISCUSSION

The results of this study underscore the complex financial burden of construction accidents, revealing that indirect costs, such as overtime, investigation, and training for replacement workers, represent a substantially larger portion of the total expenses than direct costs like injury compensation and occupational hazard allowances. Specifically, indirect costs accounted for 67.41% of total costs, significantly surpassing direct costs at 32.59%. This finding aligns with previous research indicating that indirect costs often exceed direct costs due to the less visible but extensive operational disruptions and administrative burdens following accidents [6, 17-19]. The wide variability observed in direct costs, particularly the Costs of Injury category, suggests that the severity of incidents greatly influences financial outcomes, consistent with studies by Aaltonen, Oinonen [20], who emphasized that severe injuries incur disproportionately higher direct expenses. Comparison of cost magnitudes revealed that the average indirect cost per accident, though numerically lower than the direct cost, was more consistently incurred across cases, with the Wilcoxon signed-rank test confirming a statistically significant predominance of indirect costs ($Z = 6.554$, $p < 0.001$). This supports the conclusions of prior studies that indirect costs, though often underestimated, can be 2 to 10 times greater than direct costs depending on organizational context and accident severity [21-24]. The finding that indirect costs averaged approximately 2.24 times the direct costs in this research highlights the critical need for construction firms to broaden their safety cost frameworks to include these hidden expenses, thereby improving risk management and financial planning. Such comprehensive cost assessment aligns with recommendations by Cheng, Li [25] for more holistic accounting of occupational accident costs to foster safer and more economically sustainable construction practices. The analysis of construction accident costs in the Eastern Province of Saudi Arabia underscores the significant influence of sociodemographic factors, particularly age, on the distribution of direct and indirect costs. The positive correlation between age and mean total direct cost aligns with Gyekye and Salminen [26], who found that older and more experienced workers tend to have greater risk awareness yet suffer more severe consequences from accidents. Similarly, our findings resonate with [27-31], who reported that while younger workers experience more frequent but less severe injuries, older workers face higher injury severity leading to increased costs and longer recovery times. This age-related cost pattern highlights the need for tailored safety interventions focusing on older worker populations to reduce injury severity and associated expenses. Contrary to expectations from prior research, our study did not find significant differences in accident costs across nationality groups within the construction workforce. Although non-Saudi workers constitute the majority in the Saudi building industry and previous studies suggested they bear higher indirect costs post-accidents, the current data show variation in mean costs across nationality groups without reaching statistical significance. This could indicate improvements in workplace safety practices or compensation policies that mitigate nationality-based disparities. However, the range of costs such as higher direct costs among Pakistani workers and variable indirect costs suggests nuanced factors at play, warranting further investigation into how nationality intersects with other risk and recovery determinants.

The influence of organizational and project factors on accident costs was evident, with larger companies and projects incurring significantly higher mean direct and indirect costs. The findings are consistent with prior studies showing that larger entities often face more complex operational hazards and potentially more costly accidents due to scale and exposure [27, 32-35]. Additionally, work location emerged as an important factor; scaffolding, rooftops, and ladders, which represent higher-risk environments, were associated with increased costs. This finding supports the notion that site-specific hazards contribute critically to accident severity and thereby elevate financial impacts, emphasizing the importance of targeted risk control measures in these environments. Finally, injury severity was strongly linked with both direct and indirect costs, confirming existing literature on the economic burden of workplace injuries [26, 27, 36, 37]. Permanent injuries resulted in substantially higher costs compared to temporary injuries, reflecting extended medical care, rehabilitation, and potential loss of labor productivity. This robust association accentuates the need for preventive strategies to minimize severe injuries and effectively manage post-accident support. While accident type did not show a significant effect on costs, the role-based differences such as higher direct costs for construction laborers highlight how job roles influence exposure and financial consequences, consistent with prior occupational safety research.

The current study effectively utilized generalized linear models (GLMs) with Gamma distribution and log link functions to analyze the multifaceted factors influencing the direct, indirect costs of construction accidents in the Eastern Province of Saudi Arabia. The results highlight the significant role of organizational characteristics, particularly company size, and injury severity in shaping cost outcomes. For indirect costs, midsized companies (50–100 employees) showed a cost advantage over smaller companies, possibly due to greater operational flexibility and resource availability, aligning with Kyriakidis, Simanjuntak [38] findings. Permanent injuries consistently predicted higher costs across models, confirming previous work by Robinson, Sarkies [39] which emphasized the long-term economic burdens of severe injuries due to medical, administrative, and productivity losses. These results extend Michie and Williams [40] conclusions about the impact of work-related factors on health outcomes and associated absences, underscoring the need for targeted safety interventions to mitigate long-term indirect costs.

Regarding direct costs, the study corroborates and extends prior research by demonstrating that larger companies (especially those with more than 500 employees) incur significantly higher direct accident costs. This supports Hanani, Yuhan [41] assertion that larger firms face elevated uninsured costs due to bigger projects and heightened occupational risk exposure. Additionally, the significant impact of mechanical force-related accidents on direct costs aligns with Syal, Duah [42] identification of high financial severity from such incidents. The comprehensive total cost model, which revealed strong predictors including injury severity and firm size, reinforces the necessity of multifactorial analyses as advocated by Duan, Xiang [43], who integrated human, environmental, and management dimensions in construction safety research. Together, these findings validate the models' theoretical soundness and practical relevance, echoing Polit and Beck [44] emphasis on rigorous model validation for credible, actionable insights in occupational safety economics.

This study has several limitations. Its focus on the Eastern Province restricts the generalizability of the findings to other regions with differing economic conditions, construction practices, and reporting standards. Although the sample size of 40 companies is sufficient for preliminary cost estimation, future research could benefit from expanding the sample to include a more diverse range of sectors. Additionally, employing longitudinal or mixed methods approaches, complemented by third-party audits, would help validate self-reported data and enhance the accuracy of the cost estimation models. The cross-sectional design of this study limits causal inferences and may overlook variability among different worker groups, such as those of varying nationalities, that could be better analyzed using non-parametric tests. Future research should consider parametric methods and incorporate workplace variables such as stress, job satisfaction, training, and safety culture to develop a more comprehensive and nuanced cost model. Furthermore, this study did not address intangible long-term losses such as reduced employee morale, productivity declines, and reputational damage which are critical to construction firms and should be incorporated in subsequent studies despite the inherent challenges in their measurement.

CONCLUSION

In conclusion, the study reveals that indirect costs of construction accidents consistently surpass direct costs, emphasizing the substantial financial burden of factors beyond immediate injury expenses. Company size and injury severity emerge as significant predictors, with larger companies and permanent injuries driving higher direct and indirect costs. The demographic analysis highlights a predominance of workers from India and other South Asian countries, primarily engaged as construction laborers on medium-sized projects. Notably, accidents involving scaffolding, rooftops, or ladders incur greater costs, underscoring the risks associated with elevated work environments. The generalized linear models demonstrate robust predictive value for cost estimation, though with varying fit quality for direct and indirect costs. These findings underscore the critical need for targeted safety interventions, especially in large firms and high-risk job sites, to mitigate both human and economic impacts. Overall, prioritizing preventive measures could substantially reduce cost burdens and improve worker safety in the construction sector.

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