Fall Fatalities in Construction:

Root causes and Precursors

Oklahoma State University

# Abstract

In construction incidents, falling incidents were the highest, accounting for 32% of the total number of incidents. However, only a few research studied the relationship between precursors and Serious injury or fatality(SIF) in the construction fall incidents. The previous research mainly focused on incident analysis and expert judgment, and the research ideas based on incident analysis were primarily subjective. In the process of cause analysis, whether the incident itself had typical characteristics was not considered. Too many qualitative studies caused the research results to be significantly affected by incidental factors. In this thesis, our team found out common root causes and SIF Precursors to study the correlation between SIF Precursors and construction fall incidents. This study determined four parameters in the SIF Precursors section for content analysis and choose Analytical Hierarchy Process (AHP) for correlation analysis. Our research helped enterprises in the construction industry to better understand the causes and pre-conditions of falling incidents.

*Keywords: SIF precursor, fall events during construction, Content Analysis, Analytical Hierarchy Process*

# Introduction

Construction safety is the basis for the long-term and stable development of the construction industry and the premise for construction enterprises to carry out production and operation activities. In the new era of rapid economic development, the frequent occurrence of construction safety incidents has always been a major problem hindering economic development and construction progress. Due to bad weather conditions, many open-air operations, various work forms, long work cycle, high labor intensity, and frequent replacement of operators, safety incidents such as falling from a height, object strike, electric shock, mechanical injury, and collapse often occurred in the process of construction (Ma Lin, 2004). In construction incidents, falling incidents ranked first, accounting for 32% of the total number of incidents in America (R Arifuddin, R U Latief & A Suraji, 2019). A fall incident refers to a personal injury incident that occurs when a person falls from a height of more than 2 meters.(Jia Xiaoshan, 2017) In construction, fall incidents from height had the highest frequency and the greatest danger, accounting for one-third of on-the-job deaths in construction in China( Li Shanhua, 2018). General speaking, falling incidents in construction were also the types of incidents with high frequency. For example, according to the statistics of Japan's Ministry of health, labor and welfare, falling incidents accounted for 37% of the total number of construction incidents between 1990 and 2001; In Canada, 41% of the production incidents at construction sites from 1997 to 2005 were caused by falling incidents.(Shang jie, 2008)

The falling incident has become the main cause of serious injuries and fatalities (SIFs) for construction workers all over the world. The impact/consequences of falling incidents mainly involved death (56%) and serious injury (28%) (R Arifuddin, R U Latief & A Suraji, 2019). The rate of serious injuries and fatalities (SIFs) in construction fall incidents was as high as 84% (56%+28%), so studying the precursor of SIFs in construction fall incidents is necessary. Through content analysis of existing historical incident reports, the research team determined the common root causes leading to the fall incidents and identify any precursors to these SIFs in the construction fall incident. Our research could provide a basic framework to assist enterprises in the construction industry to better understand the causes of falling incidents.

Although previous studies have focused on falling incidents in building construction, a large part of the research focuses on the preventive countermeasures after finding out the causes. Early studies on fall incidents at heights focused on incident statistics. The early studies on falling incidents mainly focused on incident statistics. Ma Bin et al. (2004) determined the high-frequency locations of falling incidents through the statistics of safety incident archived from 1995 to 2001, and established a prediction model to estimate the number of incidents.; Zhang Jianshe (2015) classified and counted the falling incidents of building construction in China from 2004 to 2013 according to the temporal and spatial distribution, and revealed the occurrence law and causes of the incidents. In order to reveal the causes of falling incidents, Huang Guoyao(2007) decomposed the incidents and counted the cause frequency of incidents on the basis of incident statistics. Zhang Shuling(2015) discussed the causes of falling incidents in the construction industry from the aspects of construction personnel, equipment, and management and put forward countermeasures such as organizing safety education, eliminating potential safety hazards, and strengthening construction management so as to create good conditions for building safety construction. Zheng Xiazhong(2017) identified the human error factors affecting the occurrence of incidents from multiple levels, such as organizational influence, safety supervision, and unsafe behavior through the investigation and report of 152 High-altitude Falling incidents of construction projects, designed the questionnaire on human error of high-altitude falling, carried out the questionnaire survey of first-line high-altitude operators, and established the structural equation model of human error of high-altitude falling. The path analysis of human error factors leading to high-altitude falling incidents was carried out.

In addition, to identify the causes of falling incidents, a large number of scholars have applied the Analytic Hierarchy Process (AHP), Fault Tree Analysis, Bayesian network model, and other methods to study the causes of falling from height. Wang Dongxue (2018) applied AHP to establish a falling from height index system, calculated the weight of each index through expert scoring, and sorted it according to the size. The results showed that the most influential factor was human factors. This method relied on expert scoring and was highly subjective. Xiao Huade (2009) summarized the main causes of incidents from three aspects and established a falling from height risk evaluation index system in combination with the characteristics of falling from height. Jia Xiaoshan et al. (2017) first used the fault tree analysis method to analyze the causes of high-altitude falling incidents, and then used the analytic hierarchy process combined with expert opinions to find out the three main causes. Zhang Mingxuan et al(2008). combined the probability with the incident analysis tree method to calculate the probability of simple events and non-simple events in the incident. Guo Haoshou(2007) used the fault tree analysis to qualitatively analyze the high-altitude falling incident, fought out the main factors affecting this kind of incident, and put forward the countermeasures to prevent the high-altitude falling incident.

By summarizing the above studies, our research group found that the current research on the causes of falling incidents mainly focused on incident analysis and expert judgment, and the research ideas based on incident analysis were mostly subjective. However, in the process of cause analysis, whether the incident itself had typical characteristics was not considered, and too many qualitative studies caused the research results to be greatly affected by incidental factors. Although these studies on falling incidents have been analyzed from multiple angles, the proposed research models and evaluation indicators are becoming more and more perfect. However, there were many research results in improvement measures, but there were few articles on the detailed definition and classification of the causes of incidents and the occurrence law of falling incidents. In order to more accurately review the precursor of SIFs in construction fall incidents, our research group foundout the root causes included in the immediate causes. On the basis of immediate causes, our team would find out common root causes and SIF Precursors through the content analysis method of the incident report and study the correlation between immediate causes and construction fall incidents.

For the research on the correlation between root causes and incidents, previous studies have used two research methods: analytical hierarchy process (AHP) and dynamic Bayesian network (DBN). Firstly, Jia Xiaoshan (2017) used fault tree analysis and AHP to analyze the causes of falling incidents. He got the weight of each root cause, which was the correlation with the incident. Three preventive measures were put forward for the root causes of great correlation. Then Chen Hongyu (2019) used DBN to analyze the causes of construction fall incidents. However, the root cause and immediate cause were not separated, and they were directly collectively referred to as risk factors. Through the use of a dynamic Bayesian network, the incident probability at each time and the weight of each risk factor were finally obtained.

This study tends to choose AHP for correlation analysis because the AHP model could be divided into three layers, which was consistent with the research team’s incidents, direct causes and root causes. In the AHP used by Jia Xiaoshan, he subjectively weighted each root cause and established a judgment matrix. In our research, the research group would first use content analysis to obtain the number and frequency of each root cause. Based on these factors, the root causes were weighted, and finally, the correlation between SIF Precursors and the incident was obtained.

