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Validating and Estimating Indirect Accident Costs in Saudi Construction: A Bottom-Up Approach

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ABSTRACT

Accurately estimating the indirect costs of construction accidents is essential to fully understand their economic and social impacts, especially in Saudi Arabia's rapidly growing construction sector. While direct costs like medical expenses are documented, indirect costs-including lost productivity, project delays, and training-often surpass direct costs but remain difficult to quantify. This study aimed to develop and validate a bottom-up framework to estimate indirect costs of construction accidents across diverse company sizes and project types in Saudi Arabia's Eastern Province. A quantitative explanatory study was conducted from November 2020 to December 2022 involving 40 construction companies selected via quota sampling to represent various sizes and project types. Indirect cost indicators were identified based on Haupt and Pillay's framework and validated by an expert panel using the Content Validity Index (CVI) and Kappa statistics. Data on overtime, supervisory time, investigation, training, equipment damage, legal/administrative, and miscellaneous costs were collected through structured questionnaires. Descriptive statistics analyzed cost variations by company size. All nine indirect cost indicators showed strong content validity with CVI scores of 0.8 to 1.0 and substantial expert agreement. Survey results revealed significant differences in indirect costs by company size. Medium-sized firms (101–500 employees) incurred the highest overtime and investigation costs, while large firms (>500 employees) exhibited the greatest supervisory, training, and legal expenses.

Smaller firms (<50 employees) faced relatively higher equipment damage and miscellaneous costs. Geographic and project type diversity ensured comprehensive regional representation. The validated framework effectively captures the multifaceted indirect costs of construction accidents in Saudi Arabia. Findings highlight the need for size-specific safety interventions and resource allocation to reduce financial burdens. Tailored prevention strategies and enhanced training programs are crucial, particularly for medium and large companies, while smaller firms require targeted support to manage indirect cost challenges. This study provides a robust foundation for policymakers and industry leaders to improve occupational health and safety investments in the construction sector.

Keywords: Indirect Costs, Construction Accidents, Cost Estimation Framework, Occupational Health and Safety (OHS), Construction Industry, Saudi Arabia.

INTRODUCTION

Accurately estimating indirect costs of construction accidents is crucial for understanding the full economic and social impact of workplace incidents, where the construction sector is a major employer and economic driver. While direct costs such as medical expenses and property damage are typically recorded and compensated, indirect costs-including lost productivity, project delays, reduced morale, replacement and training of workers, and reputational damage-often far exceed direct costs and are more challenging to quantify [1-4]. In Saudi Arabia, studies estimate that the total cost of a single construction accident can reach approximately US$ 91,940, with the annual economic burden on the national economy estimated at US$ 261.11 million. These figures underscore the magnitude of the problem and the necessity for precise cost estimation frameworks [1, 5-7].

The indirect costs are particularly significant because they encompass a wide range of hidden impacts: lost workdays, decreased productivity among both injured and non-injured workers, costs associated with hiring and training replacements, administrative burdens, and potential penalties for project delays [8-10]. Studies from the UK and US suggests that indirect costs can be several times higher than direct costs, sometimes by a factor of 4 to 11 [11]. In Saudi Arabia, the lack of comprehensive data on direct costs has often led researchers to estimate them as a proportion of indirect costs, further highlighting the need for robust, context-specific methodologies [5, 12, 13].

In the Eastern Province, where rapid urbanization and industrial expansion have intensified construction activity, the risk and frequency of workplace accidents are heightened. The region's construction sector not only supports a large workforce but also underpins vital infrastructure and economic projects [14, 15]. Therefore, underestimating indirect costs can lead to inadequate investment in occupational health and safety (OHS) measures, insufficient compensation for affected workers and families, and ultimately, a diminished capacity for firms to compete and thrive [16-18]. Moreover, accurate estimation is essential for policymakers and industry leaders to justify and prioritize OHS investments, as studies consistently show that the benefits of accident prevention far outweigh the costs [19-21].

