STRATEGY FOR MANAGING FACTORS INFLUENCING SAFETY HAZARDS ON CONSTRUCTION SITES: A SYSTEM DYNAMICS APPROACH

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

in

Construction Engineering & Management

by

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This is to certify that the thesis titled

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has been accepted towards the partial fulfillment of

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THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by Mr. Syed Muhammad Taimur Shah, Registration No. NUST2019-MSCE&M00000319155, of National Institute of Transportation (NIT) – SCEE has been vetted by the undersigned, found complete in all respects as per NUST Statuses / Regulations, is free of plagiarism, errors, and mistakes, and is accepted as partial fulfillment for the award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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DEDICATED

TO

MY PARENTS, TEACHERS AND SISTERS!

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ABSTRACT

Safety-related hazards have gotten a lot of attention in the previous few decades, especially on construction sites. There hasn't been a well-defined, reliable, efficient, and thorough measuring model for safety hazard evaluation and/or minimizing construction cost, duration, and ensuring the safety of construction workers until now. Previous studies have been conducted to identify construction site safety concerns and design appropriate models to mitigate them. There has been insufficient study on dynamic simulation models leveraging VENSIM® software to explicate the basic processes of safety hazard assessment and decreasing hazards at construction sites, notably in worker behavior, managerial, environmental, and technology challenges. These components interact in a variety of ways, resulting in both positive and negative feedback loops that influence safety hazards, resulting in increased complexity. The goal of this research is to look at the elements that influence safety hazards on construction sites in developing countries, and then develop a System Dynamics (SD) model to deal with the complexity. Using systems thinking and causal loop diagrams, the study demarcates the interrelationships between sixteen nominated contributing factors. CLD consisted of five reinforcing and two balancing loops in total. In addition, CLD was employed/used to create an SD model with five stocks. To depict the cumulative/collective effect of all stocks, a new stock termed safety hazards was added/incorporated. The model was run for five years, and the findings/conclusions showed an increase in safety hazards under the specified scheme. The CLD and SD models that emerge represent the systems thinking and behavior for safety hazards in construction throughout time. The study uses an innovative methodology in the form of SD to address the construction culture coherently/holistically, as well as the factors influencing safety hazards and complexities of behavior that make up the causal relationship that are responsible for repercussions. Incorporating a policy framework in light of the created model to regulate the safety hazards on construction sites can be studied in further depth.

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List of Acronyms

- ACM Accident Causation Model
- GDP Gross Domestic Product
- PPE Personal Protective Equipment
- CP Construction Project
- PPP Public Private Partnership
- MCP Mega Construction Project
- RII Relative Importance Index
- CLD Causal Loop Diagram
- SFD Stock and Flow Diagram
- BOT Behavior Over Time
- SD System Dynamics

1. INTRODUCTION

Safety-related hazards along with high incident rates are considered the common issues of the construction industry(Xu et al., 2020). These safety problems at construction sites are mostly associated with the insecure behavior of construction labor on site along with managerial and technological issues (Xu & Zou, 2021). Understanding the causes of hazardous behaviors requires a thorough examination of worker behavior. Because of the particular intensity and extent of accidents in the construction industry, safety is a significant issue for various stakeholders in construction projects (Akroush et al., 2017). There are a number of safety metrics that have progressed through time in addition are used by way of measuring tools for safety performance; these metrics may be categorized as either lagging or leading indicators. Leading aspects are considered metrics connected with preventive behavior, whereas lagging indicators are aligned to the result of an accident (Toellner, 2001). Many studies have found out that a risk-based study is a crucial approach to the management and deterrence accidents (Nabi et al., 2020). Accident causation theory demonstrated that several interlinked factors influencing hazards lead to safety accidents. Furthermore, these factors do not remain constant and independent during the construction period; rather, they remained to change and interact with one another continuously (Li et al., 2018). Although, as (Hallowell et al., 2011; XU et al., 2021) pointed out, a few of these previous studies failed to take into account the associations among factors leading to hazards, and accordingly miscarried to forecast the well-being state in a flexible and integrated manner. Generally, investigating the causes of unsafe behavior of workers is difficult to predict because it varies from worker to worker. Additionally, the hazard factors related to technology and managerial aspects are needed to investigate interconnection with worker behavior against any specific hazard. In order to effectively manage factors influencing safety hazards, a broader understanding of the primary hazard framework in mega construction projects is thus required (Xu & Zou, 2021). Therefore, the chief motive of this investigation / study is to modify a system dynamic model to formalize causal interrelationships among the safety management aspects such as human, organizational, environmental and technical. These are the major aspects that are responsible for the safety situation at worksites of constructional industry. Subsequently, the system dynamic model using VENSIM® software will be implemented to investigate safety of the construction labors by demonstrating the operating way of the construction industry (Li et al., 2017). According to previous studies, system dynamics (SD) is a form of qualitative modelling technique that emphasizes the use of both qualitative and quantitative research. Deep scrutiny of system during the modelling process will provide a clear picture of the system's internal structure and conduct, which is an important tool for solving similar problems in complex systems. Traditional approaches and technologies are incapable of efficiently identifying and managing project hazards because of the project risk's fluctuating complexity. Therefore, through use of system dynamic methods in the management of project hazards is thus obvious, particularly in the risk dynamic difficulty of a pre-engineered construction project(Li et al., 2017) . In present study, cellular-based mechanization will be presented to investigate the effect of the hazards on worker's behavior, and thus, to examine safety hazards being emergent conduct. Finally, the model will comprise interaction between managerial issues along with the environmental circumstances and goals to assist as an instrument for the modeling of numerous new projects and administrative decisions.

1.1 Level of Research Already Carried Out on the Proposed Topic

The construction industry mainly focuses on the project's cost, timeline, and worth as vital components to assess the achievement level, especially in Pakistan. That's why safety and health-related facets are badly unkempt and seen as unmentionable or taboo topics in most industries (Williams et al., 2018). The leading cause of the coincidences at construction workplaces is needed to identify practical measures to alleviate or minimize such casualties from happening in the coming future.

Considering the damaging aspects of accidents, numerous theories have been created by the researchers recognized as the Accidents Causation Model (ACM) described that there is a cause behind every accident (Jasni et al., 2019). The first phase of ACM was described by Heinrich (1959) with a "Domino Theory" which explained that any manager could be affected by the following five consecutive factors 1) domino effect starts with the lineage or physical environment, 2) worker carefulness, 3) unsafe behavior or mechanical or physical situation, 4) followed by cause of the accident, 5) resulted in an injury (Hosseinian & Torghabeh, 2012). The Functional Resonance Accident Model is the most recent ACM upgrade or model (Salmon et al., 2011), which stated that numerous accident causing factors along with appropriate information needs to be identified for the alleviation of the accidents in coming future.

Over time, there are numerous safety metrics, including leading and lagging, that are involved and considered measuring instruments for safety management and performance. Among both safety metrics, lagging indicates the result of an accident while, leading indicates the possible dimensions correlated to defensive actions (Akroush et al., 2017).

Moreover, lagging indicators are the conventional capacity methods for safety management given seal of approval by Occupational Safety and Health Administration (OSHA). OSHA safety assessment indicators comprise; 1) experience modification rate on workers' compensation, 2) recordable injury rate, 3) transfer injury rate (Toellner, 2001). Alternatively, leading indicators as an effective substitute for lagging-indicators helped improve safety performance at construction sites. Commonly, leading indicators cover areas including safety planning, credits for safe behavior and accident evaluation, management commitment to safety culture along safety-related directions and exercises (Nabi et al., 2020).

The construction industry has been ranked above the nonfatal occupational injuries and illness by the Bureau of Labor Statistics (Konda et al., 2016). The main contributor to the total costs is the construction-related injuries for both constructors and owners. Generally, the cost of construction projects has been increased day by day because of increased costs of life and health insurance, healthcare, and increased incidence of court cases of construction workers on sites. Thus, both owner's and contractors' combined interest is to plan appropriate safety measures during all stages of construction. The present study may help both owners and constructors simulate construction safety behavior to recognize better the causing aspects of safety incidents on construction sites.

1.2 Problem Statement

During the last several decades, safety-related hazards have attained intensive consideration specifically at construction sites. Up to now, there is a lack of a well-described, reliable, efficient, and comprehensive measuring model regarding safety hazard assessment and/or to minimize construction cost, duration, and to ensure construction workers' safety. Previous researchers have done various studies to assess safety hazards at construction sites and alleviate them by developing appropriate models (Jasni et al., 2019; Li et al., 2017; Xu et al., 2020; Yan et al., 2021). Inadequate research has been done on the dynamic simulation models by using VENSIM® software to elucidate the basic processes of safety hazard assessment and minimizing hazards at construction sites, particularly in worker behavior, managerial, environmental and technological issues. The most challenging factors in the dynamics simulation for the safety hazards are followed as 1) Assessment of factors influencing hazards and building a relationship between them, 2) Valuation of factors on construction period, 3) Assessment of factors regarding a situation like weather, management, technical, and human. The goalmouth of this study aims to reconnoiter the factors influencing safety hazards in terms of environment, management, technical, and human at construction sites and develop an appropriate, cost-effective, and reliable system dynamic model by using VENSIM® software to alleviate and/or minimize construction related hazards.

1.3 Reason/Justification for the selection of the Topic

Safety assessment and management play an essential role to minimize the number of accidents effectively that is being happening in workplaces on daily basis, specifically in complex industries like the construction industry. However, numerous researches have studied on the awareness of hazards assessment and management but their results cannot be applied to the whole construction sector. Because construction is entirely categorized by its dynamism where the type of work, situation, and consequential hazards are continually fluctuating. Therefore, the construction industry needs an obvious study that can address the existing and coming hazards because the conclusions from the findings of other sectors may be misleading. Previous researchers have conducted studies on the causes of construction accidents in unsafe site conditions like unguarded opening, inadequate storage of equipment and materials, and defective tools and devices. Even though remarkable research exertions have been done to alleviate the unsafe situations, the construction industry is still observing numerous unseen factors that cause accidents. Moreover, very few researchers have discussed in detail the accident causing hidden factors like environmental, technical, managerial, and human on construction sites. There is an intensive need to research to reveal the interaction between hazard-causing factors and safety management. The reason for the selection of the topic is to assess the underlying factors that are causing accidents on construction sites and to develop an appropriate and reliable model to ensure workers' safety. This research will help to build the interaction between the underlying factors / elements and accidents by utilizing the System Dynamic model with VENSIM software. Moreover, this research will help to properly and timely design the remedial measures in a timely manner to avoid mishaps / accidents, specifically at the construction sites.

1.4 Objectives of Study

i. To identify safety related hazards associated with construction workers on constructions sites.

ii. To determine the interconnectivity of factors influencing safety hazards and develop a causal loop diagram.

iii. To develop a system dynamic model to address complexity in terms of safety related hazards associated with construction workers on construction sites for improved performance.

1.5 Relevance to the National Need

Pakistan is facing several problems in the construction sector, specifically in the way of hazard assessment and management as compared to other countries in the region. The rate of accidents is increasing day by day at construction workplaces. Being a third-world country, Pakistan cannot afford the substantial and insubstantial expenses associated with accidents at workplaces. However, in several years the safety hazard assessment and management culture are being tossed and experienced by numerous national and international companies but the protective measures to limit the unsafe behavior are still substandard. To control accidents on construction sites, it is necessary to understand worker behavior, unforeseen circumstances, quality control systems, and safety awareness from the perspective of any hazard. Subsequently, an appropriate model on hazard assessment and management will help the safety engineer to manage the hazards factor and eventually minimize the excessive cost of the project that will reduce the financial burden on the Pakistan construction industry.

1.6 Advantages of Research

The research has the following advantages:

i. This research will help to make decisions to alleviate hazards at the construction site and to implement managerial tools using system dynamics approaches.

ii. The model will cover the dynamic aspect through building a casual association between the components of the system and will cover the time aspect by demonstrating the behavior of system dynamic components over time.

iii. The model will help to identify the hidden factors of the accidents that happen, the association will develop as variables by using system dynamic approaches.

1.7 Areas of Application

The present study has a main application in the occupational health and safety domain of construction industry.

2. LITERATURE REVIEW

2.1. Construction Industry

The construction industry is a country's primary source of occupation and cater for an indispensable role in the evolution of the socio-economic segment (Isa et al., 2013; Maqsoom et al., 2020). However, this industry has not been deliberated in detail till now rather than few aspects of the industry got intention as individual projects. Generally, the construction industry accounts for more than 10% of global GDP and 7% of employees- over 273m people worldwide. As the French Saying;

"Everything flourishes with Construction Industry."