Our research is based on the content analysis of the construction fall incident report in NIOSH database. Our purpose was to find the common root causes leading to the SIFs in the construction fall incident, and explore the correlation between the root causes and the incident. Finally, our research group would completely reveal the precursors of SIFs in building fall incidents, including the type of precursor, which immediate cause was associated with, and the correlation between each precursor and SIFs in the construction fall incident.

Our study of common root causes used the content analysis method to analyze the construction fall incident report in the NIOSH database. The first step in the study was to determine five parameters in the immediate causes section of scan chart for content analysis based on literature review and using human factors analysis and classification system (HFACS), which was using equipment improve, failure to follow procedure, failing to use PPE properly, Inadequate Guards or Barriers and Improper Position for Task. On this basis, combined with the content analysis method, the root causes corresponding to the five direct causes were summarized, and the common root causes of SIF in construction falling events were put forward. The content analysis process was described in detail in the method section.

The study of the correlation between root causes and falling incidents used Analytic Hierarchy Process (AHP) for quantitative research. By using AHP, incidents, immediate causes and root causes were divided into three layers, corresponding to target layer, criterion layer, and index layer respectively. Then got the weight coefficient of each root causes as well as the correlation with the incident after figuring out the weight to each layer of variables. The expected final result of the study was to get a complete model of precursor(Figure 2) to reveal the precursors of SIFs in building fall incidents.

# Methods of Content Analysis

## **Step 1. Research Sketch**

**Source, Message, and Receiver**

The proposed content analysis pilot study for this research studiedthe investigative reports of fatalities caused by falls in construction documented by The National Institute for Occupational Safety and Health (NIOSH). The proposed research question involved finding the general root cause of the incident and the direct cause corresponding to each root cause, categorizing and integrating all the data and determining the presence of any common precursors to the incidents. The data source was The National Institute for Occupational Safety and Health (NIOSH) Fatality Assessment and Control Evaluation (FACE) Program database, and the information source was the incident investigation in the incident report. The recipient would be all companies in the construction industry.

**Message Data**

For this study, our research group obtained 60 incident reports from the U.S. Centers for Disease Control NIOSH Fatal incident database. These reports included the time and location of the incident, the specific details of the incident, the incident result, the incident analysis report and the opinions of the investigator.

**Extra Message Data**

At this point, additional message data was reviewed. For some future work in this field, some potential sources of additional information data may be news stories about events published through print or video media. Each company should conduct an internal investigation into the incident, and the national workers' compensation commission have investigation data, but access to these data sources was not feasible for the purpose of this course.

**Source-Message Data Linkage**

In this project, the most suitable source message link type was the integrative logical linking source -- > message described by Neuendorf (2017) on page 54. This method describes the "logical connection between theory based content and other studies..." using the theories and information collected from the literature review, the article described the prevalent safety theories of major incidents and death (SIF) precursors. In addition to the risk identification and acceptance theory, the article also determined whether any of these theories can be separated from the investigation content.

**Insight**

Comprehensive logical links help to better understand NIOSH's legal investigation process. NIOSH was a law enforcement entity compared with the popular safety theories of risk identification, SIF precursors and root cause analysis. Although this was a pilot study designed to practice the content analysis methods learned in this course, there was a more important study with a much larger data set that can reveal valuable information on the causes of fatal workplace incidents.

## **Step 2. Sampling**

**Unit of Sampling**

For this pilot study, the unit of sampling is the investigation report as prepared and submitted by a NIOSH investigator following the investigation of a workplace incident resulting in a fatality. This kind of incident report was about high-altitude falling incidents. It mainly described the introduction of each incident, including the cause, process and results of the incident.

**Sampling Frame**

The sampling frame was curated from the National Institute for Occupational Safety and Health’s index of falling incident investigation available from their website <https://www.cdc.gov/niosh/face/inhouse.html>. A convenience sample was drawn from within the NIOSH for calendar year from 1982 and 2019.

**Population**

60 cases were selected from the 210 total incident cases in the US during this time period, which was because in the whole 210 construction incidents, only 60 high-altitude falling incidents can be used as research samples. Specifically within the case documents, content relating to incident causation, and organization or individual risk was extracted for analysis.

**Dataset Link**

A skeleton framework spreadsheet has been established with basic information about each case for content analysis. See *Table1*. The data collection table includes:

1. Title
2. Brief description of incident
3. Incident consequences: Death on the spot, ineffective rescue, serious injuries that affect life, serious injuries that can be healed, and minor injuries
4. Training: Clarify whether the company has given correct work instructions to the construction staff
5. Experience: Clarify whether the construction personnel have experience in the same kind of work
6. Equipment: Clarify whether safety equipment is provided, whether safety equipment is used, and whether safety equipment is working normally
7. Safety program: Clarify whether the general contractor has developed a written safety plan, including safety rules, contractor safety plan, subcontractor responsibilities, roof subcontractor’s understanding statement, subcontractor agreement, fall protection plan and site safety checklist. When the incident happened, did the general contractor start the fall protection training plan.

## **Step 3. Conceptualization**

This study sought to analyze the content of 60 High-altitude Falling incident investigations that occurred in the Construction Industry and was published in the U.S. NIOSH Fatality Assessment and Control Evaluation (FACE) Program to identify and understand the common precursors and root causes of fatal fall events in construction.

The variables to be evaluated in the investigation report were related to immediate causes, root causes and SIF precursors.

1. **Immediate Cause -** refers to the reasons that directly promoted the occurrence and development of things and directly contributed to their changes. It referred to the recent surface phenomena that cause the development and changes of things. It generally analyzed the closest factors in time relationship or logical relationship without going through intermediate things and intermediary links
2. **Root Cause -** refers to the root cause or the essential reason for the change of things. It referred to the most important reason that plays a key and decisive role among the many reasons for the development and change of things.
3. **SIF Precursors -** a high-risk situation in which management controls were either absent, ineffective, or not complied with, and which would result in a severe or fatal injury if allowed to continue (Martin & Black, 2015).

Modern causation theory held that SIF was more accurately attributed to precursors; Operating conditions in the workplace may lead to SIF because of its inherent risk (manuele, 2008) (Krause & Murray, 2017) described SIF precursors as events with the following characteristics: process instability, major process chaos, unexpected maintenance, unexpected changes, high potential work, and emergency shutdown procedures. For example, events such as mobile equipment operation / interaction with pedestrians, confined space entry, tasks requiring lock out / tag out, lifting operations, work at height and manual hauling may be precursors of SIF. In addition, Cooper (2019) found that 90% of potential SIF events in construction operations are related to daily conditions.

Another component of SIF precursors that government investigators may ignore was to assess organizational and individual risks. The organizational risk model developed by the United Kingdom (AEON, 2001) established an organizational risk framework, including the following factors: personal factors, training / competence, procedures, planning and coordination, engineering design and preventive maintenance. An important component of organizational risk was affected by the safety environment or culture. The organization's safety culture had a significant impact on both organizational and individual risk decisions. (Patel & JHA, 2016).

By evaluating the investigation report of NIOSH high-altitude fall, the study considered the identification mode of incident causality, identify the direct and root causes, and look for any signs indicating SIF precursors in the investigation text individually or organized.

