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Development of a Paradigmatic Model of Fall Incident-Related Injuries Based on Comprehensive Data in Residential Construction Projects

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Abstract

Falls are a significant public health risk and a leading cause of both fatal and non-fatal injuries among construction workers worldwide. A more comprehensive understanding of the causal factors contributing to fall incidents is essential for preventing falls in the construction industry. However, there is no general review of causal factors in the existing literature. Given the importance of addressing accidents and incidents in the construction industry, this study aims to develop a paradigmatic model of injuries caused by fall incidents based on comprehensive data from the residential construction sector. The main objectives of this research include identifying the injuries and factors influencing falls in the construction industry, developing a model, and providing solutions to reduce fall risks. The research methodology is content analysis, using a qualitative approach. To extract the factors influencing fall risk management, the meta-synthesis approach is employed. For data analysis in the qualitative section, 110 codes were derived from 48 domestic and international articles that met the criteria for relevance and quality, which were then combined to present an overall view. Following coding and identification of new factors, validity was assessed using the fuzzy Delphi technique, with consultation from 15 experts in Tehran. After validation of the indicators, the paradigmatic model was developed, which illustrates that causal, contextual, and intervening conditions lead to the occurrence of incidents. Along with appropriate strategies, these factors can control or mitigate various consequences. These findings contribute to research on the causes of falls in construction, the development of engineering controls, policy-making, intervention design to reduce fall risks, and the improvement of research synthesis methods.

Keywords: *Paradigmatic model, Fall incidents, Causal conditions, Contextual conditions, Intervening conditions.*

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1. Introduction

Undoubtedly, one of the most important industries in any country, especially in Iran, is the construction industry, which not only contributes to the development and progress of the country but also has a significant impact on job creation and economic growth [1]. However, the construction industry has always been associated with unfortunate incidents, and despite advancements in construction safety and health measures, the number of incidents in construction processes continues to rise as the volume of construction increases in countries [1-3]. As a result, today the construction industry is considered one of the most hazardous industries in Iran. The growing trend of fatalities resulting from construction accidents in recent years has raised serious concerns for both public health and the economy. Statistics show that annually, 317 million work-related accidents occur worldwide, resulting in the deaths of more than two million and thirty thousand [4-6]. For instance, in the United States in 2012, 4,383 people lost their lives in the workplace due to work-related accidents, with deaths caused by construction accidents accounting for 18% of the total fatalities. According to the International Labour Organization’s report, 60,000 fatal accidents occur annually in the construction industry, averaging one fatal accident every ten minutes. In other words, one out of every six work-related accidents occurs in the construction industry. These high accident rates have led to the construction industry being recognized as a high-risk and unsafe sector. In industrialized countries, approximately 25% to 40% of work-related deaths occur in the construction industry, despite this sector employing only 6% to 10% of the workforce [5]. In Iran, according to statistics received from the Ministry of Cooperatives, Labour, and Social Welfare in 2021, 46% of all work-related accidents occurred in the construction sector, with construction workers being the majority of those affected. Among the fatal accidents in the construction industry, falls account for the largest share. Therefore, investigating the factors and evaluating the risk of falls in the construction industry, as well as providing solutions for managing this risk, is essential. Studies conducted by the U.S. Occupational Safety and Health Administration (OSHA) on the fatality rate in the construction sector from 2010 to 2015, covering 3,496 accidents, concluded that falls from height were the leading cause (33%) of all construction-related fatalities. Other causes, including being struck by an object, caught in or between objects, and electrocution, accounted for 22%, 18%, and 17% of fatalities, respectively. Nearly 40% of fatalities from falls were from heights of 30 feet (9 meters) or more, with 25% occurring between 3 meters and 6 meters. One of the reasons for the high mortality rate in the construction industry in Iran may be the mindset of project managers and industry professionals. These individuals often view safety measures as an additional cost that increases production costs, and thus do not give them the necessary attention [6]. On the other hand, despite the mandatory implementation of safety regulations in construction projects, incidents often occur due to negligence and non-compliance with safety guidelines, leading to irreparable damages. Therefore, identifying hazards and their contributing factors is the first step in analyzing and addressing [7]. Among the various types of construction accidents, falls are one of the most frequent, causing significant physical and financial damage.