2.2. Construction industry in Pakistan

In developing countries like Pakistan, the construction industry has become the second-largest sector after agriculture with 30 to 35% direct or indirect employment opportunities from an economic point of view. After decades in the 1990s, Pakistan's economy has recovered and has been growing at more than 7% in recent times (Economic Survey of Pakistan, 2006-07). As a consequence, Pakistan's construction sector has been important in creating employment and helping the country's economic revival. The construction industry, pooled with population evolution rates of above 2% (Economic Survey of Pakistan, 2006-07), means that fundamental and intermediate infrastructure is in tremendous need. The current power failures are a classic illustration of the rapidly developing economy's aged and weak power infrastructure that failed to meet with expanding demand, leading to a country-wide energy crisis. Moreover, a similar trend has been observed in terms of transportation infrastructure provision in Pakistan.

The construction industry mainly concerns with the improvement of cultural, financial, and ecological quality indices (Ullah et al., 2018) . Generally, the engineering and construction sector faces various issues, including claims and counter-claims, low-profit margins, ongoing project cost, and time over-run (Yeo & Ning, 2002). Moreover, the construction industry faces several known and unknown hazards, which badly affect project efficiency.

2.3. Challenges to Construction Industry

The construction division is one of the world's supreme lethal industries (Hosseinian & Torghabeh, 2012). The working environment, as well as work tasks, are both complicated. In general, there are a considerable number of laborers on the job site. Heavy apparatus and an assembly of pipelines, materials, and wires stay constantly present. Furthermore, construction sites are typically not "tidy," so it is unsurprising that the serious injury rates on construction sites are greater than in other industries (Hallowell et al., 2011). According to a survey report carried out in United States of America by the Bureau of Labor Statistics between 2008 and 2012, 4253 construction workers died on the job (US Bureau of Labor Statistics 2008-2012). Similarly, according to official Chinese figures, 2722 people died in construction-related workplace accidents in a single year in 2007 (Dongping & Mengchun, 2012). In this context, megaprojects have been proven to have more severe working circumstances relative to alternative construction sites, the safety organization of such huge projects is complex rather than other industrial area (Li et al., 2017; Xu et al., 2020).

Pakistan is a third-world country facing the most horrific industrial disasters in recent history due to several managerial, environmental, human, and technological issues (Mohamed et al., 2009). For instance, the under-construction factory collapse in Lahore in 2008 caused the deaths of more than 45 people. Similarly, in September 2012, a fire that destroyed a factory in Baldia Town, Karachi, claimed the deaths of around 260 workers (Mohamed & Chinda, 2011). In addition, there are numerous incident reports on construction sites that demonstrate that workplace safety and health are not a high priority in Pakistan, specifically in the construction industry. This unserious behavior raised international notice about Pakistan's appalling labor conditions. Due to national and international pressure, short and medium-term strategies were established in the context of the incidents at construction sites; however, they have not yet to be executed completely. Commonly, factories continue to engage in illegal and dangerous behaviors with abrasive carelessness.

Moreover, in Pakistan, construction workers are more likely to suffer serious injuries from falls. A daily wage laborer hired by a construction corporation or private contractor is usually seen on large buildings and houses sealing roofs, hauling bricks, or dragging wheelbarrows without any safety gear. As there is no idea of wearing a safety dress, helmet, and other safety gears, the slips, trips, or falls resulted in life-threatening injuries leading to death (Abbas, 2015). Similarly, ignorance of wearing eye shields; resulted in eye injuries due to dust and gravel at construction sites. To prevent the workers from falling debris on construction sites, some businesses have recently begun to provide helmets to their employees. To take into account the deleterious consequences of life-threatening injuries at construction sites, it is an intensive need to study the causing factors contributing to hazards and develop an appropriate, easy to adopt, and cost-effective model to minimize accident-causing hazards in Pakistan.

2.4. Definition of Hazard

A Hazard is a potential source of harm or adverse health effect on a person or persons(Ojo, 2010). The source of hazard is something that multiplies the possibility of something happening by a hundred. It could be a single factor or a collection of factors. Furthermore, the occurrence of one hazard may be a precursor to the occurrence of another hazard. In addition, the hazard's response could be the initiator for a new danger, referred to as a secondary hazard. Thus, hazard can have a good or negative influence or a combination of both. The greatest number of hazards exist throughout the beginning segment owing to the high level ambiguity; however, as more information is gathered throughout the completing phase, the level of uncertainty tends to diminish during the project period (Balocco & Capone, 2005).

Numerous construction projects miss the mark of their original objectives. Such a failure could manifest itself in the form of a significant project delay, cost invades, and low worth. The existence of hazards and qualms implicit in project development and execution plays a crucial influence in all phases of a project disaster (i.e., contracting, bidding, planning, and construction phases). As a result, there is a significant need to integrate hazard mitigation techniques into construction practice in order to improve project performance.

The factors influencing hazards are diverse and evolve during the project. In other words, it can be separated into two groups: internal and external factors. For clarification, internal sources are those in the project manager's control, whereas external sources are not within the project manager's control. For example, economic, political, legal factors, environmental factors, social situations, and natural surroundings are external factors. Alternatively, Internal factors, like manufacturing technology and human factors, pose a threat.

2.5. Causes of Safety hazards on construction sites

Many researchers have recognized various kinds and reasons for an accident at construction sites (Williams et al., 2018). There are twenty-five potential causing factors of the hazard at the construction site after a critical review of previous articles. For instance, innovative technology on safety measures (Bouloiz et al., 2013), knowledge regarding hazard (Williams et al., 2018), qualified workers and managers (Hosseinian & Torghabeh, 2012), lack of managerial interest (Akroush et al., 2017), environmental issues (Xu et al., 2020), communication gaps between manager and workers (Ismail et al., 2012), defective personal protective equipment (Bouloiz et al., 2013), poor safety consciousness (Konda et al., 2016), lack of personal protective equipment

(Konda et al., 2016), shortage of safety manuals on site (Isaac & Edrei, 2016), no willingness to follow safety norms (Poh et al., 2018), excessive overtime work for labor (Jasni et al., 2019), nature of construction projects (Li et al., 2017), lack of information flow from managerial team to workers (Hallowell et al., 2011), unforeseen circumstances (Jasni et al., 2019), lack of strict operational procedures (Jasni et al., 2019), lack of information systems implementation and customization (Li et al., 2018), lack of skilled labor (Xu et al., 2020), lack of rigorous enforcement of safety regulations, lack of safety training and orientation (Jasni et al., 2019), lack of onsite first aid safety measures (HSE, 2006) and lack of safety policy (Akroush et al., 2017).

Moreover, after a thorough review of the literature, thirteen major categories (types) of accidents were discovered. For instance, accidents regarding lifting and handling of objects, welding-related accidents, slips, trips, and falls-related accidents, struck by an object, vehicle/machine-related accidents, human conflicts related accidents, explosions, animal behavior related accidents, collapse accidents, electrocution accidents, drowning/asphyxiation accidents, and equipment/tools-related accidents are among them. Additionally, observational research on the kinds and regularity of accident in Nigeria's south-western states, four categories of the accident were most prevalent: interaction with working equipment, slip trips, and fall-related accidents, and vehicle-related accidents, however, each category had subtypes of the accident.

2.6. Factors contributing to the occurrence of Accidents at construction sites

To uncover aspects associated with the prevalence of construction accidents, numerous researchers have investigated some of these factors like technical, environmental, spanning from personal and physical variables. Accordingly, construction site accidents are caused by technical, physical, and environmental variables. Similarly, the recognized variables that are primarily responsible for construction accidents are unsafe equipment, worksite circumstances, the unique nature of the project, dangerous procedure, and human element (Shapira & Simcha, 2009). Furthermore, (Poh et al., 2018) divided the causes of construction accidents into three categories: human-caused, environmental, and technology-caused. Moreover, according to (Akroush et al., 2017), the two variables that cause accidents are human and environmental. Similarly, according to the Department of Occupational Safety and Health (2009), regulatory failure, horseplay, inadequate personal protective equipment (PPE), and insufficient labeling are all factors that contribute to a workplace accident.

Furthermore, some researchers observed that the following characteristics are missing that encourage the causes of accidents on site: professional supervision, training, qualified project managers, implementation of safety standards, skilled professional workers, personal protective equipment, first aid measures, innovative technology on safety measures, inadequate behavior of workers regarding hazards, lack of worker knowledge, managerial commitment, teamwork spirit, and with the inclusion of unwillingness to finance in safety, awareness from management, strict operative measures, maintenance of machinery, and communication between top management and workers (Bouloiz et al., 2013). Other scientists conducted research on the occurrence of accidents and discovered a variety of causes why accidents occur on the worksite, including the following: lack of implementation of safety measures; unawareness of safety standards; less safety concern of people at the construction site; engaging unskilled laborers; non-vibrant competence; lack of maintenance of constructional equipment; physiological and emotional pressure; chemical impairment. In addition, (Maryani et al., 2015; Z.O, 2014) backed up other researchers in identifying the following factors as contributing to accidents: lack of support in material transport and storage, collaboration, leadership attention, training, emergency measures, managers' expertise, technical guides, and the wearing of personal protective equipment (PPE). (Mortazavi et al., 2020) conducted a more in-depth investigation into the accident's factors, finding negligence and carelessness, failure to comply with safety standards, inappropriate use of safety gear, irresponsible conduct, unsafe working conscientiousness of management, untrained labor, lack of equipment and maintenance, non-rigorous implementation of safety standards, uncertain organizational performance, inefficient organization commitment, inefficient operation on safety measures, uneducated labor, overtime working hours for labor, lack of safety management, and inadequate informational flow to be the most common. Nonetheless, all of these elements are intertwined.

2.6.1. Safety/environmental concerns

The level of safety and environmental threats that may occur when two companies are near one another may influence site employees by raising the chance of mishaps. This study broadens the concept of safety/environmental concerns and categorizes them into five groups: Hazard due to human factors, hazards due to worker attitude, hazard due to environmental factors, hazards due to technical factors, and hazards due to managerial factors, which are described in following;

2.6.1.1. Hazard due to Human factors

Doctor Russel Ferrel (1997) established an accident theory based on a series of human elements. Human factors, he argued, are the primary causes of accidents, and the following factors induce them:

1. Overload; the overload factor indicates a mismatch between both the load and the human's potential. Anxiety, stress, weariness, and emotions result from this imbalance, which can be increased by the actual environment in which the person is working, such as dust, light, noise, odors, etc.
2. Improper reaction; the person's incorrect response is induced by the unsuitable circumstances in which he or she is employed.
3. Inappropriate activity; the individual does the activity incorrectly due to a lack of awareness of the proper manner to execute the activity or take the Risk on purpose.

2.6.1.2. Hazard due to worker attitude

Regardless of whether the work environment is safe or unsafe, a worker may engage in dangerous behavior. In these instances, workers may continue to work in hazardous conditions or execute tasks without regard for safety norms, such as working without safety equipment or working when tired (Hosseinian & Torghabeh, 2012; Jasni et al., 2019).

2.6.1.3. Hazard due to environmental factors

It is known as the external factors related to politics and legislative problems on construction sites that concern the economic view of when services, equipment, and labor supply cause the accidents (Jaafar et al., 2018). Moreover, environmental factors consist of weather conditions, windy or rainy season etc.

2.6.1.4. Hazards due to technical Factors

The technical component, also known as the worksite factor, is characterized as the workplace, bad site management, materials and equipment quality, and the tasks performed during construction, all of which contribute to the occurrence of accidents (Jaafar et al., 2018).

2.6.1.5. Hazards due to managerial factors

The elements that contribute to accidents under this subject are management strategy, source management, management culture, and the safety precautions of the management handled on-site (Jaafar et al., 2018).

Table 1 : Hazard causing factors on construction sites with their frequencies

Sr. #	Hazard Causing Factors	Frequency
1	Innovative technology on safety measures	10
2	Knowledge regarding appropriate hazard	16
3	Qualified workers and managers	20
4	Lack of managerial interest	16
5	Environmental issues	16
6	Low level education of Labors	4
7	Communication gaps between manager and workers	6
8	Defective personal protective equipment	10
9	Nature of construction projects	21
10	Lack of information flow from managerial team to workers/Lack of technical guidance	6
11	Unforeseen circumstances	10
12	Lack of information systems implementation and customization	5
13	Poor Safety Awareness	11
14	Lack of personal protective equipment	15
15	Lack of safety training and orientation	14
16	lack of safety policy	18
17	Shortage of safety management manuals on site	2
18	No willingness to follow safety norms	7
19	Excessive overtime work for labor	4
20	Lack of strict operational procedures	6
21	Lack of Skilled Labor	2
22	Lack of rigorous enforcement of safety regulation	5
23	Lack of onsite first aid safety measures	1
24	Lack of organizational commitment;	5
25	Reluctance to input resources for safety measures	3

These hazard-causing factors are graded as shown in Table 1 and 2 based on their literature score derived by content analysis, in which the influence of each factor (high, medium, low) is determined via a thorough examination of the literature. Each impact is given a numerical value (high 5, medium 3, or low 1), the impact with the uppermost frequency/occurrence is chosen for each element. Equation 1 demonstrates how to calculate the literature score, where A represents the greatest possible score, N represents the total number of articles considered for factor recognition, and frequency represents the frequency with which factors appear in different publications.

$$\text{Literature Score } = Impact\ score \times \frac{Frequency}{A \times N}$$ **Equation 1**

The next step was to transform this literary score into a normalized score by dividing each factors' individual literature score by the total literature score. After that, the normalized score is organized in descending order, and the cumulative score is computed. This method is used to eliminate less significant aspects (Ullah et al., 2018).