## **Step 4. Operationalization**

This study sought to analyze the content of selected Severe Injury & Fatality investigation reports determining if NOISH compliance officer investigators applied to identify cases as meeting the criteria for Significant Incidents or Fatalities (SIF) precursors. The three main variables that were evaluated in the investigation reports related to the incident's immediate causes, root causes and SIF precursors. Within each fatality investigation document, there are two units of analysis. The incident's causes and SIF precursors. At the top of the page, enter the following meta-data: Coder ID**:** Indicated the identification value for the individual who coded the document. And Coding Date**:** Indicate the date of coding, using the convention mm/dd/yyyy.

**Coding Instructions (Variable Columns)**

1. **Investigation ID** (column 1):

Enter the unique investigation Identification number for the document being coded.

1. **Immediate Causes – Nominal** (column 2):

Definition - The final act in a series of provocations leading to a particular result or event, directly producing such result without the intervention of any further provocation.

Operations – Immediate Causes are identified in the description of the incident. There can possibly be more than one cause to an incident therefore the causes will be identified by I.C.1, I.C.2, I.C.3 …

Categories – Improper Position for Task, Using Equipment Improperly, Failure to Follow Procedure, Failing to Use PPE Properly, Inadequate Guards or Barriers.

Coder Instructions – Review the incident Description and Investigative data. Identify the immediate causes of the incident.

1. **Root Causes - Nominal** (column 3):

Definition - Root cause. A root cause was an initiating cause of a causal chain which leads to an outcome or effect of interest. In our study, the root cause was analyzed based on the immediate cause of the incident, which was the cause of the immediate cause.

Operations – Identify any of the following conditions(one incident can correspond to multiple root causes)

Categories –

(1) Incorrect guidance, orientation, and / or training：the enterprise's safety training for construction personnel was incorrect

(2) Incorrect physical and psychological stress tolerance : the psychological or physical stress of construction workers was greater than the maximum limit they could bear.

(3) Incorrect responsibility allocation: the company's allocation of responsibilities to the operators was incorrect.

(4) Incorrect monitoring of construction: the safety administrator's monitoring of the construction site was incorrect

(5) Incorrect standards, specifications and/or design criteria: there were loopholes or imperfections in the company's standards for construction

(6) Incorrect adjustment/repair/maintenance: there were no correct daily maintenance for the construction equipment

(7) Incorrect Tools and Equipment: the construction personnel did not use the correct construction tools and equipment

(8) Inadequate personal work experience: the construction operators did not have sufficient construction experience

1. **SIF Precursors** (column 4):

Definition - A SIF precursor was defined as a factor that caused a nonconformance and shall be permanently eliminated through process improvement. The SIF precursor was the core issue—the highest-level cause—that sets in motion the entire cause-and-effect reaction that ultimately leads to the problem(s).

Operations – Identify any of the following conditions. In our study, SIF precursors were determined according to root causes

Categories –

(1) Wrong personal behavior: Personal non-compliance with standards leads to incidents.

(2) Wrong organization management: the organization had defects in selecting construction personnel and formulating a training plan.

(3) Inadequate maintenance of mechanical equipment: the mechanical equipment used by the construction personnel was damaged, or the personal protective device was damaged, which cannot protect the construction personnel.

(4) Routine operations: before the incident, there was no improper situation.

(5) None - SIF Precursors not identified by the investigator.

## **Step 5. Coding Form**

A spreadsheet has been established to complete the establishment of direct causes, root causes and SIF precursors for each report for content analysis research. See *Table3.*

## **Step 6. Example**

Verify the feasibility of the research method. An incident report was selected for content analysis to verify the feasibility of the method. This is the website of the report used: https:/www.cdc.gov/niosh/face/pdfs/full201202.pdf

A spreadsheet has been established to show the data collection and coding scheme of the report. See *Table 4.*

## **Step 7. Pilot Coding determine reliability**

**Purpose**

Reliability assessment in a pilot study of the content under investigation was essential to the development of a valid, reliable, and useful coding scheme. It addressed all four threats to reliability outlined earlier, by allowing the following three diagnostic measures: 1. Identification of problematic measures: When a variable with poor reliability is identified in a pilot test, remedies include (a) further training and rechecking reliability, (b) rewriting coding instructions to clarify the measurement of the variable, (c) changing the categories of the variable (e.g., collapsing categories), and (d) splitting the variable into two or more simpler or more concrete (more manifest) variables.

**Method**

In our project, we use Cohen’s kappa (κ) to Test our results. This statistic was planned as an improvement over pi, taking into account the differences in coders’ distributions by using a multiplicative term instead of an additive one (Cohen, 1960). Since its introduction, numerous adaptations of this agreement coefficient have been proposed (Banerjee et al., 1999; Falotico &amp; Quatto, 2015; Hsu &amp; Field, 2003; Kraemer, 1980). Like pi, it assumes nominal-level data and has a typical range from 0.00 (agreement at chance level) to 1.00 (perfect agreement), and a value of less than 0 again indicates agreement less than chance. In our project, Cohen's kappa value is greater than 0.75, which means it can pass the reliability test. The formula was as follows:

 Equation 4

**Subsample size**

10% of the sample size, subsample size is 6.

## **Step 8. Final Coding form**

**Conduct Actual Coding Process of Data set**

Our research group has made the table of coding form for data set coding. Next, Our research group encoded the 60 samples randomly sampled. Each person read the 60 randomly selected reports to determine the most appropriate code. This experiment had three different variables. Each variable was encoded by two people.

A spreadsheet has been established to show Content Analysis of Selected NIOSH Fatality Investigations. See *Table 13*.

**Secondary analysis of different codes**

After coding, Our research group processed the data and count the number of the same and different report types judged by the two people in charge of coding. The next step was to analyze the reasons why they judged the different results of the same report and discuss a reasonable result together.

**Variable result sorting**

After coding, our group counted the number of three groups of variables for subsequent data analysis. See *Table 14.*

# Methods of Analytical Hierarchy Process

## **Method Overview**

In the study of the first problem, the immediate causes and root causes in 60 construction fall indications were obtained through the coding scheme, and analyze the SIF precursors corresponding to each root cause.. In order to obtain a complete SIF precursors model, which included the type of SIF precursors, the corresponding root causes and the correlation coefficient of each root cause, our research group used Analytical Hierarchy Process (AHP) for research. Using Analytic Hierarchy Process, calculate the weight coefficient between common root causes and falling incidents obtained in the first research question, that is, study the correlation between root causes and falling incidents. The greater the weight coefficient, the greater the correlation. The data support of establishing the decision matrix was based on the results of the coding scheme obtained in the first research problem.

## **Model introduction**

AHP was a powerful tool for decision-making technique and had been delivered by Saaty, and developed a decision method for measuring the priorities of all alternatives according to the ratio scale. This tool’s approach depended on evaluating pairs’ options within pertinent criteria. This value compared the criteria consistent with their intensity and preferences. This tool was a procedure of evaluating options that met a selected group of criteria and goals. In the model, the correlation of each layer was based on the number of causes and precursors obtained in the coding scheme.

## **Step1. Structure the hierarchy**

Structure the hierarchy from the top (the objectives from a decision-maker’s viewpoint) through the intermediate levels (criteria on which sub-sequent levels depend) to the lowest level, which usually contains the list of alternatives. In analytic hierarchy process, it is usually divided into three layers: goal, criteria and alternative. In our study, the goal layer was construction fall incident, the criteria layer is SIF precursor, and the alternative layer is root causes. Our research group brought the SIF precursor and root causes obtained from the coding scheme into the hierarchical model and make the *Table 5*.