Thus, this study focuses on investigating the factors contributing to fall risks and presenting a model to predict the degree of injury caused by falls, based on comprehensive data in the construction industry, using artificial neural networks.

2. Methodology

The method of this research is content analysis within a qualitative approach, utilizing the meta-synthesis technique to extract the factors influencing the management of fall risks. The validity of the extracted indicators is then evaluated using the fuzzy Delphi method. Finally, the paradigmatic model of the research is presented. In this study, a combination of library and field methods is used for data collection. To gather scientific information for the development of concepts, books, articles, dissertations, theses, and databases are studied, and note-taking methods are employed. Data collection to address the research questions is carried out using documents related to fall incidents in construction projects and a researcher-designed questionnaire. The statistical population of this study, for assessing the validity of the accident management model, consists of experts in the construction and construction management fields. Additionally, the data from construction workers over the past ten years will be used to analyze the factors influencing fall risk. The expert population includes industrial experts and university professors in the construction management field. This research uses purposive sampling, with industrial experts having higher education levels than a master's degree and more than five years of experience, as well as university professors with more than five years of experience and a PhD or higher, selected as the sample.

3. Findings

This qualitative study was conducted in Tehran, with 15 professors and experts selected using snowball sampling. Semi-structured individual interviews were used to collect data. The data analysis method employed is qualitative content analysis with a conventional approach. The research method of this study is descriptive-analytical, of the content analysis type. Content analysis is a systematic and objective technique for extracting the characteristics of a message (Table 1).

Table 1. actors Affecting Fall Risk, Strategies for Reducing Fall Risk, Fall Consequences, and Injury-Related Risks

Factors Affecting Fall Risk	Strategies for Reducing Fall Risk	Fall Consequences	Injury-Related Risks	Sources
Inappropriate thinking of managers	Identifying the main causes of accidents	Wasted capital	Hardware capital loss	[8]
Disregard for safety measures	Controlling personnel performance	Wasted lifespan	Loss of lifespan	[3]
Operations in confined spaces	Controlling mechanical conditions	Wasted costs	Cost loss	[9]
Non-standard construction methods	Engineering	Wasted time	Time loss	[10]
Complexity of the work environment	Training	Project delay	Medical burden	[3]
Adverse working conditions	Identifying unsafe practices	Fall-related injuries	Disability	Ministry of Labour, New Zealand (2010)
Unsafe practices	Engineering	Amputation	Amputation	[11]
Worker negligence	Training	Death		[11]
Law and unsafe conditions	Toolbox meetings	Side effects		[12]
Accident	Ongoing training	Disability		[13]
Environmental factors	Managing safety activities	Unsafe equipment		[14]
Internal factors	First aid	Unsafe methods		[15]
Situational factors	Safety inspections	Human elements		[6]
Inappropriate activities	Emergency drills			HSG Standard
Inadequate response	Incident investigation and reporting			Peterson (1978)
Ergonomic traps	Personal protective equipment			[16]
Carelessness	Removing related restrictions			[9]
Negligence	Methods for procurement selection			[17]
Failure to comply with safety regulations	Extensive contracting			[18]
Unauthorized skilled workforce	Job commitment			[19]
Low management skills	Using fall protection equipment			[20]
Failure to allocate safety resources	Risk management			[11]
Strong commitment of management to health and safety	Immediate supervision			[13]
Safety policy	Capabilities of materials and equipment			[21]

Factors Affecting Fall Risk	Strategies for Reducing Fall Risk	Fall Consequences	Injury-Related Risks	Sources
Management team participation	Project management			[22]
Employee involvement in safety programs	Safety investments			[23]
Poor record keeping	Increasing project budgets			[24]
Accident reporting system	Government intervention			[23]
Poor workforce management	Wasting hardware resources			[7]
Industry-specific nature				[13]
Failure to enforce laws				[18]
Equipment/tool malfunction				[18]
Poor equipment maintenance				[25]
Lack of protection during material transport				[26]
Improper arrangement of construction materials				[27]
Poor material handling				[28]
Constant changes in site conditions				[4]
Environmental factors				[5]
Workplace conditions				[29]
Unsafe equipment				[12]
Unsafe methods				[30, 31]