2.7. Management of Safety hazards on construction sites

Hazard allocation methods include hazard retention, hazard transfer, hazard reduction, and hazard avoidance. Hazard retention becomes the sole alternative when hazard prevention or transfer is unattainable, avoidance is undesired, potential financial loss is modest, the chance of occurrence is minor, and transfer is unprofitable. hazard avoidance in construction is widely acknowledged as unworkable, as it might result in projects being canceled or a contractor delivering an unduly high bid for a project (Ismail et al., 2012; Williams et al., 2018). Consequently, hazard reduction strategy in terms of the possible effect or possibility of existence comprises the use of alternative contract approaches, new construction methods, project redesign, more extensive and in-depth site assessments, and so on. Perry and Hayes analyses hazard transfer in construction projects and contracts describe four methods practiced comprising the association among customer, builder, subcontractor, design group, guarantor, and guaranty. The majority of contractors use a 'back-to-back' subcontract agreement with specialized and local subcontractors in addition to the primary contract. Contractors also prefer insurance as a means of payment. The project managers like to transfer hazardous effects to the customer and architects via specialized indemnity and the phrasing of contract requirements. Project management approaches can do so because they offer to consult services instead of site building, which requires significant direct financial investment.

Table 2 : Identified factors, literature score, normalized score and cumulative score

Sr.#	Identified Factors	Literature Score	Normalized Score	Cumulative Score
1	Innovative technology on safety measures	0.285714	0.056882821	0.056882821
2	Knowledge regarding appropriate hazard	0.274286	0.054607509	0.11149033
3	Qualified workers and managers	0.342857	0.068259386	0.179749716
4	Lack of managerial interest	0.457143	0.091012514	0.27076223
5	Environmental issues	0.457143	0.091012514	0.361774744
6	Low level education of Labors	0.068571	0.013651877	0.375426621
7	Communication gaps between manager and workers	0.102857	0.020477816	0.395904437
8	Defective personal protective equipment	0.285714	0.056882821	0.452787258
9	Nature of construction projects	0.360000	0.071672355	0.524459613
10	Lack of information flow from managerial team to workers/Lack of technical guidance	0.102857	0.020477816	0.544937429
11	Unforeseen circumstances	0.285714	0.056882821	0.60182025
12	Lack of information systems implementation and customization	0.085714	0.017064846	0.618885097
13	Poor Safety Awareness	0.188571	0.037542662	0.656427759
14	Lack of personal protective equipment	0.428571	0.085324232	0.741751991
15	Lack of safety training and orientation	0.240000	0.04778157	0.789533561
16	lack of safety policy	0.308571	0.061433447	0.850967008
17	Shortage of safety management manuals on site	0.057143	0.011376564	0.862343572

Sr.#	Identified Factors	Literature Score	Normalized Score	Cumulative Score
18	No willingness to follow safety norms	0.200000	0.039817975	0.902161547
19	Excessive overtime work for labor	0.114286	0.022753129	0.924914676
20	Lack of strict operational procedures	0.102857	0.020477816	0.945392491
21	Lack of Skilled Labor	0.057143	0.011376564	0.956769056
22	Lack of rigorous enforcement of safety regulation	0.085714	0.017064846	0.973833902
23	Lack of onsite first aid safety measures	0.028571	0.005688282	0.979522184
24	Lack of organizational commitment;	0.085714	0.017064846	0.996587031
25	Reluctance to input resources for safety measures	0.017143	0.003412969	1

2.8. System dynamic model

The system dynamics (SD) has recently been adopted to predict the hazards in construction projects due to its excellent benefits in predicting a dynamically complex system that is continually changing, densely connected, and nonlinear (Xu et al., 2020). Furthermore, it has demonstrated its worth by substantially enhancing project performance. As a result, De Marco used the SD to investigate stakeholder behavior in complex Engineering, procurement, and construction (EPC) projects and outlined the varied effects of the project's primary participants on decision-making challenges (Goh & Love, 2012). Furthermore, this model is used to show how unanticipated changes might affect the flow of work and the primary elements that influence project efficiency. Gao and Zhao developed a SD model to forecast the evolutionary process of game participants' behavioral strategies in China's new energy power PPP project and discovered the major parameters that influenced the sustainability of these techniques (Gao & Zhao, 2018). For example, an SD for safety risk allocation was developed in a pipeline construction project that resulted in a 3.7 percent reduction in safety management expenses (Nasirzadeh et al., 2016). Consequently, SD has demonstrated its ability to deal with complex risk issues in the construction industry. However, the system dynamics have only been used in a few studies to forecast the safety risk of construction projects (CPs).

System Dynamics is based on the notion that all systems have a design, and the system's design defines the function of the system (Etemadinia & Tavakolan, 2018). Therefore, the parameters and formulas that characterize the system structure must be defined before the simulation can begin. Historical data is useful in constructing system dynamics using statistical methods like regression analysis (Khanzadi et al., 2012). Furthermore, due to a lack of historical data on safety hazard factors, describing the needed parameters in functions and equations is difficult. Previous research in the field of safety hazards modeling used a cyclic approach to determine variables through interviews. For example, (Guo et al., 2018) quantified the frequency of insecure behaviors and conducted semi-structured interviews to assess the impact of several elements in the rapid mass transit (MRT) tunneling project in Singapore to produce a causal loop diagram. In addition different combination of fuzzy logic and system dynamics is used to handle the inaccurate and ambiguous character of risks; the system dynamics simulation model also used gap arithmetic (Nasirzadeh et al., 2008). Furthermore, a system dynamic was developed to assess safety hazards in tunnel building projects to find optimal tradeoffs among production and protection objectives (Wang et al., 2016). To characterize the interconnections between a contractor's organizational and technological systems, Bayesian Belief Networks (BBNs) and smooth relevance vector machines were designed (Wang et al., 2016). When taken together, past studies have revealed that interval data support the construction of system dynamics.

System dynamics (SD) is a powerful technique for analyzing a complicated system (Xu & Coors, 2012). SD is a method of periodic modeling. It is characterized by incorporating stocks, flows, feedback loops, table functions, and time delays. A causal loop diagram (CLD) is created to depict the link between variables and balance and reinforce cycles in the integrated approach (Nguyen & Bosch, 2013). In system dynamics, each pair of variables has a cause and effect relationship indicating that the variables might move in the same or contrary way. Polarities between linkages only forecast what will happen if something changes; they don't illustrate how variables will behave.

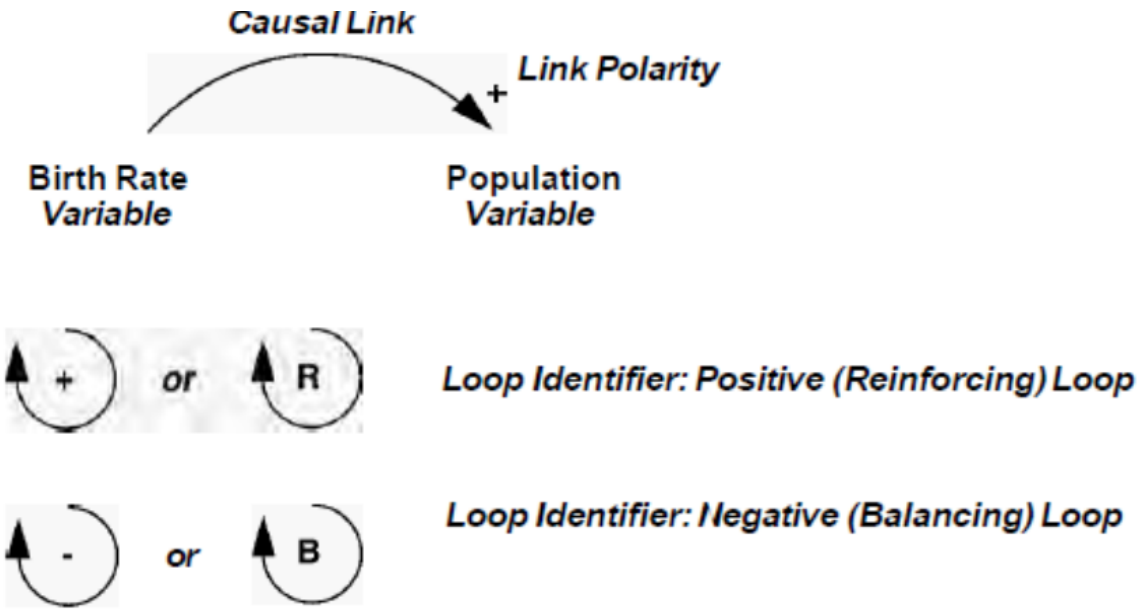

Figure 1: Causal Link and Polarity

The polarity of a variable is evaluated by tracing its effects as they traveled through the loop. A positive loop, denoted by the letter "R," illustrates activities that produce a result and lead to subsequent actions that produce different results in the same direction, whereas a negative loop, indicated by the letter "B," tries to build a state of the system in the opposite way (Coyle & Exelby, 2000).

In conclusion, there has been insufficient study into dynamic techniques to uncover the core mechanics of mega construction project (MCP) safety hazards. The following are the most difficult aspects of dynamic simulation for safety hazards: (1) the assessment of hazard causing factors and their causal linkages, and (2) the measurement of hazard factor alterations over time throughout construction. Thus, a hybrid strategy is developed by combining the Local Engineering Change (LEC) strategy and SD to address the aforementioned challenges.

2.8.1. System Thinking

Systems thinking is a comprehensive approach to assessment that emphasizes the interdependence of a system's fundamental components and how systems function through time and in the context of bigger systems. In contrast to classical analysis, which investigates systems by decomposing them into their constituent parts, systems thinking examines them holistically. It is possible to apply systems thinking to any area of research, and it has been done so in a variety of fields, including economic, educational system, medical, political, and environmental are few among the many others.

System performance in systems thinking mostly depends upon the impacts of emphasizing and assessment procedures. Several system elements increase by the process of reinforcing. Without an appropriate check on reinforcement by a balancing procedure, it may suddenly collapse. So, the balancing procedure is essential to sustain equilibrium among the system components.

Feedback has been reported as a major element of system thinking. For instance, prevalent knowledge at the managerial level might recommend more workers added to a project that results in lagging. However, practically this technique might be the reason for slow progress in the past. Focus on appropriate feedback enables the management to resolve the other issues instead of wasting time and resources on a technique that has already been proved unproductive.

Systems thinking is a method of modeling, illustrating, and predicting system behavior that uses computer simulation and a range of diagrams and graphs. The several commonly used system thinking tools are causal loop diagram (CLD) that demonstrate the association among the various system components; simulation model, that simulates the binding of system components over the period; the behavior over time (BOT), which demonstrates the activities of one or more variables over time; and the management flight simulator, that based on collaborative software to maximize the impacts of decisions made by management.

2.8.2. Complexity in System Dynamics

System features that do not track common and linear cause-effect correlations are referred to as "dynamic complexity," and they are defined as follows: Periodic linkages and interrelationships between system parts result in the emergence of dynamic complexity. It is thought to be caused particularly by delays, feedback, accumulations, and nonlinearities, among other things. For a decision-maker, circumstances that are dynamically complicated are transparent. He or she cannot instinctively perceive the relationship between circular causality and a method of forecasting them with precision and accuracy. Surprises, adverse effects, and unforeseen consequences of decisions made in different components must be anticipated by the decision-maker.

2.8.3. Norms for complexity in the dynamic system

A system is dynamically complicated if the following conditions are met, but not necessarily all of them:

1. Dynamic: The system evolves or changes over time as a result of its environment. What appears to be constant over a prolonged period is changing.
2. The strong interconnection between system components or agents: The system components or operatives in the system have a strong interconnection.
3. Feedback: Systems are regulated by the information they receive. This coupling between system constituents' actions and occurrences has the potential to cause a chain reaction.
4. Non-linearity: When at least one element in a system interacts with another in a non-linear manner, non-linearity is present. Non-linearity can be represented graphically by a curved line, such as a quadratic or an exponential line. In particular, the term "non-linear" refers to the fact that an effect is rarely proportionate to the cause of the impact.
5. Past dependent: It refers to the fact that an agent's actions are dependent on the actions that have already been made in the past. Any system's structure is a result of previous actions in the system.
6. Self-organizing: The dynamics of a system are generated by the self-organization and unexpected outcome of its internal structure, which are both deterministic.
7. Adaptive: It evolves due to its interactions with other systems and with the environment. Because of this, the abilities and selection criteria of agents in a complex system can and do evolve.
8. It is counterintuitive: Decision-makers cannot capture the origins and consequences of events solely based on intuition. The system's response is frequently in opposition to, i.e., in opposition to, the behavior that the decision-makers expect. This is because causal links are frequently not properly known since it is sometimes overlooked that causes can have various intended and unexpected consequences.
9. Intervention resistance: The complexity of the system in which an agent is immersed outweighs the agent's ability to comprehend the system, resulting in intervention resistance. As a result, remedies implemented in a complex system frequently fail, or even worse, exacerbate the condition. Interventions do not always have the expected (or visible) results, and they may even have unexpected consequences.
10. Timely balanced Choices: In a system where time delays have resulted in a system in which the long-term impacts of an intervention are frequently different from the short-term effect.