## **Step2. Construct judgment matrix**

The decision matrix showed the relative relationship between various parameters, and the constructed matrix was used for weight calculation in the next step. The judgment matrix between goal layer and criteria layer need to be constructed firstly, including the judgment matrix between the criteria layer and alternative layer. AHP pair wise comparison between two parameter scales： In the Figure 1, numbers represent the relationship between two parameters. For example, 1 represented that two parameters are equally important to the target, 3 represented that one parameter was slightly more important to the target than the other, and 2 was a level between 1 and 3.

The selection of rank scale was be based on the number of parameters obtained in the coding scheme. After completing the first research question, our research group completed the coding form to obtain the number of parameters in the construction fall incident report, including immediate causes, root causes and SIF precursors. In the establishment of judgment matrix at the same level, the selection of the rank scale of two parameters was based on the comparison of the number of these two parameters. Here, our research group built judgment matrix for the goal layer and criteria layer as an example. The *Table 6* was the number of SIF precursors we assume.

In the table 5, the number of wrong personal behaviors was significantly higher than that of inadequate maintenance of mechanical equipment. Choose rank scale 7 between the two parameters. The difference between the number of wrong organization management and the number of inadequate maintenance of mechanical equipment was 15, the number of wrong organization management was slightly more. Select rank scale 3 between the two parameters. There was a difference of 20 between the number of wrong personal behavior and the number of wrong organization management. Select rank scale 4 between the two parameters. According to the selected rank scale, the judgment matrix was established,which is the Table 7.

## **Step3. Weight calculation**

The weight calculation was based on the established decision matrix, and the decision matrix was brought into the formula to obtain the weight corresponding to each parameter. The software we used here was Matlab. The formula used is:

 Equation 1

where:

 is the value of the weight vector

is the values in the matrix, where i represents a row and j represents a column

Through calculation, the results were as follows:

Since what we finally wanted was the percentage of each parameter, the sum of the weight vector values of these three parameters should be 1, so the results were normalized. The formula is as follows:

 Equation 2

where:

 is the value of the weight vector

 is the standard weight vector

Through calculation, the results were 

After completing the judgment matrix between the goal layer and criteria layer, continued to establish the judgment matrix between the criteria layer and alternative layer according to the above steps, which should include three judgment matrices, because there were three parameters in the criteria layer. After obtaining the standard weight vectors of all parameters, the Table 8 of analytic hierarchy process results can be established.

## Step4. Consistency test

The consistency test was the last step of the method. The purpose was to test whether the previously calculated weight was reasonable. If the result can pass the consistency test, it indicates that the result was reasonable; otherwise, it indicated that the result was not reasonable. The final stage was to calculate a Consistency Ratio (CR) to measure how consistent the judgments have been relative to large samples of purely random judgements. If the CR was much in excess of 0.1 the judgements were untrustworthy because they were too close for comfort to randomness and the exercise was valueless or must be repeated. Therefore, the final result needs to meet the CR less than 0.1 in order to pass the consistency test. The formula is as follows

 Equation 3

where:

CR is consistency index

RI is the average random consistency index

λmax is maximum eigenvalue of judgment matrix

n is order of judgment matrix.

# Results

## **The first research question( Content Analysis) : Find common root causes of SIFs in the construction fall incidents.**

*The result of Step7.Pilot Coding*

Coding the subsamples with the sample size of 6, of which six incident reports were randomly selected from the database. Every two coders encoded the same report to obtain the coding results of three variables.

For variable 1 Immediate cause, the coding result of the six incident reports by the coder was 4, 4, 5, 5, 4, 2, while the coding result of the six incident reports by the other coder was 4, 4, 5, 3, 4, 2. See Table 15 for coding results. The two sets of data are imported into SPSS as two sets of variables, and the kappa coefficient was selected for calculation. The calculated kappa value was 0.75. Since the kappa value of the group was not less than 0.75, it had passed the reliability test. The calculation results are shown in Table 18. Two coders had the same understanding of the parameters in variable 1.

For variable 2 Root cause, the coding result of the coder on the six incident reports was 2, 7, 5, 1, 7, 1, while the coding result of the other coder on the six incident reports was 5, 7, 5, 1, 7, 1. See Table 16 for coding results. These two sets of data were imported into SPSS as two sets of variables, and kappa coefficient was selected for calculation. The calculated kappa value was 0.769. Since the kappa value of the group was not less than 0.75, it had passed the reliability test. The calculation results are shown in Table 19. Two coders had the same understanding of the parameters in variable 2.

For variable 3 SIF precursors, the coder coded the six incident reports as 2, 2, 3, 3, 1, 1, while the other coder coded the six incident reports as 2, 2, 3, 3, 2, 1. See Table 17 for coding results. The two sets of data were imported into SPSS as two sets of variables, and kappa coefficient was selected for calculation. The calculated kappa value was 0.75. The calculation results are shown in Table 20. Since the kappa value of the group was not less than 0.75, it had passed the reliability test. Two coders had the same understanding of the parameters in variable 3.

The kappa value obtained by the coders for the pilot coding of the three variables was greater than 0.75, so the result of the seventh step pilot coding belonged to the excellent agreement, and the eighth step final coding was allowed.

*Table 15 Pilot coding result of variable 1*

|  |  |  |
| --- | --- | --- |
| Variable 1: Immediate cause | | |
| Investigation title | Coder1 | Coder2 |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana | 4 | 4 |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina | 4 | 4 |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening | 5 | 5 |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina | 5 | 3 |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama | 4 | 4 |
| Hispanic Worker Dies After Fall From Step Ladder While Cleaning Windows - North Carolina | 2 | 2 |

*Table 16 Pilot coding result of variable 2*

|  |  |  |
| --- | --- | --- |
| Variable 2: root cause | | |
| Investigation title | Coder2 | Coder3 |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana | 2 | 5 |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina | 7 | 7 |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening | 5 | 5 |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina | 1 | 1 |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama | 7 | 7 |
| Hispanic Worker Dies After Fall From Step Ladder While Cleaning Windows - North Carolina | 1 | 1 |

*Table 17 Pilot coding result of variable 3*

|  |  |  |
| --- | --- | --- |
| Variable 3: SIF precursors | | |
| Investigation title | Coder3 | Coder4 |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana | 2 | 2 |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina | 2 | 2 |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening | 3 | 3 |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina | 3 | 3 |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama | 1 | 2 |
| Hispanic Worker Dies After Fall From Step Ladder While Cleaning Windows - North Carolina | 1 | 1 |

*Table 18 Kappa value of variable 1*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Value | Asymptotic standard error | Approx t | Approx Sig |
| Protocol measurement kappa | 0.75 | 0.198 | 0.087 | 0.002 |
| Number of effective cases | 6 |  |  |  |

*Table 19 Kappa value of variable 2*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Value | Asymptotic standard error | Approx t | Approx Sig |
| Protocol measurement kappa | 0.769 | 0.188 | 3.216 | 0.001 |
| Number of effective cases | 6 |  |  |  |

*Table 20 Kappa value of variable 3*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Value | Asymptotic standard error | Approx t | Approx Sig |
| Protocol measurement kappa | 0.75 | 0.218 | 2.714 | 0.007 |
| Number of effective cases | 6 |  |  |  |

*The result of Step 8 Final Coding Form*

After passing the first reliability test, the project proceeds to the final coding form. In this step, every two coders are responsible for the coding of one variable. A total of 180 data are recorded from 60 reports in NIOSH database. The records of each coder are filled in the form. See *table 13* for details.