In the second part of the qualitative analysis, the initial constructs, which were extracted through the review of sources and literature, were presented to experts in order to gather their opinions. To identify the dimensions and indicators of the research, the results obtained from the interviews in the qualitative section of the study were collected. For this purpose, semi-structured interviews were conducted with 13 participants (facilitators and sample individuals) in a purposeful manner, followed by content analysis of the interviews, as shown in Table 2. The content analysis of the interviews was performed in several stages. After the interviews were conducted, the oral interviews were transcribed into written form. Then, the complete interview texts, without omitting any details, were carefully reviewed. Key points from each interview were identified, and using inductive content analysis, the components found in each interview were recognized. In this stage, sub-components were first extracted, then the main dimensions were identified, and similar components were merged into broader categories. After categorizing the components and placing each under its relevant theme, the common components across interviews were compared and analyzed, and the main components and their subcategories were determined. The findings from the interview analysis, based on the questions of the qualitative section of the study, are presented below.

In this stage, all identified codes, based on their concepts, were categorized into groups with similar concepts. Table 2 presents the codes and categories of the research components using a comparative approach:

Table 2. Codes and Categories of the Research Components

Factors Affecting Fall Risk	F#	Fall Risk Reduction Strategies	R#
Poor managerial thinking	F1	Identifying main causes of accidents	R1
Ignoring safety measures	F2	Controlling personnel performance	R2
Operations in confined spaces	F3	Controlling mechanical conditions	R3
Non-standard construction methods	F4	Engineering	R4
Complexity of the work environment	F5	Training	R5
Adverse working conditions	F6	Correct implementation	R6
Unsuitable materials	F7	Identifying unsafe practices	R7
Workplace accidents	F8	Safety inspections	R8

Worker's negligence	F9	Emergency drills	R9
Social background and environment	F10	First aid	R10
Unsafe laws and conditions	F11	Safety training	R11
Accidents	F12	Safety planning/emergency procedures	R12
Injury or harm	F13	Workplace risk assessment	R13
Environmental factors	F14	Management of project risks	R14
Internal factors	F15	Regular training	R15
Situational factors	F16	Removing related restrictions	R16
Inappropriate activities	F17	Selection methods for materials	R17
Inadequate response	F18	Broad contracting	R18
Superhero syndrome	F19	Project management	R19
Ergonomic traps	F20	Safety investments	R20
Equipment/tool malfunction	F21	Removing communication barriers	R21
Poor equipment maintenance	F22	Risk assessment	R22
Lack of protection during material transport	F23	Worker commitment	R23
Poor arrangement of building materials	F24	Emergency drills	R24
Constant changes in site conditions	F25	Fall protection use	R25
Environmental factors	F26	Accident investigation and reporting	R26
Workplace conditions	F27	Worker actions	R27
Unsafe equipment	F28	Risk management	R28
Unsafe methods	F29	Immediate supervision	R29
Industry-specific nature	F30	Safety inspections	R30
Worker fault	F31	Local hazards	R31
Non-allocation of safety resources by the organization	F32		
Unsafe working conditions	F33		
Failure to implement safety procedures	F34		
Insufficient safety training	F35		
Inadequate supervision	F36		
Lack of hazard reporting systems	F37		
Poor workplace maintenance	F38		
Limited safety equipment	F39		
Inadequate government intervention	F40		
Poor management skills	F41		
Lack of safety commitment by management	F42		
Poor teamwork in safety management	F43		
Poor risk management	F44		
Poor safety culture	F45		
Mismanagement of resources	F46		
Insufficient hazard identification and control	F47		
Poor emergency planning	F48		
Unclear roles and responsibilities in safety	F49		
Poor supervision of workers	F50		
Insufficient use of fall protection devices	F51		
Lack of safety equipment	F52		
Inadequate accident investigation	F53		
Unsafe working methods	F54		
Inadequate hazard mitigation procedures	F55		
Poor communication	F56		
Lack of safety collaboration	F57		
Poor workplace design	F58		
Lack of fall prevention systems	F59		
Inadequate PPE	F60		