Top-down, bottom-up and local are the three methods of indirect cost estimation of workplace accidents. In the top-down approach, general national or industry data is used to get the average cost of incidents by drawing on national-level statistics [22-25]. This approach

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provides a big picture perspective of workplace costs, but is less accurate, because it does not capture company-specific variables. The local approach uses in-company data and real time reporting, with cost-benefit analyses applied to detailed records of workplace accidents to determine the true cost of accidents [26-29]. This approach is the most accurate, but is also very time consuming and resource-intensive, and therefore often not feasible for organizations. The bottom-up approach uses survey or interview data collected at the company level to produce cost estimates [30].

In this research, the bottom-up method was used to calculate indirect costs. In this way, data on cost items are collected at the company level using surveys, interviews, or records of occupational accidents. Data are then aggregated and analyzed, and average cost per accident or industry sector is determined. In the top-down approach, national statistics and other estimates and generalized data are used. The primary advantage of the bottom-up method is that it provides an accurate measurement of cost items for a specific context, which can be reflected in lost productivity, management time, and property damage. This method is used in many studies to calculate the economic impact of accidents, for example, in the construction industry, where it is important to use detailed cost data per event [30].

Given the regulatory environment in Saudi Arabia, where employers are legally obligated to ensure worker safety and are subject to fines and compensation requirements for workplace incidents, the ability to accurately estimate and manage indirect costs is not only a financial imperative but also a legal and ethical one [31]. The development and validation of a bottom-up framework for calculating these costs, as proposed in this study, is therefore a timely and necessary step toward improving safety outcomes, supporting sustainable growth, and protecting both workers and the broader economy in Saudi Arabia's Eastern Province.

METHODS

The study comprised three phases: first, the generation of relevant indicators; second, the validation of these indicators by experts to ensure their accuracy and relevance; and third, the estimation of costs associated with implementing and monitoring these indicators, providing a comprehensive evaluation framework.

Phase 1: Identification and Definition of Indirect Cost Indicators

The initial step involved identifying and defining suitable indirect cost indicators for construction accident cost estimation. This was accomplished through a comprehensive review of the literature combined with industry standards. The study adopted Haupt and Pillay's [32] framework, which classifies indirect costs into components such as productivity loss, supervision time, investigation expenses, training costs, and equipment damage. These indicators were derived from empirical case study data and anchored in prior validated research and international costing models, providing a robust theoretical foundation for their relevance and applicability. The finalized indirect cost indicators included:

- Overtime Costs: Compensation for employees working extra hours due to accident-related disruptions.
- Supervisor/Manager Time Costs: Time spent by supervisors and managers on accident investigations, paperwork, and organizational adjustments.

- Investigation Costs: Resources and personnel time dedicated to formal accident investigations.
- Training Costs for Replacement Workers: Expenses related to training new hires or reallocating staff to cover injured workers' roles.
- Legal/Administrative Costs: Legal fees, insurance claims, regulatory reporting, and administrative processing expenses.
- Equipment Damage Costs: Costs to repair or replace damaged equipment and property.
- Other Costs: Transportation for injured workers, additional medical treatments, and impacts on employee morale.

Phase 2: Validation of Indicators through Expert Panel

The study employed a rigorous expert panel validation method to ensure the relevance and clarity of indirect cost indicators for estimating construction accident costs by assembling a panel of occupational health and safety experts, construction managers, and industry specialists who reviewed each indicator for necessity, helpfulness, or irrelevance; based on their feedback, minor adjustments were made to improve clarity while highly relevant indicators remained unchanged. To quantify consensus, the study used the Content Validity Index (CVI), which measures the proportion of experts rating an item as relevant, and the Kappa Statistic (K), which accounts for chance agreement, retaining items with a CVI of 0.80 or higher to confirm strong agreement on their importance and clarity.