In *Table 13*, not only has the immediate cause, root cause and SIF precursors of each incident, but also the letter "D". The reason for the letter "D" is that each coder records the responsible variable independently. Before the final result is obtained, the two coders responsible for the same variable will not communicate, so in the same report, two coders may have different opinions, which means that the letter "D" will appear at this time, representing different opinions. In this case, what need to do is to discuss with team members and choose the most reasonable reason to fill in the coding form. The letter "D" appears three times in the final coding form.

After recording the immediate cause in 60 incident reports, there were 5 incidents due to improper position for task,accounting for 8.33% of the total incident immediate causes, there were 1 incidents due to using equipment improperly,accounting for 1.67% of the total incident immediate causes, there were 14 incidents due to failure to follow procedure, accounting for 23.33% of the total incident immediate causes, there were 16 incidents due to failing to use PPE properly, accounting for 26 .67% of the total incident immediate causes, there were 24 incidents due to inadequate Guards or Barriers, accounting for 40% of the total incident immediate causes. Among them, the immediate cause causing the most falling incidents is inadequate guards or barriers, see *Table 14 (1).*

*Table 14(1) Results of recorded number of immediate causes*

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Parameter | Number | Percentage |
| Immediate cause | 1. Improper position for task | 5 | 8.33% |
| 2.Using equipment improperly | 1 | 1.67% |
| 3.Failure to follow procedure | 14 | 23.33% |
| 4.Failing to use PPE properly | 16 | 26 .67% |
| 5.Inadequate guards or barriers | 24 | 40% |

After recording the root cause in 60 incident reports, there were 25 incidents due to Incorrect guidance, orientation and / or training, accounting for 41.66% of the total incident root causes, there were 2 incidents due to incorrect physical and psychological stress tolerance, accounting for 3.33% of the total incident root causes, there were 3 incidents due to incorrect responsibility allocation, accounting for 5% of the total incident root causes, there were 1 incidents due to incorrect monitoring of construction, accounting for 1.67% of the total incident root causes, there were 10 incidents due to incorrect standards, specifications and/or design criteria, accounting for 16.67% of the total incident root causes, there were 5 incidents due to incorrect adjustment/repair/maintenance, accounting for 8.33% of the total incident root causes, there were 4 incidents due to incorrect Tools and Equipment, accounting for 6.67% of the total incident root causes, there were 10 incidents due to inadequate personal work experience, accounting for 16.67% of the total incident root causes. Among them, the root cause causing the most falling incidents is incorrect guidance, orientation and / or training, see *Table 14 (2).*

*Table 14(2) Results of recorded number of root causes*

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Parameter | Number | Percentage |
| Root cause | 1.Incorrect guidance, orientation and / or training | 25 | 41.66% |
| 2.Incorrect physical and psychological stress tolerance | 2 | 3.33% |
| 3.Incorrect responsibility allocation | 3 | 5% |
| 4.Incorrect monitoring of construction | 1 | 1.67% |
| 5.Incorrect standards, specifications and/or design criteria | 10 | 16.67% |
| 6.Incorrect adjustment/repair/maintenance | 5 | 8.33% |
| 7.Incorrect Tools and Equipment | 4 | 6.67% |
| 8.Inadequate personal work experience | 10 | 16.67% |

After recording the SIF precursors in 60 incident reports, there were 19 incidents due to wrong personal behavior,accounting for 31.67% of the total incident SIF precursors, there were 35 incidents due to wrong organization management,accounting for 58.33% of the total incident SIF precursors, there were 6 incidents due to inadequate maintenance of mechanical equipment,accounting for 10% of the total incident SIF precursors. Among them, the SIF precursors causing the most falling incidents was wrong organization management, see *Table 14(3)*.

*Table 14(3) Results of recorded number of SIF precursors*

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Parameter | Number | Percentage |
| SIF precursors | 1.Wrong personal behavior | 19 | 31.67% |
| 2.Wrong organization management | 35 | 58.33% |
| 3.Inadequate maintenance of mechanical equipment | 6 | 10% |
| 0.not addressed by investigator | 0 | 0 |

## **The second research question(Analytical Hierarchy Process): Study the correlation between root causes and falling incidents, get a complete precursor model.**

*The results of AHP on criteria layer*

According to the results of the three parameters of the variable SIF precursor obtained in the coding form, a decision matrix was established for this layer, and the relative relationship between the parameters was displayed in the matrix. After the establishment of the matrix, the next step was to use the computer to carry out weight calculation, and conduct consistency test on the obtained weight value. If it could pass the test, reasonable results could be obtained, and the next layer could be analyzed. The results of the three parameters of the variable SIF precursor are shown in *Table 18*, the decision matrix of criteria layer was shown in *Table 19*, the weight value of criteria layer was shown in *Table 20*.

The decision matrix was established according to the number of parameters of SIF precursor. For wrong organization management and unacceptable maintenance of mechanical equipment, the two parameters differ the most, so rank scale 7 was selected. For wrong organization management and wrong personal behavior, the difference between these two parameters was less than that of the previous group, so rank scale 3 was selected. After establishing the decision matrix according to the selected rank scale, the following plan was to calculate the matrix through the computer, and get the weight results: wrong organization management (0.705), wrong personal behavior (0.211), inverse maintenance of mechanical equipment (0.084). In the final consistency test, the calculated CR value was 0.0311, less than 0.1, so the weight result was reasonable.

*Table 18 Results of the three parameters of the variable SIF precursor*

|  |  |
| --- | --- |
| Criteria(SIF precursors) | Number |
| Wrong personal behavior | 19 |
| Wrong organization management | 35 |
| Inadequate maintenance of mechanical equipment | 6 |

*Table 19* *The decision matrix of criteria layer*

|  |  |  |  |
| --- | --- | --- | --- |
|  | Inadequate maintenance of mechanical equipment | Wrong organization management | Wrong personal behavior |
| Inadequate maintenance of mechanical equipment | 1 | 1/7 | 1/3 |
| Wrong organization management | 7 | 1 | 4 |
| Wrong personal behavior | 3 | 1/4 | 1 |

*Table 20 The weight value of criteria layer( computer result )*

|  |  |  |
| --- | --- | --- |
| **Variables** | **Geometric mean** | **Weight** |
| A1-Inadequate maintenance of mechanical equipment | 0.3624601243342974 | 0.08414414848170168 |
| A2-Wrong organization management | 3.0365889718756622 | 0.704936008606964 |
| A3-Wrong personal behavior | 0.9085602964160698 | 0.21091984291133417 |

*Consistency test of criteria layer：*





*The results of AHP on alternative layer( Parameters 2, 7, 8)*

According to the results of parameters 2, 7 and 8 of the variable root cause obtained in the coding form, a decision matrix was established for this layer, and the relative relationship between the parameters was displayed in the matrix. After the establishment of the matrix, the next plan was to use the computer to carry out weight calculation, and conduct consistency test on the obtained weight value. If it could pass the test, reasonable results could be obtained, and the next layer could be analyzed. The results of parameters 2, 7 and 8 of variable root cause are shown in *Table 21*, the decision matrix of parameters 2, 7 and 8 was shown in *Table 22*, and the weight value of parameters 2, 7 and 8 was shown in *Table 23*.