2.9. Summary

The construction industry is a country's primary source of employment and plays an essential role in the progress of the socio-economic segment. The construction industry in Pakistan has become the second-largest sector after agriculture, with 30 to 35% direct or indirect employment opportunities from an economic point of view. Commonly, the construction industry is suffering several types of problems in Pakistan, most specifically injuries leading to the death of construction workers due to lack of safety assessment and management, which causes destruction of company reputation along with project delay, cost invades, and low quality. Generally, the accidents caused at construction sites due to hazards caused by human factors, environmental factors, technological factors, and managerial factors.

The system dynamics (SD) model is recently adopted to predict the factors influencing hazards in construction projects due to its excellent benefits in predicting a dynamically complex system viz-a-viz continually changing, densely connected, plus nonlinear/chaotic. There are several possible uses of the SD model at the construction site after a critical review of previous articles. For instance, SD model used in project monitoring and managing, work schedule, forecasting exact cost, duration, and resources of project, timely action for project acceleration, evaluating decision level, managing risks and uncertainties etc. Overall, the SD modeling is a powerful technique for analyzing a complicated system. Generally, SD is a method of periodic modeling. SD is characterized by incorporating stocks, flows, feedback loops, table functions, and time delays. A causal loop diagram (CLD) is created to depict the link between variables and balance and reinforce cycles in the integrated approach. In SD models, each pair of variables has a cause and effect relationship indicating that the variables might move in the same or contrary way. Polarities between linkages only forecast what will happen if something changes; they don't illustrate how variables will behave.

3. RESEARCH METHODOLOGY

3.1 Introduction

This study focuses on the factors influencing safety hazards at Construction sites by using System dynamic approach. The research is carried out in various stages/phases. The schmetic representation for the methodology of this study is presented in figure 2.

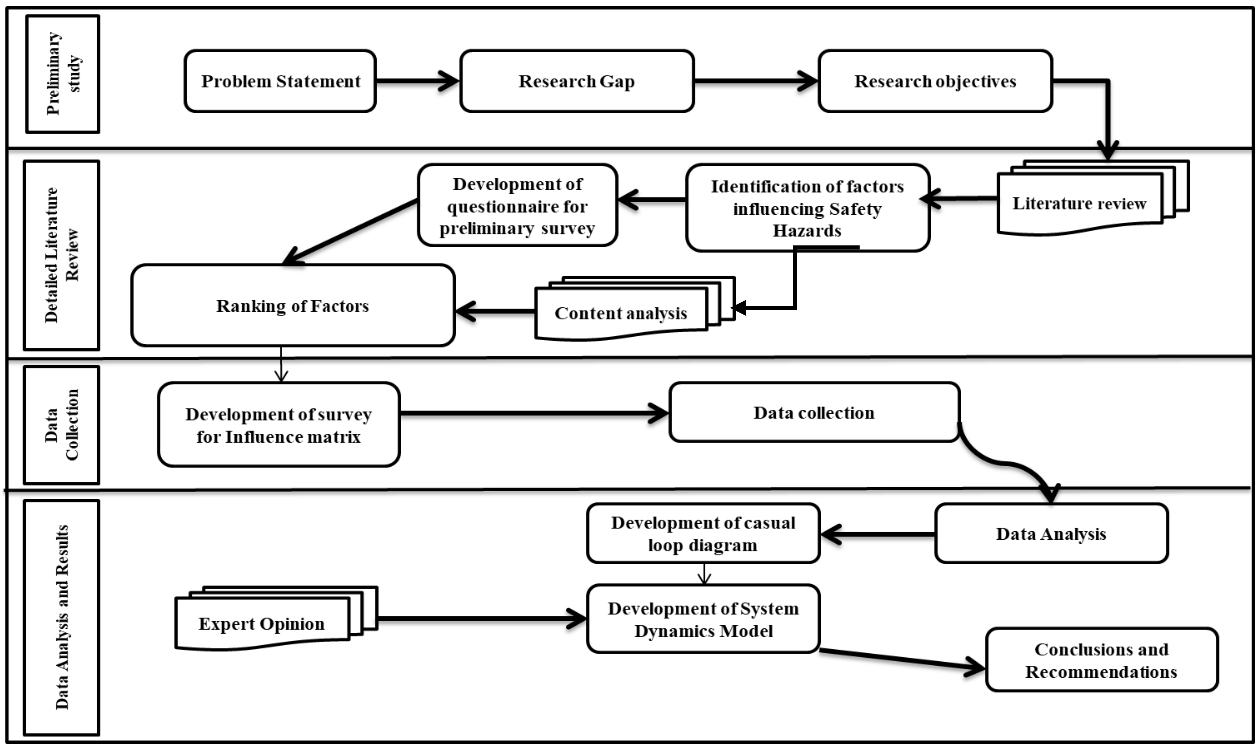

Figure 2: Flow Chart of Research methodology

3.2 Preliminary Study

This phase involved basic steps such as finding research gap and problem statement. After the development of problem statement, research objectives were identified. This helped in answering certain questions such as work already done on this topic? Why is this research carried out? What would be its benefits to construction industry? What will be its relevance to national needs?

3.3 Detailed Literature review

Literature review was carried out to find factors of Safety hazards on Construction sites. 35 research papers were reviewed for the identification of factors influencing hazards pertaining to safety on Construction sites. Data analysis revealed 25 factors that contribute to the occurrence of safety hazards at Construction sites ranging from human related, environmental related, technical related and managerial related hazards. Content analysis was conducted for selection of most important factors. This was carried out using literature score and field survey. The identified factors from literature were ranked conferring towards their respective literature score acquired through content/factor analysis wherein the impact of each factor (high, medium, low) was evaluated through detailed review of literature. A quantitative number was assigned to each impact (high as 5, medium as 3 and low as 1) as described in the study. The highest frequency impact was selected for each factor. The next step was to convert this literature score into normalized score by dividing individual literature score of each factor with the sum of literature score. Normalized score was then arranged in descending order and cumulative score was calculated. Data was collected through questionnaires, a weightage of 60/40 was selected, Pareto analysis was used and then most important factors were considered and rest were discarded from the list.

3.4 System Thinking

To evaluate the polarity as well as the causative strength of one factor on the other, a rigorous questionnaire survey was conducted. Respondents were asked to rate the causal intensity of each component on the other on a scale of Low (1), Medium (3), and High (5), as well as the polarity of each element as Direct or Indirect. Data was obtained from 117 respondents from developing nations, 19 of whom were invalid, leaving 98 for further study (Dillman et al., 2014). Interrelationships having relative importance index (RII) greater than 0.7 were selected for further analysis (Sambasivan & Soon, 2007). Systems thinking was established using this information and causal loop diagrams. VENSIM ® was used to create a causal loop diagram based on shortlisted interrelations, which was then updated by including expert viewpoints to make it more meaningful and relevant to the construction sector.

3.5 System Dynamic Model

To be applied in a system dynamics model, the relative importance index of each connection/interrelationship was normalised. Consequently, a system dynamics model was built using causal loop diagrams, polarity, and causal strength of the elements/factors. The model was tested/simulated over a five-year period to see how it behaved. Two criteria were used to validate the model that had been built i-e structural validity and behavioral validity (Qudrat-Ullah & Seong, 2010). Hence, the developed model addressed the factors that were actually influencing the safety hazards at construction sites.

4. RESULTS AND DISCUSSION

4.1 Preliminary Questionnaire Survey (Phase-1)

A preliminary questionnaire survey was done in order to select contributing factors that were influencing the safety hazards at construction sites for factor analysis. According to the central limit theorem, data was obtained from 30 respondents, which is considered an adequate sample size (Chan et al., 2018). Pakistan, India, Bangladesh, Turkey, Oman, and the United Arab Emirates were among the developing nations represented among the respondents. Gmail ®, LinkedIn ®, and Facebook ® were being used to gather information.

Using Google ™ Docs, a preliminary survey was designed. The first component dealt with the respondent's private details, such as name, organization name, organization nature, organization type, professional experience and years of working experiance. The second segment focused on factors that influenced safety hazards on construction sites, and respondents were asked to score them on a Likert scale ranging from very low to very high (1 - 5). There were 25 factors identified by a rigorous content analysis.

4.1.1. Respondent Details

To guarantee authentice feedback that is particular to construction, individuals mostly with a civil engineering background were targeted.

4.1.1.1 Years of Professional Experience

In terms of professional experience, 0% of respondents had 0 to 1 year of experience, while 7% had 2 to 5 years of experience. Similarly, 37% of respondents had 6 to 10 years of experience, and 30% had 11 to 15 years of experience. Likewise, 13% of respondents had 16 to 20 years of experience. The remaining 13% of respondents have more than 21 years of professional experience.

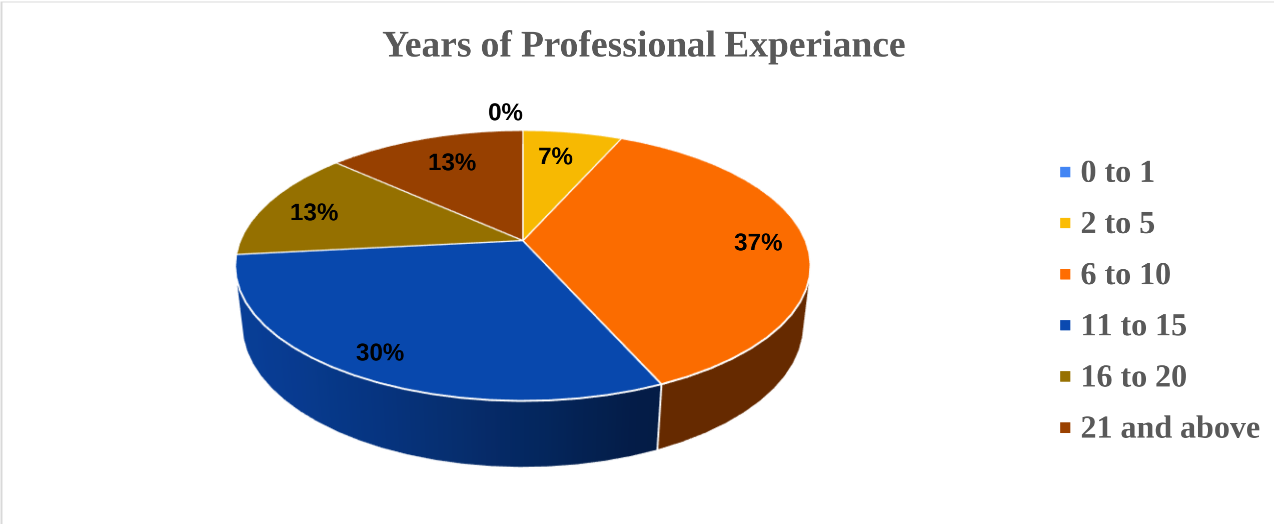

Figure 3: Preliminary Survey – Years of Professional Experience

4.1.1.2 Organization Type

In terms of organization type, contractors accounted for 3% of the respondents from the total of 30 respondents, while consultants accounted for 77% of the total. The remaining 20% came from various sources.