Phase 3: Data Collection from Construction Companies

Once the validation of key indicators to estimate construction accident indirect costs was completed, then primary data collection was conducted to estimate the cost per unit for all indicators (per hour or per accident). Data for this phase were collected from construction companies across Saudi Arabia using a structured questionnaire. The structured questionnaire was created based on the finalized indicators after completing the validation phase to guarantee systematic and reliable data collection covering all necessary aspects. The research structured and adapted indicators according to the indirect-cost calculation framework proposed by Jallon, Imbeau [30]. Through quota sampling, construction companies from across the country were selected from a comprehensive directory from the General Organization for Social Insurance (GOSI), ensuring balanced representation based on company size through predefined quotas. Over 150 companies were surveyed to secure responses from at least 50 organizations, resulting in a diverse sample that prevented dominance by any size category. The companies were categorized by size (less than 50, 50–100, 101–500, and more than 500 employees) and project type (pipeline, infrastructure, building construction, civil works, and specialized projects) to capture regional diversity. This classification allowed the study to analyse variations in indirect costs, accident rates, and related expenses across different organizational contexts, reflecting how safety management, workforce structure, and project complexity influence cost patterns. By using stratified sampling and detailed categorization, the research provided a robust and generalizable understanding of indirect cost differences within the Eastern Province's construction industry.

DATA ANALYSIS

Data was analysed using IBM SPSS Statistics version 30 for Windows. Descriptive statistics were applied to data collected from construction companies to estimate costs associated with

each validated indirect cost indicator. The analysis involved calculating key metrics such as the median, mean, standard deviation, as well as the minimum and maximum values for all cost components. This approach provided a comprehensive overview of the variability in indirect costs across companies of varying sizes and types. The use of descriptive statistics was instrumental in identifying underlying patterns and central tendencies within the data, thereby laying a solid foundation for more advanced comparative analyses. This methodology aligns with the recommendations of Jallon, Imbeau [30], Gibb and Isack [33], who emphasize its effectiveness in cost estimation studies.

RESULTS

Validation of Indirect Cost Indicators

The validation process for the nine indirect cost indicators involved expert review by five specialists in occupational health and safety, construction management, and cost analysis to ensure content validity of the questionnaire items. Using the Content Validity Index (CVI) and Kappa Statistic (K) as per Polit and Beck [34], the experts rated each indicator's relevance and clarity. Table 1 provides the validation results. All indicators achieved a perfect CVI score of 1 for relevance, indicating unanimous agreement on their necessity, while clarity scores were mostly perfect except for Overtime Costs, Training Costs, and Legal/Administrative Costs, which scored 0.8. Kappa values corroborated these findings, with perfect agreement (K=1.000) on relevance for all indicators and substantial agreement (K=0.763) for the three clarity-limited indicators. These results confirm that the indirect cost indicators possess strong validity and mostly clear wording, demonstrating that the questionnaire items accurately represent the indirect accident cost construct and are suitable for future data collection.

Table 1: Results of CVI and Kappa Analysis for Indirect Cost Indicators

Indicators	Relevance		Clarity	
	CVI	Kappa	CVI	Kappa
Overtime Costs:(Time lost by injured & coworkers) What is the cost per hour for overtime work? (Include any overtime premium rate)	1.000	1.000	0.800	0.763
Supervisor/Manager Time Costs: What is the hourly cost of the supervisor/manager involved in the accident?	1.000	1.000	1.000	1.000
Investigation Costs: What is the total cost of the investigation per accident ?	1.000	1.000	1.000	1.000
Training Costs for Replacement Workers: What is the total training cost per accident (if a specific figure is available)?	1.000	1.000	0.800	0.763
Equipment Damage Costs: What is the estimated total cost for repairing or replacing damaged equipment due to the accident?	1.000	1.000	1.000	1.000
Legal/Administrative Costs: What is the total legal/administrative cost incurred per accident?	1.000	1.000	0.800	0.763
Other Costs: Are there any other indirect costs related to the accident? (e.g., loss of employee morale, transportation, etc.)'	1.000	1.000	1.000	1.000