The decision matrix was established according to the number of parameters 2, 7 and 8 of root cause. There was a big difference between the number of inadequate personal work experience and incorrect physical and psychological stress tolerance, so rank scale 7 was selected. For incorrect physical and psychological stress tolerance and incorrect tools and equipment, the number difference between them was only two, and the difference was small, so rank scale 2 was selected. For inadequate personal work experience and incorrect tools and equipment, rank scale 5 was selected. After establishing the decision matrix according to the selected rank scale, the subsequent work was calculate the matrix through the computer, and get the weight results（The total weight was 0.211）: Inadequate personal work experience（0.156），Incorrect Tools and Equipment（0.035），Incorrect physical and psychological stress tolerance（0.020）. In the final consistency test, the calculated CR value was 0.0136, less than 0.1, so the weight result was reasonable.

*Table 21 Results of parameters 2, 7 and 8 of variable root cause*

|  |  |
| --- | --- |
| Criteria(SIF precursors) | Number |
| Incorrect physical and psychological stress tolerance | 2 |
| Incorrect Tools and Equipment | 4 |
| Inadequate personal work experience | 10 |

*Table 22 Decision matrix of parameters 2, 7 and 8*

|  |  |  |  |
| --- | --- | --- | --- |
|  | Incorrect physical and psychological stress tolerance | Incorrect Tools and Equipment | Inadequate personal work experience |
| Incorrect physical and psychological stress tolerance | 1 | 1/2 | 1/7 |
| Incorrect Tools and Equipment | 2 | 1 | 1/5 |
| Inadequate personal work experience | 7 | 5 | 1 |

*Table 23 Weight value of parameters 2, 7 and 8( computer result)*

|  |  |  |
| --- | --- | --- |
| **Variables** | **Geometric mean** | **Weight** |
| A1-Incorrect physical and psychological stress tolerance | 0.41491326668312173 | 0.09381265072730688 |
| A2-Incorrect Tools and Equipment | 0.7368062997280773 | 0.16659325598971333 |
| A3-Inadequate personal work experience | 3.2710663101885897 | 0.7395940932829799 |

*Consistency test of criteria layer：*





*The results of SIF precursor model*

In the above steps, the weight values of various parameters in the variables SIF precursor and root cause were calculated respectively. The purpose of this step was to sort out the obtained weight values into a tree view for intuitive observation. Among them, the parameter of SIF precursor with the largest weight was wrong organization management, and the weight value was 0.705, which indicates that wrong organization management was the most relevant SIF precursor of construction falling incidents. The root cause with the largest weight was incorrect guidance, orientation and / or training, and the weight value was 0.558, which indicated that among all the common root causes listed, root cause was incorrect guidance, orientation and / or training, which was the most relevant omen of construction falling incidents. See Figure 2.

*Figure 2 Tree view of construction falling incidents*

Construction falling incident

Wrong personal behavior (0.211)

Inadequate maintenance of mechanical equipment (0.084)

Wrong organization management(0.705)

Incorrect standards, specifications and/or design criteria（0.063）

Inadequate personal work experience（0.156）

Incorrect guidance, orientation and / or training（0.558）

Incorrect adjustment/repair/maintenance（0.021）

Incorrect Tools and Equipment（0.035）

Incorrect responsibility allocation（0.09）

Incorrect physical and psychological stress tolerance（0.020）

Incorrect responsibility allocation（0.09）

# Discussion and Conclusion

## Summary of Findings

## Falling incidents are the main cause of casualties in construction.This paper started with the analysis of the causes of falling from height in construction. Using the content analysis method, this paper analyzed the personnel falling incidents in NIOSH database, found out immediate causes and their corresponding SIF precursors, and put forward the common root causes of SIF in construction falling events. Then, combined with the analytic hierarchy process, the causes of falling from height were divided into different factors, the weight of each factor was calculated, so as to pointed out the key elements for the prevention of falling from height in the construction of high-rise buildings.

According to the previous AHP analysis, the three SIF precursors of high-rise building construction are Wrong personal behavior, Wrong organization management, and Inadequate maintenance of mechanical equipment. Wrong organization management ranks first(0.705) and is the biggest SIF precursor of production safety incidents. Among the eight root causes selected in this study, incorrect guidance, orientation and / or training(0.558) accounts for more than the sum of the other seven root causes. Illegal command, illegal operation, and violation of operating procedures are mostly caused by poor construction management and weak safety awareness of employees. Therefore, strengthening the safety training of construction personnel and strengthening the safety management of the site is one of the important means to prevent such incidents. Only by deeply carrying out safety standardization management and seriously implementing the current safety technical standards, specifications and procedures, can we effectively reduce and avoid the occurrence of falling incidents from height.

## Significance and Recommendations

Measures to strengthen internal management of the construction company

1. Strengthen the management of safety supervisor. Many accident reports show that the construction company did not assign a safety supervisor to conduct safety inspection on the construction site, resulting in the failure to identify the fall hazard. In addition, during the construction of workers, the company did not arrange a safety supervisor on the site, resulting in the lack of guarantee for the safety of construction personnel. Therefore, the construction company needs to clarify the company's management structure to ensure that each construction project is assigned a safety supervisor. For example, information management can be adopted, and the specific personnel of each construction project can be listed in detail on the company's website, including construction project manager, safety supervisor and workers. Ensure that the safety supervisor knows which project he is responsible for, so that the safety supervisor can carry out safety inspection on the construction site in advance.
2. Strengthen the management of construction area. Many accident reports show that although the safety supervisor reported the potential hazards of the construction area to the company after inspecting, the company did not prohibit workers from construction, this resulting in falling accidents. Therefore, the construction company needs to pay attention to the management of the construction area and close the potentially dangerous construction area. If worker must be carried out in the identified hazardous area, the protective measures must be implemented according to the requirements of the safety supervisor. This can also adopt information management. After the safety supervisor reviews the construction area, the potential hazards can be uploaded to the website in time to ensure that the project manager and workers can see them.

Measures to strengthen guidance and training

1. Strengthen the training of safety supervisors. In many accident reports, it is indicated that the safety supervisor did not review the safety expertise of the workers and directly asked the workers to work. And at the construction site, some safety supervisors did not correct the workers who did not wear protective measures according to the safety plan, resulting in accidents. Therefore, employers need to strengthen the training of safety supervisors, so that safety supervisors can guarantee the safety of workers as required, and reduce the risk of slacking off and evading responsibility.
2. Improve the safety plan. Although many construction companies have safety plans, they are not complete because they do not include fall prevention plans. Therefore, the company needs to improve its safety plan before carrying out construction projects. For the part of fall prevention plan, it needs to be prepared in accordance with 29 CFR 1926.500. This Code covers the requirements and standards for fall protection in construction workplaces.

*Limitations*

Based on the research results of other scholars' incident cause analysis, this paper studied the SIF precursors that fall from high places in building construction, and also proposed corresponding control measures. However, limited by the research conditions and the author's academic level, there are some deficiencies in the research, which mainly focus on the following aspects:

1. The effective index of the cause of falling from a height in this paper was based on the incident data, and the content analysis method was used to screen the index, but the index still needs to be verified in engineering practice to verify the operability of the index.
2. This paper selected 60 falls from heights that occurred in 1991-2012 from the NOISH database for the research on building construction fall from heights as research samples. The selection of samples has certain limitations.
3. This paper only started with the SIF precursor with a higher incidence, and proposed corresponding countermeasures. Due to the limitation of time and energy, most of the representative SIF precursors in the building fall incident were used in this paper, and many influencing factors were not included in the scope of investigation.