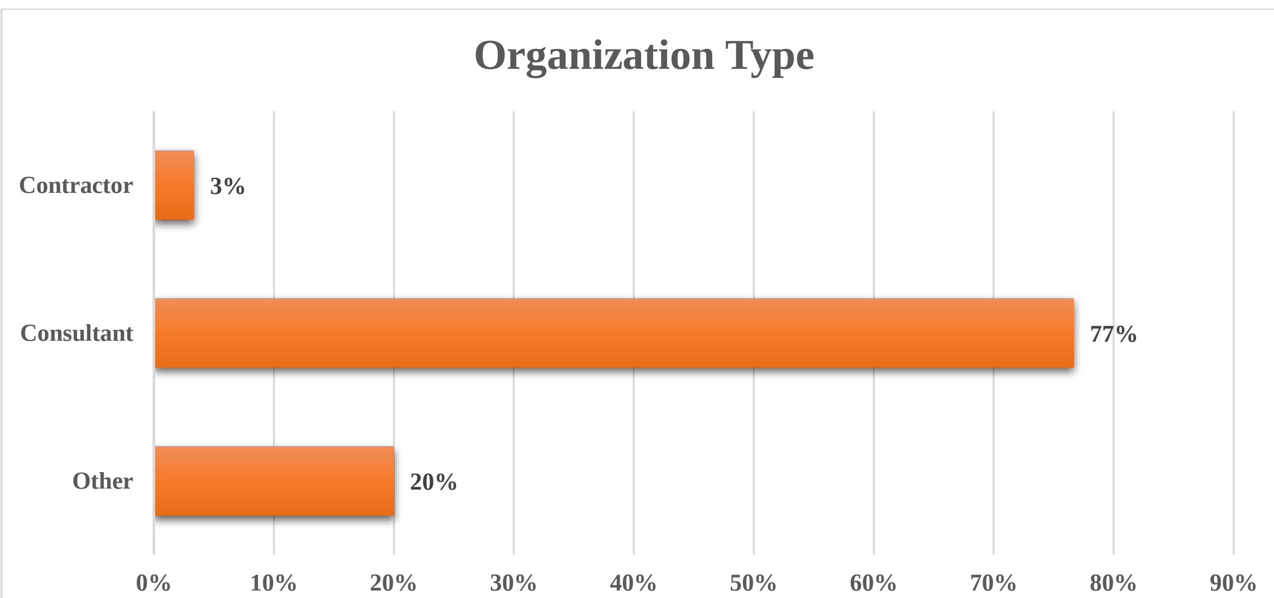

Figure 4: Preliminary Survey – Organization Type

4.1.1.3 Region of Respondents

The respondents were from developing nations such as Pakistan, India, Bangladesh, the United Arab Emirates, and Turkey. Pakistan had 47 percent of the responses, Bangladesh had 27 percent, India had 17 percent, the United Arab Emirates had 3%, the United Kingdom had 23.33 percent, and Turkey had 7%.

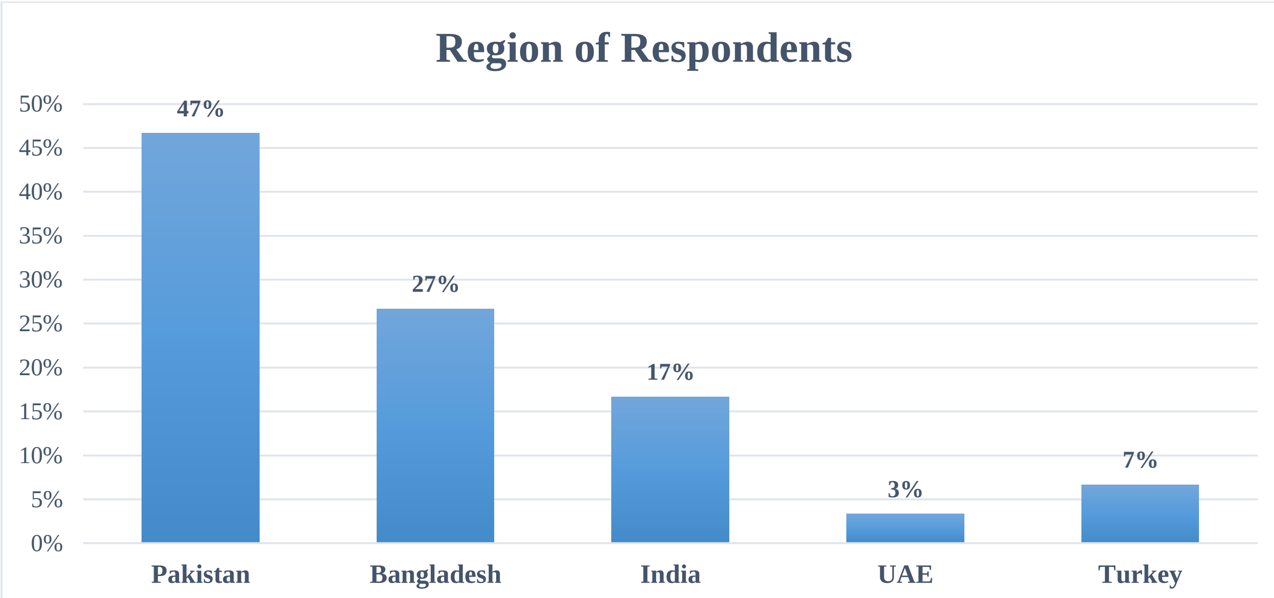

Figure 5: Preliminary Survey – Region of Respondents

4.1.2 Reliability Check

Cronbach's Alpha test is used to verify data reliability and internal consistency, and also its benchmark value is 0.7 (Polat et al., 2017). As demonstrated in figure below, the greater the number, the more dependable and internally consistent the data is. The value of Cronbach's Alpha was 0.926, indicating that the data is sufficiently trustworthy and internally consistent.

Cronbach's alpha value (α)	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable

Figure 6: Cronbach's Alpha Values Benchmark

Cronbach's Alpha	N of Items
0.926	30

Figure 7: Cronbach Alpha Value

4.1.3 Classification of Factors based on Respondent and Literature Normalized Score

Using field survey data, a field normalized score was derived for each component. The final ranking was created by combining the field normalized score and the literature score. The ratio chosen in this case is 60/40 as to allow a stable consolidation between field respondents and literature score (Rasul et al., 2021).

Table 3 : Ranking Factors Upon Literature and Normalized score (60/40)

RANKING BASED UPON RESPONDENT NS and LITERATURE NS (60/40 RATIO)			
S.	**Factors influencing Safety Hazards at Construction sites**	**60/40**	**Normalized**
1	Innovative technology on safety measures	0.052456099	0.04950495
2	Knowledge regarding appropriate hazard	0.04560538	0.03960396
3	Qualified workers and managers	0.045125536	0.02970297
4	Lack of managerial interest	0.060167382	0.03960396
5	Environmental issues	0.060167382	0.03960396
6	Low level education of Labors	0.029223127	0.03960396
7	Communication gaps between manager and workers	0.031953503	0.03960396
8	Defective personal protective equipment	0.046515505	0.03960396
9	Nature of construction projects	0.052431318	0.03960396
10	Lack of information flow from managerial team to workers/Lack of technical guidance	0.031953503	0.03960396
11	Unforeseen circumstances	0.046515505	0.03960396
12	Lack of information systems implementation and customization	0.030588315	0.03960396
13	Poor Safety Awareness	0.044720035	0.04950495
14	Lack of personal protective equipment	0.057892069	0.03960396
15	Lack of safety training and orientation	0.042875004	0.03960396
16	Lack of safety policy	0.048335755	0.03960396
17	Shortage of safety management manuals on site	0.028313002	0.03960396
18	No willingness to follow safety norms	0.039689566	0.03960396
19	Excessive overtime work for labor	0.032863628	0.03960396
20	Lack of strict operational procedures	0.031953503	0.03960396
21	Lack of Skilled Labor	0.028313002	0.03960396

RANKING BASED UPON RESPONDENT NS and LITERATURE NS (60/40 RATIO)			
22	Lack of rigorous enforcement of safety regulation	0.030588315	0.03960396
23	Lack of onsite first aid safety measures	0.026037689	0.03960396
24	Lack of organizational commitment;	0.030588315	0.03960396
25	Reluctance to input resources for safety measures	0.025127564	0.03960396

4.1.4 Shortlisted Factors – Factors influencing Safety Hazards at Construction Sites

After deciding on a 60/40 ratio, the top ten (10) most essential factors influencing safety hazards at construction sites were sorted in order, with a cumulative impact of 50% to cover the most ground. Primary data was given more weight than secondary data, owing to the relevance of current data (Rasul et al., 2021).

Table 4 : Shortlisted Factors Upon Literature and Field Normalized Score

S.	Code	Shortlisted Factors	60R/40L	Cumulative Score	Rank
1	A1	Lack of managerial interest	0.060167382	0.060167382	**1st**
2	A2	Environmental issues	0.060167382	0.120334764	**2nd**
3	A3	Lack of personal protective equipment	0.057892069	0.178226833	**3rd**
4	A4	Innovative technology on safety measures	0.052456099	0.230682932	**4th**
5	A5	Nature of construction projects	0.052431318	0.28311425	**5th**
6	A6	Lack of safety policy	0.048335755	0.331450005	**6th**
7	A7	Defective personal protective equipment	0.046515505	0.37796551	**7th**
8	A8	Unforeseen circumstances	0.046515505	0.424481015	**8th**
9	A9	Knowledge regarding appropriate hazard	0.04560538	0.470086394	**9th**
10	A10	Qualified workers and managers	0.045125536	0.515211931	**10th**

4.2 Detailed Questionnarie Survey

The next step is to identify the causal relationship as well as the polarity of each element on the other after shortlisting a total of 10 (ten) contributing factors that influenced/impacted safety hazards at construction sites.

In order to evaluate the amount of influence/impact (causal strength) and interrelationship/connection (polarity) of one component over the other, an international thorough questionnaire survey was conducted. The survey was divided into two sections: The past part was devoted to demographic information such as education, experience, field of employment, and type of organization; (Wong et al., 2016) and questions about causal strength and relationships among variables are included in the latter half. The level scales of Low, Medium, and High were used to record the causal strength of each component. To assess polarity, respondents were asked to pick between direct and indirect. This was made possible through the Google^{TM} Docs.

4.2.1 Sample Size

Prior to data collection, a simple formula was used to determine the proper sample size:

$$n = \frac{(z^2 * p * q)}{E^2} \qquad \textbf{Equation 2}$$

Where n is the sample size, z is the desired confidence level's critical value, p is the proportion being tested, q = 1 – p, and E is the required margin of sampling error (Dillman et al., 2014).

The z-value for a 95 percent confidence interval is 1.96 (Goodman & Berlin, 1994), whereas the p-value and q-value are calculated using a 50/50 split, i.e. the likelihood of receiving 50 percent "yes" answers and the remaining 50 percent "no." also the desired margin of sampling error is set at 10% (Dillman et al., 2014). Substituting the value of sample size comes out to be 96.

$$n = \frac{(1.96^2 * 0.5 * 0.5)}{0.1^2}$$

4.2.2 Respondents Details

A total of 117 respondents provided data, 19 of which were invalid/flawed or incomplete, and 98 replies were included in the further research/analysis. To guarantee authentice feedback that is particular to construction, individuals mostly with a civil engineering background were targeted.

4.2.2.1 Years of Professional Experience

When it came to professional experience, 10% of the respondents had zero to one year of experience, while 31% had two to five years of experience. In a similar vein, 35% of respondents had 6 to 10 years of experience, 17% had 11 to 15 years of experience, and 5% had 16 to 20 years of experience. The remaining 2% of the respondents have more than 21 years of professional experience.

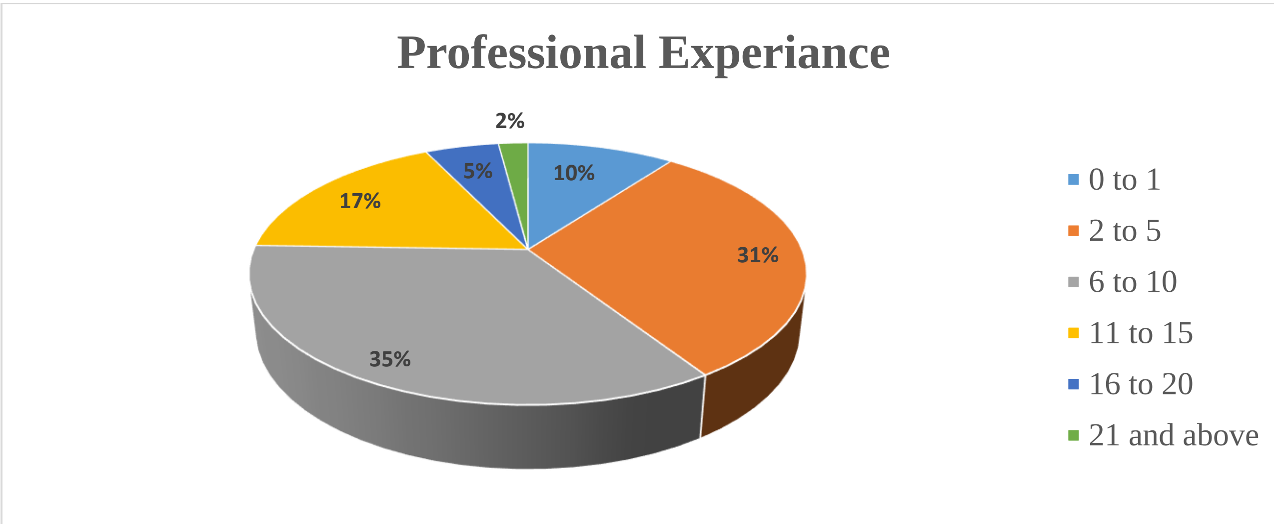

Figure 8: Detailed Survey – Professional Experience

4.2.2.2 Organization Type

In terms of organization type, 6 percent of respondents were from the construction industry's Clients side, while 36% were from the Consultants side. Similarly, 51% of respondents worked for contractors, 5% worked for educational institutions, and 0% worked for suppliers. The remaining 2% came from various sources.