Indirect Cost Survey Results

The structured survey conducted among 40 construction companies across Saudi Arabia aimed to estimate unit-level indirect costs using a bottom-up approach, collecting data based on cost per hour (e.g., supervision, overtime) and cost per accident (e.g., investigation, training, equipment damage). Geographically (see table 2), the Eastern Province was the most represented with 45% of responses, followed by the Western Region at 30%, and both the Central and Northern Regions contributing 12.5% each, providing a diverse regional perspective. Project types varied, with pipeline projects most frequent at 20%, followed by infrastructure (17.5%), construction (15%), buildings (12.5%), civil and electrical connection projects (10% each), and transportation and other projects (7.5% each), reflecting the prominence of pipeline and infrastructure work in shaping indirect costs. Company size distribution was well balanced, with medium-sized firms (50-100 employees) and large firms (over 500 employees) each representing 27.5%, and smaller companies (<50 employees) and mid-sized firms (101-500 employees) each at 22.5%, ensuring comprehensive representation for accurate cost estimation across diverse firm sizes.

Table 2: Frequency distribution of survey among companies based on location

Company's characteristics	Level	Frequency	Percent
Region	Eastern Province	18	45
	Central Region	5	12.5
	Western Region	12	30
	Northern Region	5	12.5
Project types	Buildings	5	12.5
	Civil	4	10
	Construction	6	15
	Electrical connection	4	10
	Infrastructure	7	17.5
	Pipeline	8	20
	Transportation construction	3	7.5
	Other	3	7.5
Company size	Less than 50	9	22.5
	50–100	11	27.5
	101–500	9	22.5
	More than 500	11	27.5

Indirect Cost Estimation by Company Size

Table 3 shows the indirect costs across different company sizes based on a survey of construction companies. For companies with fewer than 50 employees, overtime costs averaged 30.67 SAR per hour, supervisor/manager time costs were 56.78 SAR per hour, investigation costs per accident reached 129.71 SAR, training costs per accident were 4,122.22 SAR, equipment damage costs per accident stood at 5,375.00 SAR, legal and administrative costs per accident averaged 100.50 SAR, and other costs per accident were 666.67 SAR. In comparison, companies with 50–100 employees reported lower overtime costs at 24.09 SAR per hour and equipment damage costs at 4,830.00 SAR per accident, while their investigation costs (143.30 SAR per accident), training costs (4,277.27 SAR per accident), legal and administrative costs (112.00 SAR per accident), and other costs (405.56 SAR per accident) showed some variation, with supervisor/manager time costs at 47.55 SAR per hour. For larger

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companies, distinct patterns emerged: companies with 101–500 employees exhibited the highest overtime costs at 42.00 SAR per hour, as well as investigation costs of 156.75 SAR per accident, training costs of 4,405.56 SAR per accident, equipment damage costs of 5,450.00 SAR per accident, legal and administrative costs of 129.00 SAR per accident, and other costs of 702.86 SAR per accident, with supervisor/manager time costs at 55.57 SAR per hour. Companies with more than 500 employees reported the highest supervisor/manager time costs at 57.78 SAR per hour, investigation costs at 157.25 SAR per accident, training costs at 4,981.82 SAR per accident, and legal and administrative costs at 138.00 SAR per accident, while their overtime costs (32.22 SAR per hour), equipment damage costs (4,962.50 SAR per accident), and other costs (702.50 SAR per accident) were moderate compared to other size categories.

Table 3: Mean Indirect Costs of Construction Accidents by Company Size (in SAR)

Indicator	Cost Basis	Company Size (number of employee)			
		<50	50-100	101-500	>500
Overtime Costs	Per Hour	30.67	24.09	42.00	32.22
Supervisor/Manager Time Costs	Per Hour	56.78	47.55	55.57	57.78
Investigation Costs	Per Accident	129.71	143.30	156.75	157.25
Training Costs	Per Accident	4122.22	4277.27	4405.56	4981.82
Equipment Damage Costs	Per Accident	5375.00	4830.00	5450.00	4962.50
Legal and Administrative Costs	Per Accident	100.50	112.00	129.00	138.00
Other Costs	Per Accident	666.67	405.56	702.86	702.50

DISCUSSION

The validation of the nine indirect cost indicators for construction accidents demonstrated robust content validity, as evidenced by perfect CVI scores for relevance and high Kappa statistics. This strong agreement among experts in occupational health, safety, and cost analysis underscores the appropriateness and necessity of the selected indicators. The only minor shortfall was in the clarity of three indicators (Overtime Costs, Training Costs, and Legal/Administrative Costs), which, while still substantial (CVI = 0.8, K = 0.763), suggest that further refinement of item wording could enhance future survey clarity. This high level of validity aligns with the methodological recommendations of Polit and Beck [34], who advocate for both expert consensus and statistical confirmation in instrument development.