*Expectation*

In the process of research, many problems that can be further studied have been found. It is hoped that this paper can help other scholars to form new ideas and promote in-depth research on Fall Fatalities in Construction. The following lists the problems that can be further studied:

1. On the premise of sufficient resources and time, it is suggested to consider adding all the factors that may cause Fall Fatalities in Construction to the verification, redesign the questionnaire, and then distribute it to different types of work and managers to complete the preliminary data collection part, More construction site data will be collected as observation samples for analysis. In the questionnaire analysis, a comparative analysis can be carried out, and then the difference between the influencing factors can be drawn.
2. The selection and correlation analysis of the most ideal SIF precursors was based on quantitative analysis based on objective data. Due to the lack of relevant data at present, there are too many subjective factors based on the professional quality of experts. A lot of research and exploration are still needed to realize the qualitative leap from subjective analysis to objective judgment, and for the research on Fall Fatalities in Construction, this is also a future development direction in this field.
3. Due to the risk of falling incidents and the lack of awareness of prevention and control during construction, safety incidents in high-altitude construction operations occur frequently. Therefore, explore a practical and operable high-rise building construction safety risk analysis method and prevention and control measures applied to high-rise building construction, so as to effectively reduce the safety incidents and losses caused by safety incidents in high-rise building construction. It was also hoped that the research results of this paper can give full play to its advantages and popularize the risk early warning and prevention and control measures of falling incidents.

**Reference**

[1]. Li, Shanhua.(2020). Causes and Preventive Countermeasures of falling from height in construction safety management. *Housing and Real Estate,*Pages 144-144.

Retrieved from: http://www.lib.swjtu.edu.cn/asset/detail/0/2031016408311

[2]. R, Arifuddin .,R ,U, Latief .,A ,Suraji.(2020).An investigation of fall incident in a high-rise building project .*IOP Conference Series: Earth and Environmental Science ,*Volume 419, No. 1, 2020.

Retrieved from: http://www.lib.swjtu.edu.cn/asset/detail/0/203880602017

[3]. Donald K, Martin.,& Alison A,Black.(2015).Preventing Serious Injuries & Fatalities

Study Reveals Precursors & Paradigms. *Professional Safety,Volume 60, Issue 09.*

[4]. Ren, Chuanjun.(2014).Cause analysis and Prevention Countermeasures of falling incidents in building construction.*Construction Safety,*Volume 29, issue 3, pages 16-19.

Retrieved from: http://www.lib.swjtu.edu.cn/asset/detail/0/203110427356

[5]. Deng, Hang., Pang, Qizhi., Zhu,Deying.,Jing, Guihua., Zhang ,Xia.(2010). Analysis and Countermeasures About Falling incidents of Architecture Construction.*Industrial Safety and Environmental Protection,*Volume 36 No. 4 page: 57-59.

Retrieved from: http://www.lib.swjtu.edu.cn/asset/detail/0/203157889414

[6]. Jia, Xiaoshan., Dong, Yu.,Zhang ,Yu., Yu ,Anqi.(2017).Analysis of falling incidents in building construction based on FTA and AHP.*Construction Safety,*Volume 32, issue 10, pages: 37-40.

Retrieved from: http://www.lib.swjtu.edu.cn/asset/detail/0/203269647132

[7]. Yu ,Jiguang.(2013).Cause analysis and preventive measures of falling incidents from height.*Construction Safety,*Volume 28, issue 5, page 49-51.

Retrieved from: http://www.lib.swjtu.edu.cn/asset/detail/0/20361191512

[8]. Cooper, M. Dominic.(2019).The efficacy of industrial safety science constructs for addressing serious injuries & fatalities (SIFs). *Safety Science,* Volume 120 pages: 164-178.

Retrieved from: http://www.lib.swjtu.edu.cn/asset/detail/0/203705912758

[9]. Thomas R, Krause Ph.D.,&Glenn, Murray.(2012).On the Prevention of Serious Injuries and Fatalities.Session No. 564

[10]. FredA,Manuele.(2008).Serious,Injuries&Fatalities,A call for a new focus on their prevention.*Safety Management,Volume 53, Issue 12*

Retrieved from: https://onepetro.org/PS/article-abstract/33228/Serious-Injuries-amp-Fatalities-A-Call-For-a-New?redirectedFrom=fulltext

[11]. Nordlof, Hasse., Wiitavaara, Birgitta., Winblad, Ulrika., Wijk, Katarina.,Westerling, Ragnar. (2015)Safety culture and reasons for risk-taking at a large steel-manufacturing company: Investigating the worker perspective .*Safety Science ,*Volume 73 pages: 126-135

Retrieved from: http://www.lib.swjtu.edu.cn/asset/detail/0/20390772022

[12]. Cooper, M. D. (2019). The efficacy of industrial safety science constructs for addressing serious injuries & fatalities (SIFs). In Safety Science (Vol. 120, pp. 164–178). Elsevier B.V.

Retrieved from: https://doi.org/10.1016/j.ssci.2019.06.038

[13].Éien, K. (2001). A framework for the establishment of organizational risk indicators.

Retrieved from: www.elsevier.com/locate/ress

[14]. Krause, T. R., & Murray, G. (2017). On the Prevention of Serious Injuries and Fatalities. Retrieved from: http://data.bls.gov/timeseries/FIUOOX00000080N00

[15]. Manuele, F. (2008). Serious Injuries and Fatalities. Professional Safety, 53(12), 32–40.

Retrieved from: https://doi.org/11/30/2019

[16]. Martin, D. K., & Black, A. (2015). Serious Injuries & Fatalities. Safety Management, September, 35–44.

[17]. Patel, D. A., & Jha, K. N. (2016). Evaluation of construction projects based on the safe work behavior of co-employees through a neural network model. Safety Science, 89, 240–248.

Retrieved from: <https://doi.org/10.1016/j.ssci.2016.06.020>

# Appendix

Table 1 Data Collection Table

[https://docs.google.com/spreadsheets/d/13bBDP\_TUWBHSmLhNpmdOVfFivnLpqICYCdquYp\_0tM/edit](https://docs.google.com/spreadsheets/d/1-3bBDP_TUWBHSmLhNpmdOVfFivnLpqICYCdquYp_0tM/edit)

Table 2 Classification of the root causes about the SIF precursors

|  |  |  |
| --- | --- | --- |
| Goal | SIF Precursors | Root causes |
| Construction  Falling incident | Wrong personal behavior | Incorrect physical and psychological stress tolerance |
| Incorrect Tools and  Equipment |
| Inadequate personal work experience |
| Wrong organization  management | Incorrect guidance, orientation and / or training |
|  | Incorrect responsibility allocation |
| Incorrect monitoring of construction |
| Inadequate maintenance of mechanical equipment | Incorrect standards, specifications and/or design criteria |
| Incorrect adjustment/repair/maintenance |