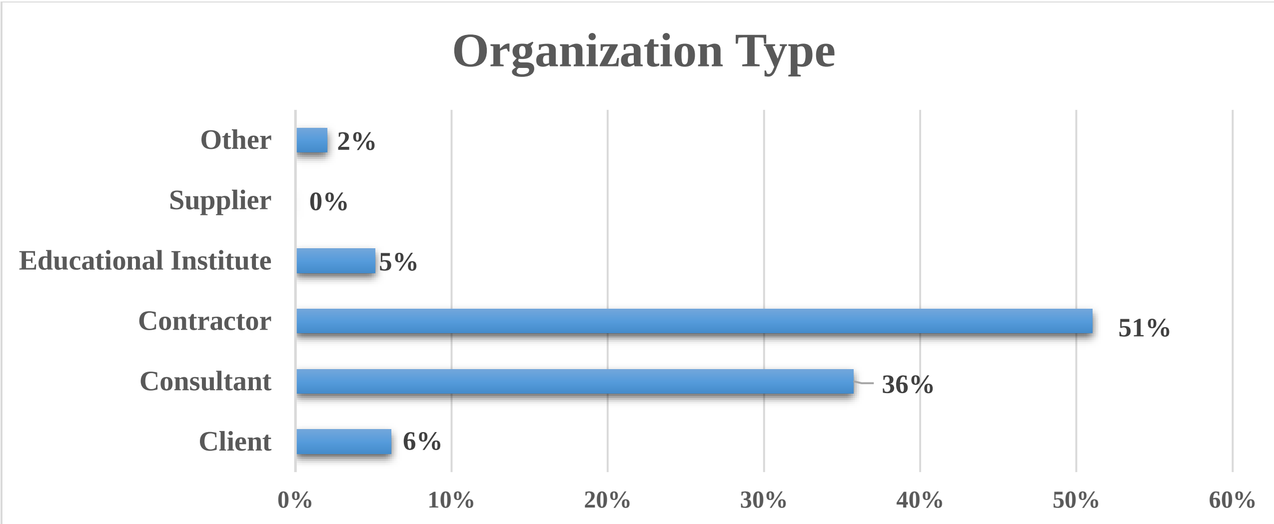

Figure 9: Detailed Survey – Organization Type

4.2.2.3 Region of Respondents

Pakistan, India, Bangladesh, the United Arab Emirates, Saudi Arabia, Kuwait, Oman, Qatar, and Bahrain were among the developing nations whose citizens were surveyed. In terms of percentages, 36% of respondents were from Pakistan, 3% from Bangladesh, 1% from India, 2% from the UAE, 15% from Oman, 30% from Saudi Arabia, 8% from Kuwait, 1% from Bahrain, and 4% from Qatar.

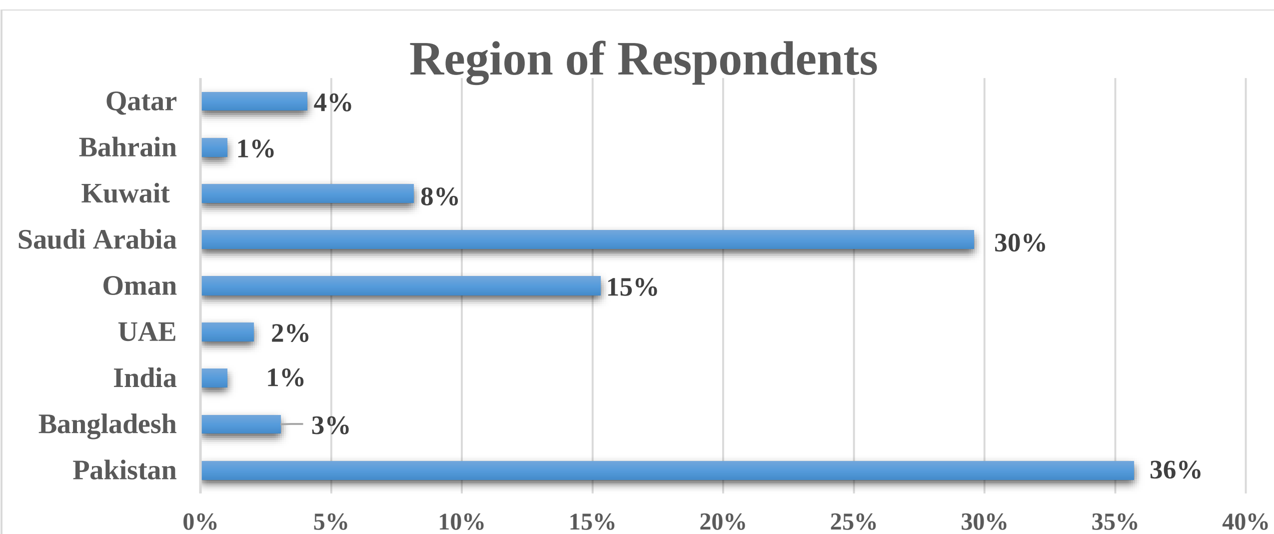

Figure 10: Detailed Survey – Region of Respondents

4.2.2.4 Highest Academic Qualification

27 percent of the 98 respondents had a bachelor's degree, while 67 percent had a master's degree. Only 5% of those polled had a PhD degree, while the remaining 1% had a diploma or certification.

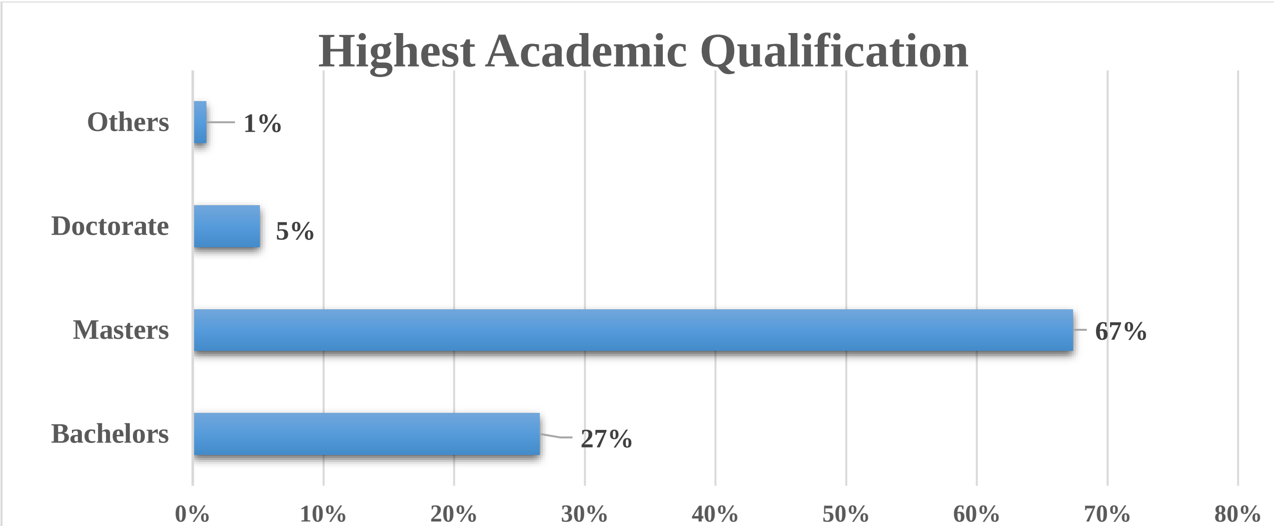

Figure 11: Detailed Survey – Highest Academic Qualification

4.2.3 Reliability Check

Cronbach's Alpha test is used to verify data reliability and internal consistency, and also its benchmark value is 0.7 (Polat et al., 2017). As demonstrated in figure below, the greater the number, the more dependable and internally consistent the data is. The value of Cronbach's Alpha was 0.742, indicating that the data is sufficiently trustworthy and internally consistent.

Cronbach's alpha value (α)	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable

Figure 12: Cronbach's Alpha Values Benchmark

Cronbach's Alpha	N of Items
0.742	98

Figure 13: Cronbach Alpha Value

4.2.4 Causal Relationships with Polarity

The relative importance index is used to narrow down the list of causal linkages for the influence matrix and causal loop diagram. Causal associations with RII values equal to or more than 0.7 or mean values equal to or greater than 3.5 are evaluated for further study (Sourani & Sohail, 2015).

Because the nature of the questions was not unique and independent, the mean value was favored above the mode value when calculating the relative significance index(Boone et al., 2012). A total of 16 causal associations with RII greater than or equal to 0.7 were nominated. The amount of counts in the categories "Direct" and "Indirect" were used to determine polarity (Hamid et al., 2008).

Table 5 : Relationships having Relative Importance Index Greater Than or Equal to 0.7

S.	Impacting Factor	Impacted Factor	RII	Polarity
1	Lack of managerial interest	Lack of personal protective equipment	0.763	Positive
2		Qualified workers and managers	0.771	Negative
3	Environmental issues	Knowledge regarding appropriate hazard	0.743	Negative
4	Lack of personal protective equipment	Unforeseen circumstances	0.771	Positive
5		Defective personal protective equipment	0.735	Positive
6	Innovative technology on safety measures	Lack of safety policy	0.751	Negative
7		Unforeseen circumstances	0.751	Negative
8	Nature of construction projects	Qualified workers and managers	0.788	Positive
9	Lack of safety policy	Lack of personal protective equipment	0.776	Positive
10	Defective personal protective equipment	Lack of managerial interest	0.751	Positive
11		Lack of safety policy	0.784	Positive
12	Unforeseen circumstances	Environmental issues	0.767	Positive
13		Innovative technology on safety measure	0.755	Positive
14	Knowledge regarding appropriate hazard	Lack of managerial interest	0.780	Negative
15		Innovative technology on safety measure	0.751	Positive
16	Qualified workers and managers	Knowledge regarding appropriate hazard	0.755	Positive

4.2.5 Influence Matrix

The interrelationship chart results are used as a foundation for the creation of an influence matrix. In the form of a feedback mechanism, the matrix depicts the influence of variable "y" on variable "x."

Influence Matrix	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
A1	**1**		0.763							-0.771
A2		**1**							-0.743	
A3			**1**				0.735	0.771		
A4				**1**		- 0.751		-0.751		
A5					**1**					0.788
A6			0.776			**1**				
A7	0.751					0.784	**1**			
A8		0.767		0.755				**1**		
A9	-0.780			0.751					**1**	
A10									0.755	**1**

A1 = Lack of managerial interest, **A2 =** Environmental issues, **A3 =** Lack of personal protective equipment, **A4 =** Innovative technology on safety measures, **A5 =** Nature of construction projects, **A6 =** Lack of safety policy, **A7 =** Defective personal protective equipment, **A8 =** Unforeseen circumstances, **A9 =** Knowledge regarding appropriate hazard, **A10 =** Qualified workers and managers

Figure 14: Influence Matrix Diagram for CLD

4.3 Causal Loop Diagram

The influence matrix aided in gaining an understanding of the dynamics of elements in a highly interrelated system by flourishing a causal loop diagram (CLD). R1, R2, R3, R4, and R5 are the five reinforcing loops while B1 and B2 are balancing loops shown in the Causal Loop Diagram. The interwoven loops depict a sensible and logical complicated structure that is responsible for influencing the safety hazards.