The survey covered a balanced spectrum of company sizes, with medium (50–100 employees) and large companies (over 500 employees) each representing 27.5% of the sample, and smaller firms (500 employees) incurred the highest supervisor/manager time, investigation, training, and legal/administrative costs. Medium-sized firms (101–500 employees) reported the highest overtime costs, suggesting that mid-sized organizations may experience greater operational disruptions from accidents, possibly due to less redundancy in staffing compared to larger firms. These patterns highlight the nuanced ways in which company scale influences the financial impact of workplace incidents. These findings are consistent with the broader consensus that indirect costs often exceed direct costs and vary by company size and sector. Studies by Leigh [35], Heinrich [36] have shown that indirect costs can be 2–10 times higher than direct costs, with larger organizations typically absorbing higher administrative and training costs due to more complex structures and compliance obligations. In Saudi Arabia,

Haupt and Pillay [32] similarly reported that indirect costs are substantial and that company size is a significant determinant, supporting the current study's results. However, the current study's detailed breakdown by cost type and company size provides more granular insight than many previous works.

Based on the analysis of cost components associated with construction site accidents, it is strongly advised that construction companies-particularly medium and large enterprises-prioritize investment in targeted accident prevention strategies and rapid response systems. These firms often face significant financial burdens from high-cost elements such as overtime labour, accident investigations, and specialized training programs. By enhancing their safety protocols and response mechanisms, companies can effectively reduce both the frequency of accidents and the subsequent economic impact. One critical area for improvement is the development and implementation of comprehensive training programs tailored to the specific risks encountered on construction sites. Research has shown that well-structured safety training not only improves worker awareness but also fosters a culture of safety that can lead to measurable reductions in workplace incidents [37]. Furthermore, clear and consistently enforced safety protocols serve as a preventive measure by minimizing unsafe behaviors and ensuring compliance with regulatory standards [38]. Efficient accident investigation procedures are equally important, as they enable companies to identify root causes quickly and implement corrective actions that prevent recurrence [39]. In addition to company-level initiatives, policymakers have a vital role in supporting smaller construction firms, which often lack the resources to manage high costs related to equipment damage and overtime effectively. Smaller firms may benefit from industry-wide safety initiatives, such as shared training platforms or cooperative safety programs, which can provide access to expertise and economies of scale not otherwise affordable [40]. Government agencies and industry associations could facilitate these efforts by offering guidance, funding, or incentives aimed at improving safety management practices across the sector.

Despite its strengths, the study has several limitations. The sample size, while diverse, is limited to 40 companies, which may restrict the statistical power and generalizability of the findings. The reliance on self-reported data introduces potential bias, particularly in cost estimation. Regional and project-type representation, though broad, may not capture all nuances of the Saudi construction industry. Future research should aim for larger, longitudinal samples and incorporate qualitative interviews to better understand the contextual factors influencing indirect costs. Additionally, refining the clarity of certain questionnaire items, as indicated by the validation results, will further improve the reliability of future studies.

CONCLUSION

In conclusion, this study successfully validated nine indirect cost indicators related to construction accidents, demonstrating strong content validity and expert consensus, thereby confirming their suitability for accurate data collection. The comprehensive survey of 40 diverse construction companies across Saudi Arabia revealed significant variations in indirect costs by company size, with medium and large firms bearing higher expenses in supervision, training, and legal costs, while medium-sized firms experienced the greatest overtime costs. These findings underscore the critical need for tailored accident prevention strategies, enhanced safety training, and efficient investigation procedures to mitigate financial impacts,

particularly for larger enterprises. Additionally, smaller firms would benefit from industry-wide support initiatives to manage costly indirect expenses.

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Conflicts of Interest
The authors declare that they have no competing interests.

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