In Table 2, after identifying the factors and merging the repetitive components, a code was assigned to each indicator. Later, by integrating the indices, the new codes shown below were extracted:

Table 3. Codes and Categories with a Comparative Approach (Second Stage)

Categories	Code	Categories	Code
Fall Risk Reduction Strategies		Factors Affecting Fall Risk	

Identification	R1, R7, R8	Mismanagement	F1, F2, F29, F30, F31, F32, F33, F37, F38, F39
Engineering	R4, R6, R17, R26	Improper Activity Execution	F3, F4, F35, F36, F43, F44, F54, F58, F59
Training	R5, R10, R11, R5, R9, R11, R12, R20	Job Conditions	F5, F6, F11, F14, F15, F16, F45, F46, F47, F48, F51, F57, F58
Proper Management	R13, R15, R16, R22, R31, R36	Suitable Equipment	F7, F40, F41, F42, F43, F52, F53, F55, F56
Proper Control	R2, R3, R18, R21, R32, R34	Accident and Injuries	F8, F9, F10, F12, F13, F27
Appropriate Measures	R19, R30, R35	Human Factors	F17, F18, F19, F20, F21, F22, F23, F24, F25, F26, F28, F34, F60
Infrastructure	R23, R24, R25, R29, R33, R37	Environmental Factors	F49, F50
Human Factors	R27, R28		

In Table 3, the codes have been merged into new codes that categorize the research components into main factors affecting fall risk and strategies for reducing fall risk.

The methodology of this study is inherently descriptive and qualitative, carried out in two stages:

A: In the first stage, a documentary and library-based approach was used to collect the dimensions and areas of the research.

B: The second stage involved qualitative research, which, based on the findings from the first stage, aims to explain the appropriate dimensions and indicators for each construct through interviews and the Delphi method.

In many studies, the threshold value from the fuzzy average is also calculated.

$$\tilde{a}_{ij} = (a_{ij}, b_{ij}, c_{ij}), \quad i = 1,2,\dots,n \quad j = 1,2,\dots,m$$

$$a_j = \min(a_{ij})$$

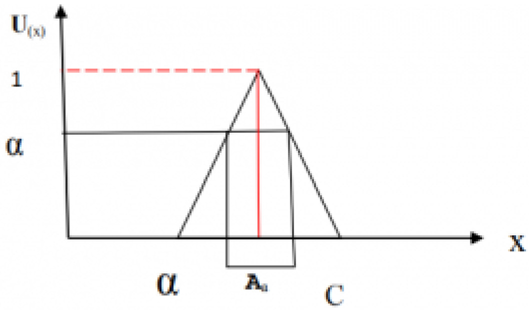
$$b_j = \left(\prod_{i=1}^{n} b_{ij}\right)^{1/n}$$

$$c_j = \max(c_{ij})$$

In the above relations, the index i refers to the expert, and the index j refers to the decision-making indicator. The defuzzified value of the fuzzy number's mean is obtained using the following formula:

$$Crisp = \frac{a+b+c}{3}$$

The term consensus refers to the point at which respondents have reached an overall decision about the factors. It is the stage after which no significant changes occur in the criteria.



In the Delphi method, since the predictions provided by experts are expressed in the form of definitive numbers, this removes the predictions from the real world. Furthermore, experts use their cognitive abilities to make predictions, indicating that the uncertainty involved in this scenario is of the possibilistic type, not probabilistic. The possibilistic nature of uncertainty is consistent with fuzzy sets. This method combines the Delphi technique with fuzzy set theory, as introduced by Ishikawa et al. In the present study, to analyze the questionnaire data obtained from the fuzzy Delphi method, Microsoft Excel software was utilized.