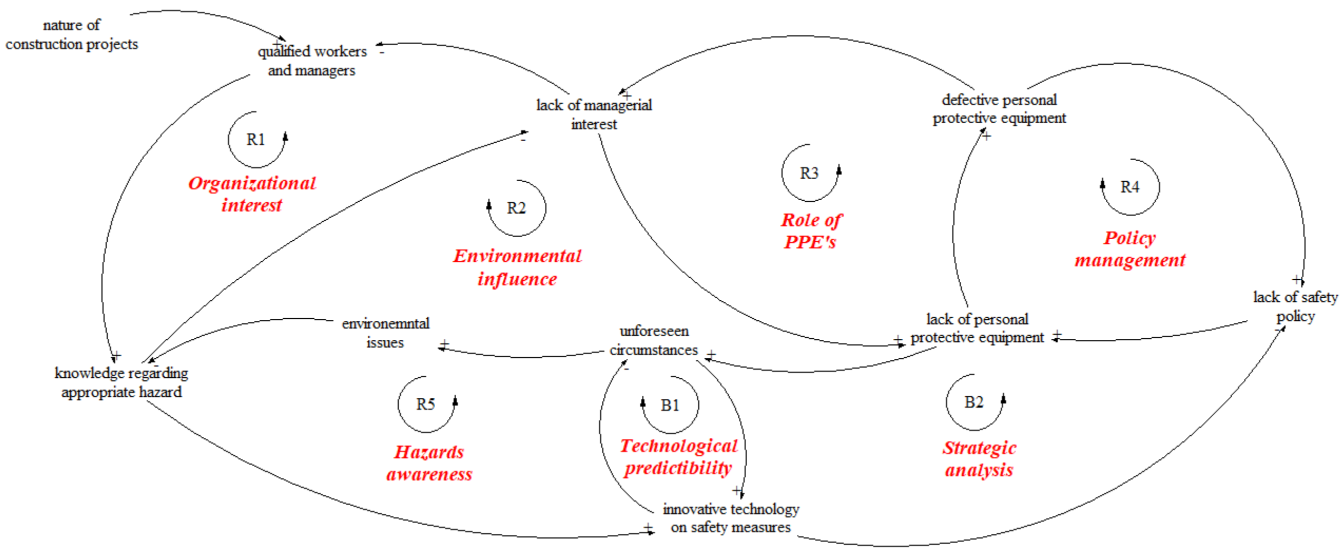

Figure 15: Causal Loop Diagram (CLD)

4.3.1 Reinforcing Loop 1 (Organizational Interest)

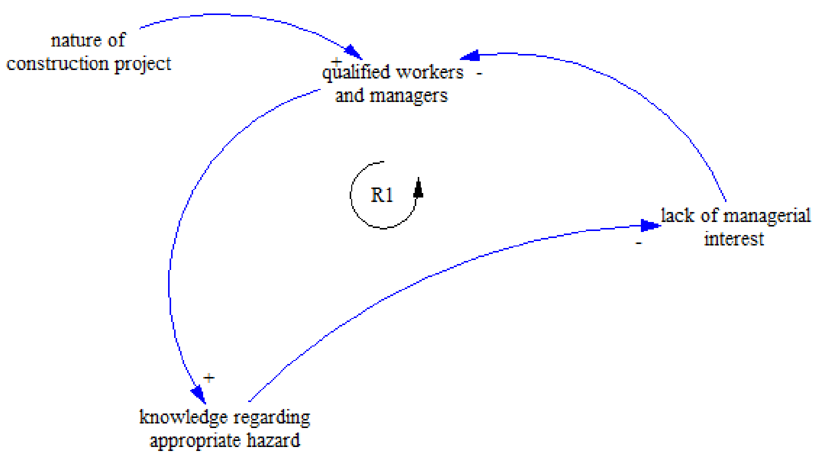

Figure 16: Reinforcing Loop – R1

Reinforcing loop R1 depicts that if the qualified worker and managers are present at construction sites so the knowledge regarding appropriate hazard will be more as compared to if there were less qualified workers and managers. Accordingly, if the knowledge regarding appropriate hazard is more so the lackness of managerial interest will be minimal. A lack of managerial interest will portray that the number of qualified workers and managers are reduced. The nature of construction project being an exogenous variable shows that if the projects are complex then there would be skilled workers and managers at site and vice versa.

4.3.2 Reinforcing Loop 2 (Environmental Influence)

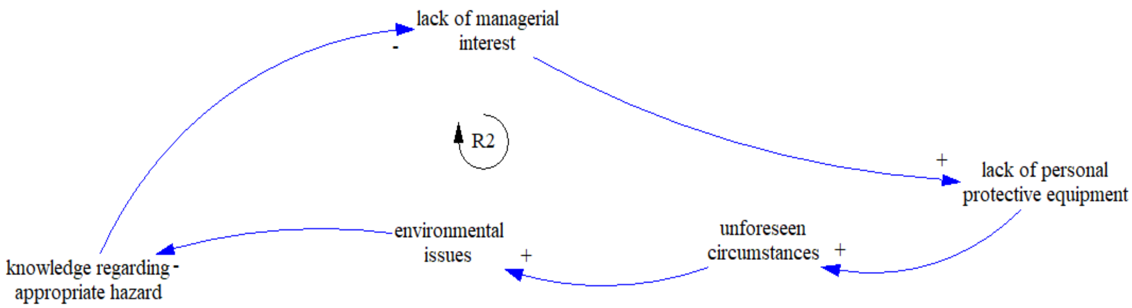

Figure 17: Reinforcing Loop – R2

Reinforcing loop R2 illustrates that the lack of managerial interest at construction sites will ultimately increase the scarcity of personal protective equipment which will give rise to certain unforeseen circumstances perceptibly giving rise to many environmental issues. The larger number environmental issues exemplifies that the knowledge regarding the appropriate hazards will be scarce. Eventually, lackness of managerial interest will be more if the knowledge regarding appropriate hazard is less.

4.3.3 Reinforcing Loop 3 (Role of PPE's)

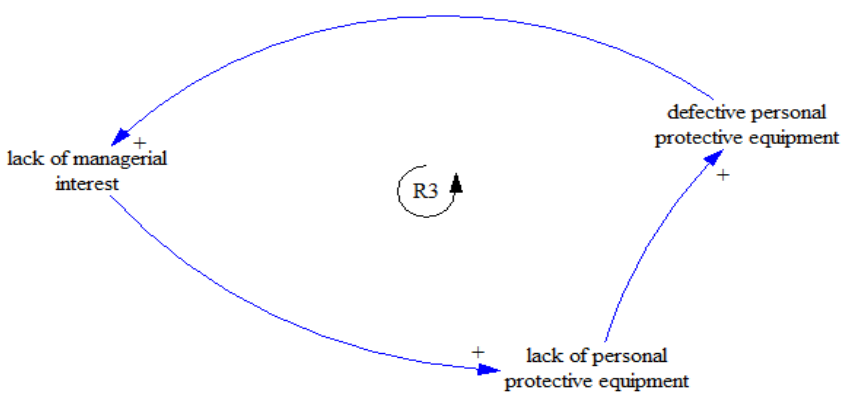

Figure 18: Reinforcing Loop – R3

Reinforcing loop R3 implies that an increase in defective personal protective equipment leads of increase in lackness of managerial interests. An increase in lack of managerial interest further upsurges the lack of personal protective equipment. The lack of personal protective equipment will further increase the chances of having defective personal protective equipments.

4.3.4 Reinforcing Loop 4 (Policy Management)

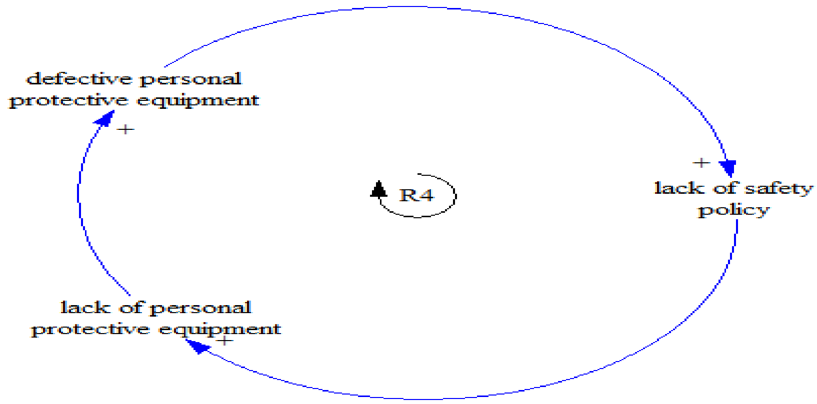

Figure 19: Reinforcing Loop – R4

Reinforcing loop R4 infers that higher the lackness of safety policy at construction sites more will be the lackness of perosnal protective equipments present at sites. This lackness of personal protective equipments will in term again increase the chances of personal protective equipments to be defective. Similarly, defective personal protective equipment will trigger a rise in the lackness of safety policy.

4.3.5 Reinforcing Loop 5 (Hazards Awareness)

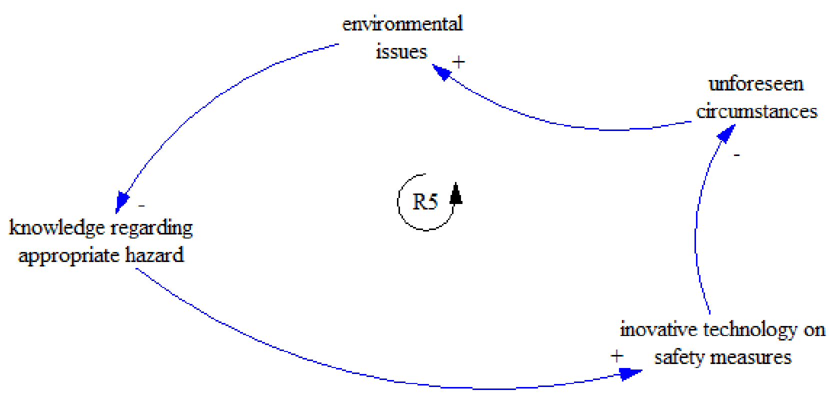

Figure 20: Reinforcing Loop – R5

Reinforcing loop R5 implies that an increase in unforeseen circumstance will lead to increase in environmental issues which eventually will lead towards a decrease in knowledge regarding the appropriate hazard. A decrease in knowledge regarding the appropriate hazard will ultimately increase the need for innovative technology on safety measures. Similarly, increase in the need for innovative technology on safety measures will inversely compliment the unforseen circumstances

4.3.6 Balancing Loop 1 (Technological Predictability)

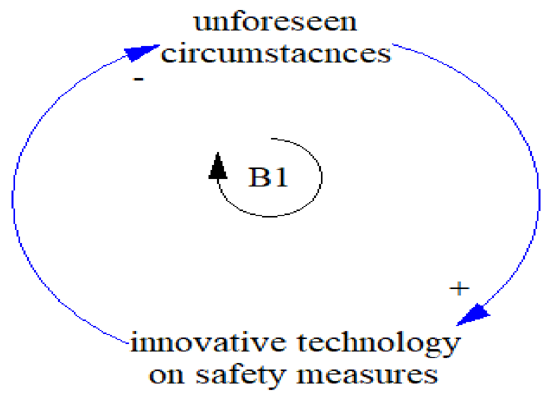

Figure 21: Balancing Loop – B1

Balancing loop B1 implies that an increase in unforeseen circumstance will lead towards increase in the need for innovative technology on safety measures. The increase in the need for innovative technology on safety measures will decrease the chances of having unforeseen circumstances/conditions.

4.3.7 Balancing Loop 2 (Strategic Analysis)

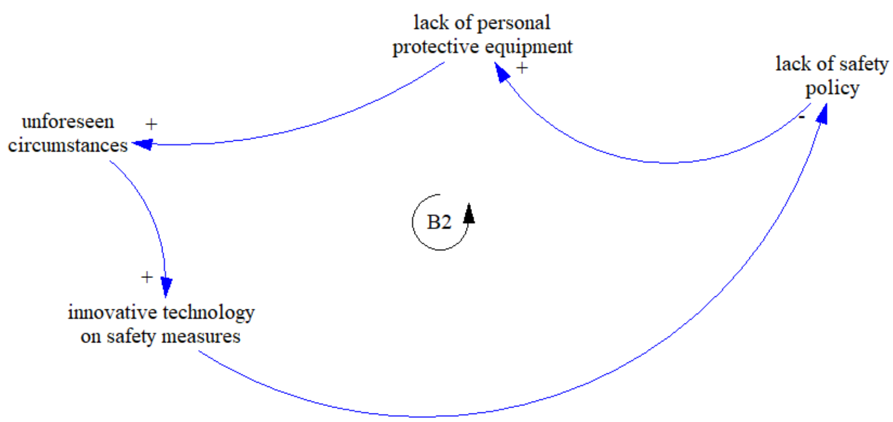

Figure 22: Balancing Loop – B2

Balancing loop B2 entails that rise in lack of safety policy will lead towards an increase in the lack of personal protective equipments. An increase in lack of personal protective equipment will trigger an increase in unforeseen circumstances/conditions. Accordingly, the increase in unforeseen circumstances will surge the need for innovative technology on safety measures.

However, an increase in need for the innovative technology on safety measures will reduce the lackness of safety policy.

4.4 Stock and Flow Diagram

A stock and flow diagram was created using a causal loop diagram. Lack of managerial interest, unforeseen circumstances, lack of personal protective equipments, innovative technology on safety measures and knowledge regarding appropriate hazadrs were recognised as five stocks.