Table 3 Coding Form - Content Analysis of Selected NIOSH Fatality Investigations

https://docs.google.com/spreadsheets/d/1-M3sT6Wv7U1vhkeSwK7ahS

QPXHGp7rZX19iX9TlXwc/edit

Table 4 Content Analysis Example

<https://docs.google.com/spreadsheets/d/1bQs__qWa6MIIo1PdiYKuPRaapVVhgTFI9ZdmHiIlFs0/edit>

Table 5 Coding Form-Content Analysis of Selected NIOSH Fatality Investigations

https://docs.google.com/spreadsheets/d/10FcsOs7xkjZoBQoOVDWNaQFYoJhQxYc0c97wBXUHdw0/edit

Table 6 Parameter table of each layer

|  |  |  |
| --- | --- | --- |
| Goal | Criteria | Alternative |
| Construction falling incident | Wrong personal behavior | Incorrect physical and psychological stress tolerance |
| Incorrect Tools and Equipment |
| Inadequate personal work experience |
| Wrong organization management | Incorrect guidance, orientation and / or training |
| Incorrect responsibility allocation |
| Incorrect monitoring of construction |
| Inadequate maintenance of mechanical equipment | Incorrect design criteria |
| Incorrect adjustment/repair/maintenance |

Table 7 Number of SIF precursors

|  |  |
| --- | --- |
| Criteria(SIF precursors) | Number |
| Wrong personal behavior | 45 |
| Wrong organization management | 20 |
| Inadequate maintenance of mechanical equipment | 5 |

Table 8 Judgment Matrix

|  |  |  |  |
| --- | --- | --- | --- |
|  | Inadequate maintenance of mechanical equipment | Wrong personal behavior | Wrong organization management |
| Inadequate maintenance of mechanical equipment | 1 | 1/7 | 1/3 |
| Wrong personal behavior | 7 | 1 | 4 |
| Wrong organization management | 3 | 1/4 | 1 |

Table 9 Analytic hierarchy process result

|  |  |  |  |
| --- | --- | --- | --- |
| Goal | Criteria | Alternative | |
| Type | Weight |
| Construction falling incident | Wrong personal behavior（0.7049） | Incorrect physical and psychological stress tolerance | 0.0661 |
| Incorrect Tools and Equipment | 0.1174 |
| Inadequate personal work experience | 0.5213 |
| Wrong organization management（0.2109） | Incorrect guidance, orientation and / or training |  |
| Incorrect responsibility allocation |  |
| Incorrect monitoring of construction |  |
| Inadequate maintenance of mechanical equipment（0.0841） | Incorrect design criteria |  |
| Incorrect adjustment/repair/maintenance |  |

Table 10 Coder of variable 1

|  |  |  |
| --- | --- | --- |
| Variable 1: Immediate cause | | |
| Investigation title | Coder | Coder |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana |  |  |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina |  |  |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening |  |  |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina |  |  |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama |  |  |
| Hispanic Worker Dies After Fall From Step Ladder While  Cleaning Windows - North Carolina |  |  |

Table 11 Coder of variable 2

|  |  |  |
| --- | --- | --- |
| Variable 2: Root cause | | |
| Investigation title | Coder | Coder |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana |  |  |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina |  |  |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening |  |  |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina |  |  |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama |  |  |
| Hispanic Worker Dies After Fall From Step Ladder While  Cleaning Windows - North Carolina |  |  |

Table 12 Coder of variable 3

|  |  |  |
| --- | --- | --- |
| Variable 3: SIF precursor | | |
| Investigation title | Coder | Coder |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana |  |  |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina |  |  |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening |  |  |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina |  |  |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama |  |  |
| Hispanic Worker Dies After Fall From Step Ladder While  Cleaning Windows - North Carolina |  |  |

Table 13 Final coding table

[coding form - Final.xlsx](file:///D:\qq下载\coding%20form%20-%20Final.xlsx)

*Table 14(1) Results of recorded number of immediate causes*

|  |  |  |
| --- | --- | --- |
| Variable | Parameter | Number |
| Immediate cause | 1. Improper position for task | 5 |
| 2.Using equipment improperly | 1 |
| 3.Failure to follow procedure | 14 |
| 4.Failing to use PPE properly | 16 |
| 5.Inadequate guards or barriers | 24 |

Table 15 Pilot coding result of variable 1

|  |  |  |
| --- | --- | --- |
| Variable 1: Immediate cause | | |
| Investigation title |  |  |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana | 4 | 4 |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina | 4 | 4 |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening | 5 | 5 |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina | 5 | 3 |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama | 4 | 4 |
| Hispanic Worker Dies After Fall From Step Ladder While  Cleaning Windows - North Carolina | 2 | 2 |

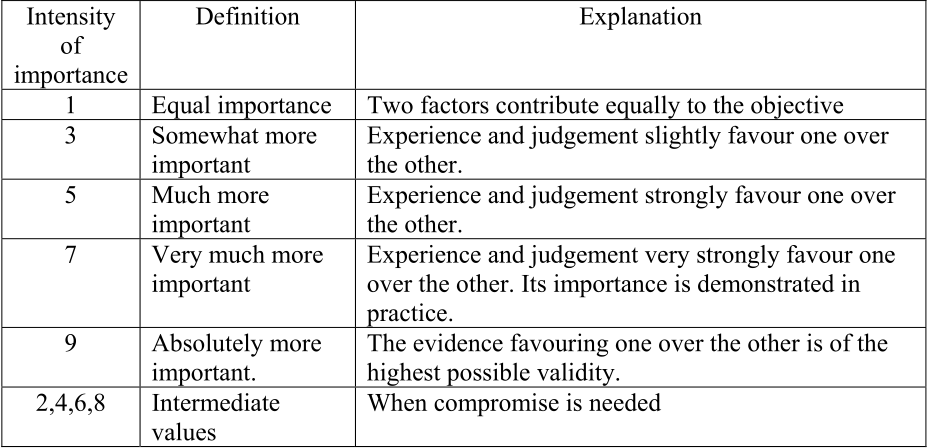
Table 16 Pilot coding result of variable 2

|  |  |  |
| --- | --- | --- |
| Variable 2: root cause | | |
| Investigation title |  |  |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana | 2 | 5 |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina | 7 | 7 |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening | 5 | 5 |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina | 1 | 1 |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama | 7 | 7 |
| Hispanic Worker Dies After Fall From Step Ladder While  Cleaning Windows - North Carolina | 1 | 1 |

Table 17 Pilot coding result of variable 3

|  |  |  |
| --- | --- | --- |
| Variable 3: SIF precursors | | |
| Investigation title |  |  |
| Labor Foreman Falls to His Death Inside Municipal Water Tank in Indiana | 2 | 2 |
| Carpenter Dies Following an 11-foot Fall from a Roof in North Carolina | 2 | 2 |
| Ironworker Dies in Ohio Following a 20-foot Fall Through a Skylight Opening | 3 | 3 |
| Tower Erector/Inspector Dies after Falling 200 Feet from Telecommunications Tower to the Ground -- North Carolina | 3 | 3 |
| A 16-year-old Died After Falling 27 Feet at a Residential Construction Site - Alabama | 1 | 2 |
| Hispanic Worker Dies After Fall From Step Ladder While  Cleaning Windows - North Carolina | 1 | 1 |

Figure 1 Rank scale



Equation 1



Equation 2



Equation 3



Equation 4