Table 4. Value of Each Construct

Variables	L	M	U	Mean	Crisp	Result
Identification	0.74	0.89	0.97	(0.737, 0.887, 0.97)	0.86	Acceptance
Engineering	0.69	0.86	0.96	(0.687, 0.859, 0.956)	0.83	Acceptance
Training	0.78	0.92	0.98	(0.781, 0.923, 0.984)	0.90	Acceptance
Proper Management	0.70	0.87	0.96	(0.703, 0.867, 0.957)	0.84	Acceptance
Correct Control	0.77	0.91	0.98	(0.771, 0.914, 0.979)	0.89	Acceptance
Suitable Actions	0.71	0.87	0.96	(0.708, 0.872, 0.96)	0.85	Acceptance
Infrastructure	0.74	0.89	0.96	(0.743, 0.889, 0.964)	0.87	Acceptance
Human Factors	0.73	0.89	0.97	(0.729, 0.888, 0.97)	0.86	Acceptance
Incorrect Management	0.69	0.86	0.95	(0.694, 0.864, 0.953)	0.84	Acceptance

Improper Activity Execution	0.68	0.86	0.95	(0.683, 0.86, 0.954)	0.83	Acceptance
Job Conditions	0.69	0.86	0.96	(0.692, 0.862, 0.958)	0.84	Acceptance
Suitable Equipment	0.70	0.87	0.96	(0.704, 0.87, 0.96)	0.84	Acceptance
Accidents and Injuries	0.71	0.88	0.97	(0.711, 0.877, 0.966)	0.85	Acceptance
Human Factors	0.71	0.87	0.96	(0.706, 0.871, 0.958)	0.84	Acceptance
Environmental Factors	0.70	0.86	0.95	(0.699, 0.861, 0.953)	0.84	Acceptance

As seen in Table 4, all indicators have received appropriate scores and have been approved.

Based on the research findings previously mentioned, the following paradigmatic model has been identified:

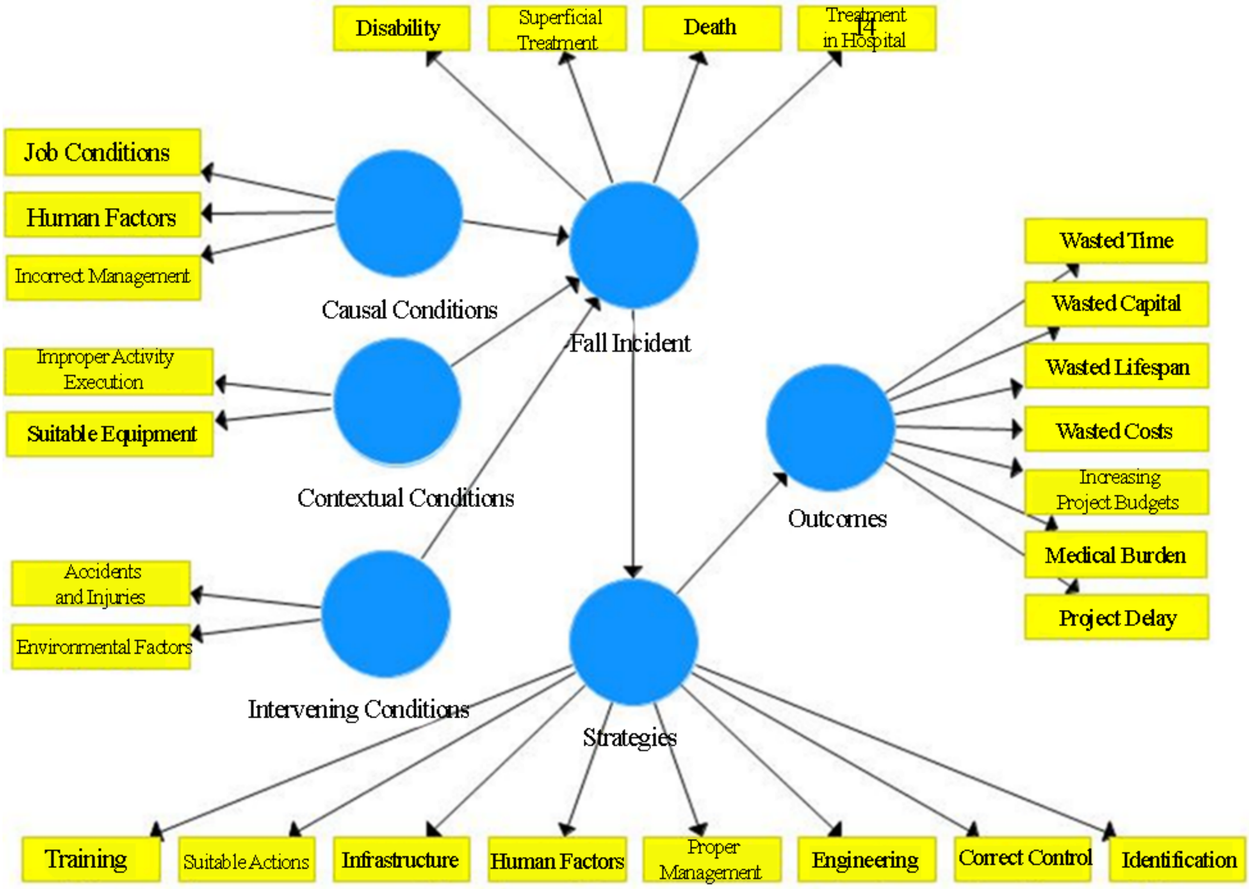


Figure 1. Research Paradigmatic Model

The above model, extracted as a draft from the Smart PLS software, is solely intended for a clear understanding of the components, mechanisms, and relationships among the research variables. The model indicates that causal conditions (job conditions, human resources, and incorrect management), contextual conditions (improper execution of activities and unsuitable equipment) are influenced by intervention conditions (occurrence of accidents and injuries, and environmental factors), leading to the phenomenon of fall accidents. If appropriate strategies, including identification, correct control, engineering, and proper management, are adopted, the consequences will include a reduction in time wastage, capital, lifespan and costs, medical burden, and project delays.

4. Discussion and Conclusion

In this study, a model for the injuries caused by fall accidents based on comprehensive data from the construction industry of residential projects has been presented. In this model, the factors influencing and affecting fall accidents were identified, including causal, contextual, and intervening factors, as well as strategies and outcomes. This section compares and discusses the results of this study with those of similar studies. As a result, ladder falls, scaffold falls, and falls from roof surfaces were identified as the three main fall events leading to fatalities from height. Given the review nature of this study, which aligns with all previously reviewed studies, it corresponds with other studies in terms of the number of factors involved. The model developed in this research revealed that causal conditions (job conditions, human resource factors, and improper management), contextual conditions (improper execution of activities and inadequate equipment), and intervening conditions (including accidents, injuries, and environmental factors) all contribute to the occurrence of fall-related accidents. These accidents typically result in hospital treatment, fatalities, superficial treatment, and disability. However, if effective management measures are taken, such as identifying influencing factors, correct control, engineering, effective management, considering human factors, developing infrastructure, and providing training, it can significantly help control and reduce the consequences of employee falls from height, including time wastage, capital loss, lifespan and cost, medical burden, and project delays.

The occurrence of fall accidents from height was due to an unknown hazard or insufficient preventive measures. Identifying all fall events and their causes provides a clear picture of the primary causes of fall accidents. Before implementing safety preventive measures, it is necessary to understand the underlying causes of accidents. It is possible that reducing the risk of any hazard requires the implementation of various preventive measures in combination. This study focuses on fall-related events and the causes of fall accidents from height, and it can serve as a benchmark for future studies in the Iranian construction industry, particularly those focusing on the research area of fall accidents from height. Our analysis provides valuable insights into understanding the risks of falls in construction. We present a systematic integration of relevant research on the causes and factors of construction falls. The results can assist future researchers and practitioners in conducting more relevant research and designing more effective safety interventions that can help reduce work-related falls. For example, our study highlights the gap between qualitative and quantitative research on fall causes, where more quantitative studies are needed to evaluate the final impact of psychological and organizational factors and how they relate to necessary management interventions. Better estimation of various pathways for analyzing the cost-effectiveness of different management and engineering interventions is required. For instance, both "worker safety behaviors and attitudes" and "work levels and platforms" are significant fall triggers.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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