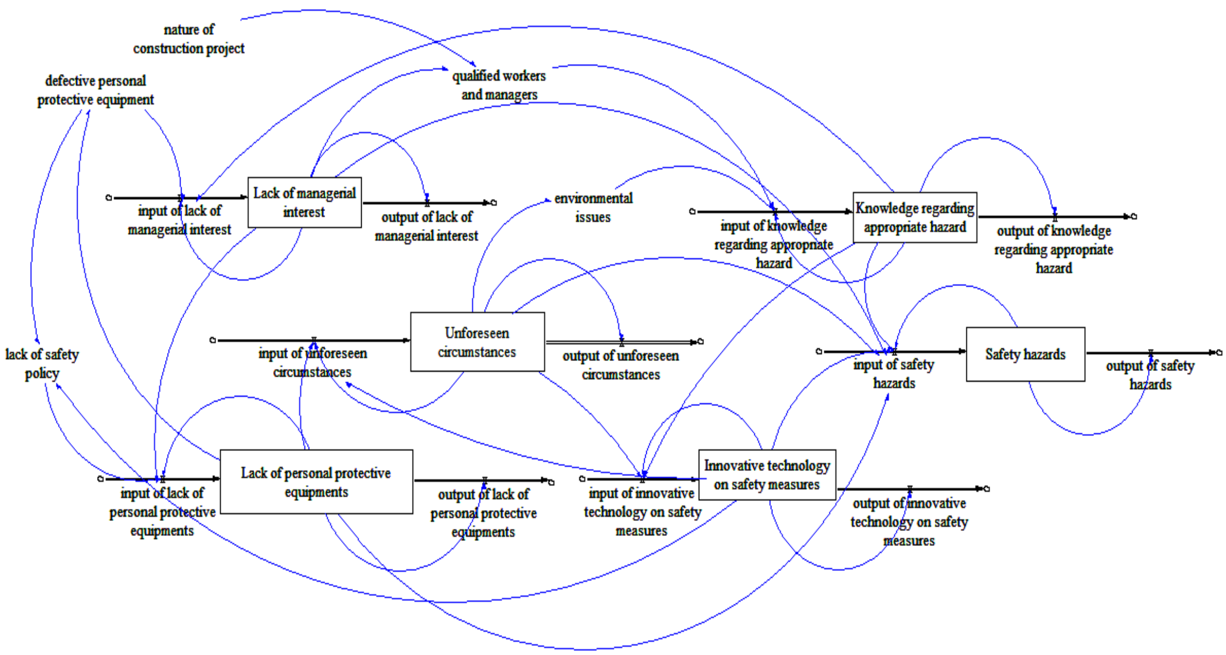

Figure 23: Stock & Flow Diagram (SFD)

4.5 System Dynamic Model

In regard to cultivate equations for each stock and assorted flows, the feedback attained in detailed questionnaire survey aided in development of equations in the model. Relative importance index of each causal relationship was normalized as given hereunder:

Table 6 : Relationships for System Dynamic Model with Normalized Relative Importance Index

S.	Impacting Factor	Code	Impacted Factor	RII	Normalized RII	Polarity
1	**Lack of managerial interest**	**A1**	Lack of personal protective equipment	0.763	0.0627	Positive
2			Qualified workers and managers	0.771	0.0632	Negative
3	**Environmental issues**	**A2**	Knowledge regarding appropriate hazard	0.743	0.0609	Negative

S.	Impacting Factor	Code	Impacted Factor	RII	Normalized RII	Polarity
4	**Lack of personal protective equipment**	**A3**	Unforeseen circumstances	0.771	0.0632	Positive
5			Defective personal protective equipment	0.735	0.0603	Positive
6	**Innovative technology on safety measures**	**A4**	Lack of safety policy	0.751	0.0616	Negative
7			Unforeseen circumstances	0.751	0.0616	Negative
8	**Nature of construction projects**	**A5**	Qualified workers and managers	0.788	0.0646	Positive
9	**Lack of safety policy**	**A6**	Lack of personal protective equipment	0.776	0.0636	Positive
10	**Defective personal protective equipment**	**A7**	Lack of managerial interest	0.751	0.0616	Positive
11			Lack of safety policy	0.784	0.0643	Positive
12	**Unforeseen circumstances**	**A8**	Environmental issues	0.767	0.0629	Positive
13			Innovative technology on safety measure	0.755	0.0619	Positive
14	**Knowledge regarding appropriate hazard**	**A9**	Lack of managerial interest	0.780	0.0640	Negative
15			Innovative technology on safety measure	0.751	0.0616	Positive
16	**Qualified workers and managers**	**A10**	Knowledge regarding appropriate hazard	0.755	0.0619	Positive

Five (5) stocks were pinpointed, named as lack of managerial interest, unforeseen circumstances, lack of personal protective equipments, innovative technology on safety measures and knowledge regarding appropriate hazard. Equations developed through normalized relative imporatnce index for inflows and outflows of all stocks are given below;

1. Input of lack of managerial interest = (0.0616* A7) - (0.064* A9) + (1*A1)

Equation 3

2. Output of lack of manegerial interest = (1*A1)

Equation 4

3. Input of unforeseen circumstances = (0.0632*A3) – (0.0616*A4) + (1*A8)

Equation 5

4. Output of unforeseen circumstances = (1*A8)

Equation 6

5. Input of lack of personal protective equipments = (0.0627*A1) + (0.0636*A6) + (1*A3)

Equation 7

6. Output of lack of personal protective equipments = (1*A3)

Equation 8

7. Input of knowledge regarding appropriate hazard= -(0.0609*A2) + (0.0619*A10) + (1*A9)

Equation 9

8. Output of knowledge regarding appropriate hazard = (1*A9)

Equation 10

9. Input of innovative technology on safety measures= (0.0616*A9) + (0.0619*A8)+(1*A4)

Equation 11

10. Output of innovative technology on safety measures = (1*A4)

Equation 12

11. Input of Safety Hazards = A4 * A9 * A1 * A3 * A8 + (1*Safety Hazards)

Equation 13

12. Output of Safety Hazards = (1* Safety hazards)

Equation 14

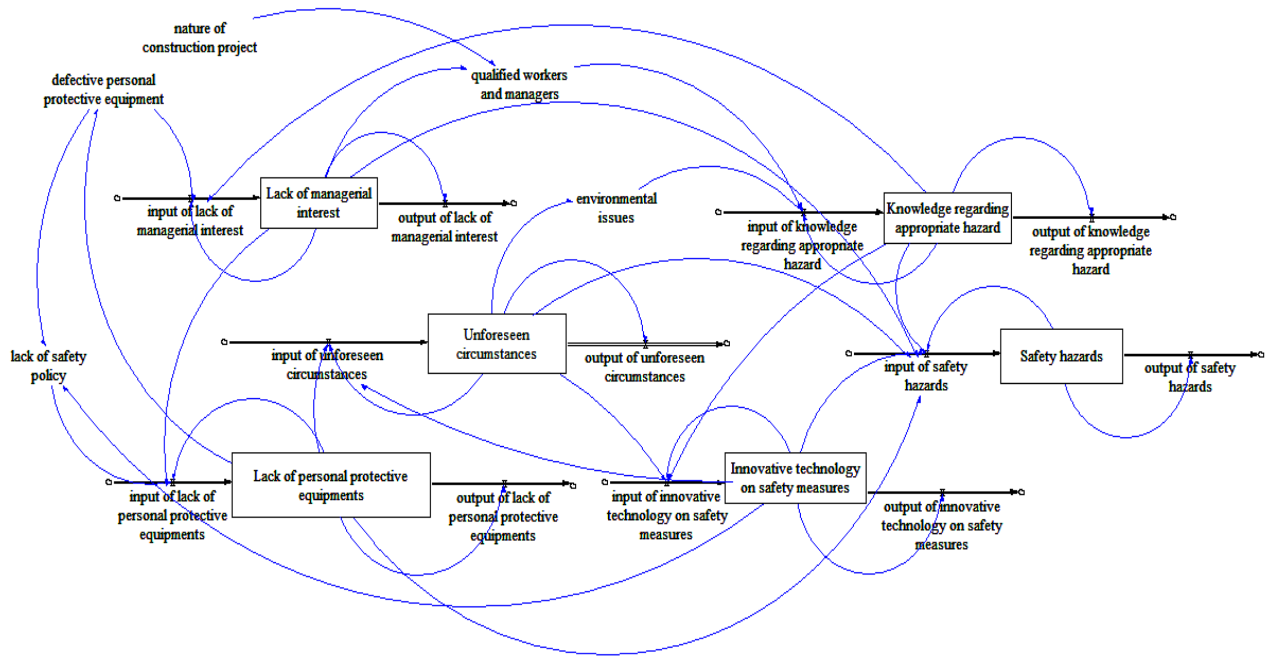

Figure 24: System Dynamic Model (SDM)

4.5.1 Simulation Results and Discussions

The simulation depicts the system's behaviour throughout a five-year timeframe. Throughout the simulation, the values of exogenous variables i-e nature of construction project and defective personal protective equipment were held constant, i.e. 1 (one). *Lack of managerial interest*, *unforeseen circumstances*, *lack of personal protective equipments*, *knowledge regarding appropriate hazard* and *innovative technology on safety measures* were all simulated independently over a five-year period, with the outcomes explained separately. Finally, a sixth stock, *Safety Hazards*, was simulated to see how all of the five stocks that were converged on it affected it.

Lack of manegerial interest decreased in a perfectly linear mode during the timeframe of five years. This was mainly due to the effects of the negative influence of *knowledge regarding appropriate hazard* due to which it was negatively complimenting the *lack of managerial interest*.

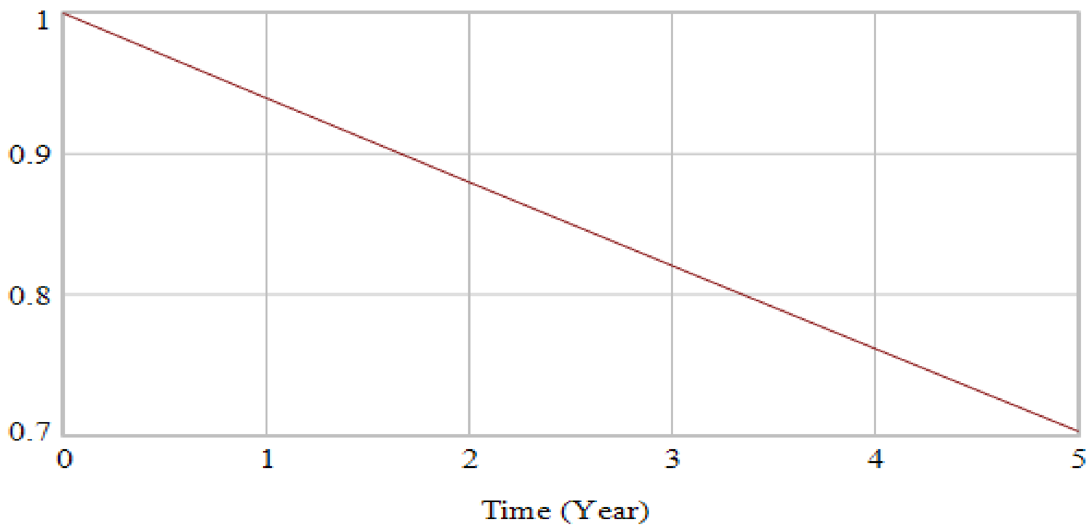

Figure 25: Lack of managerial interest – Simulation Graph

Accordingly, *unforseen circumstances* slighlty increased but then abrubtly decreased over the period of five years of simulation. This slight increase was due to the positive influence of *lack of personal protective equipment* on *unforeseen circumstances* but the cumulative impact of negative influence resulting from *innovative technology on safety measures* was much greater causing the *unforeseen circumstances* to decrease brusquely.

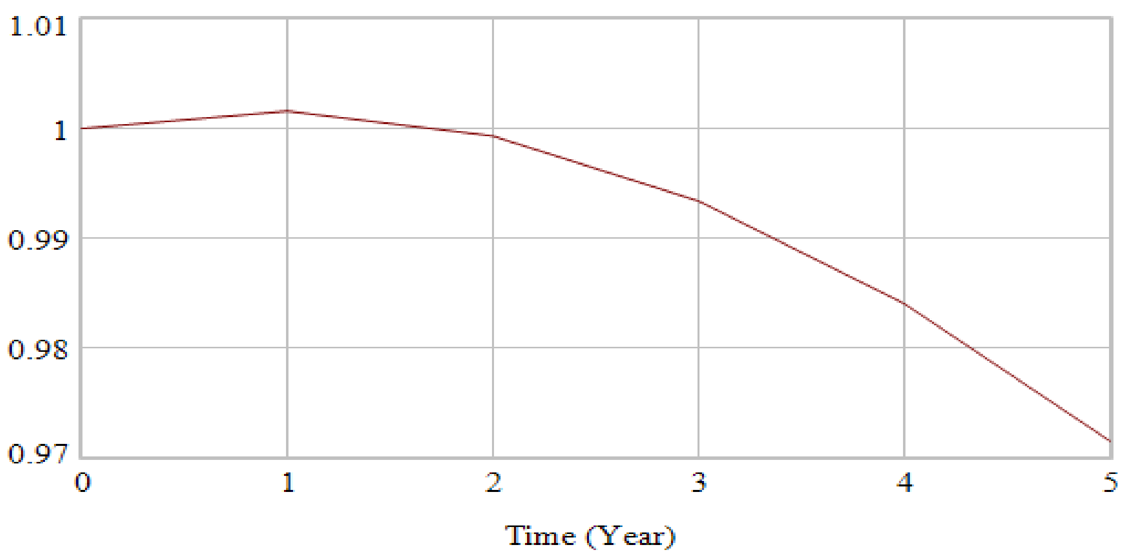

Figure 26: Unforeseen Circumstances – Simulation Graph

Likewise, *lack of personal protective equipment* also increased in an almost linear mode. This was mainly due to factors like *lack of safety policy* and *lack of managerial interest* which were positively complimneting the *lack of personal protective equipments* and in term increasing the *lack of personal protective equipment*.

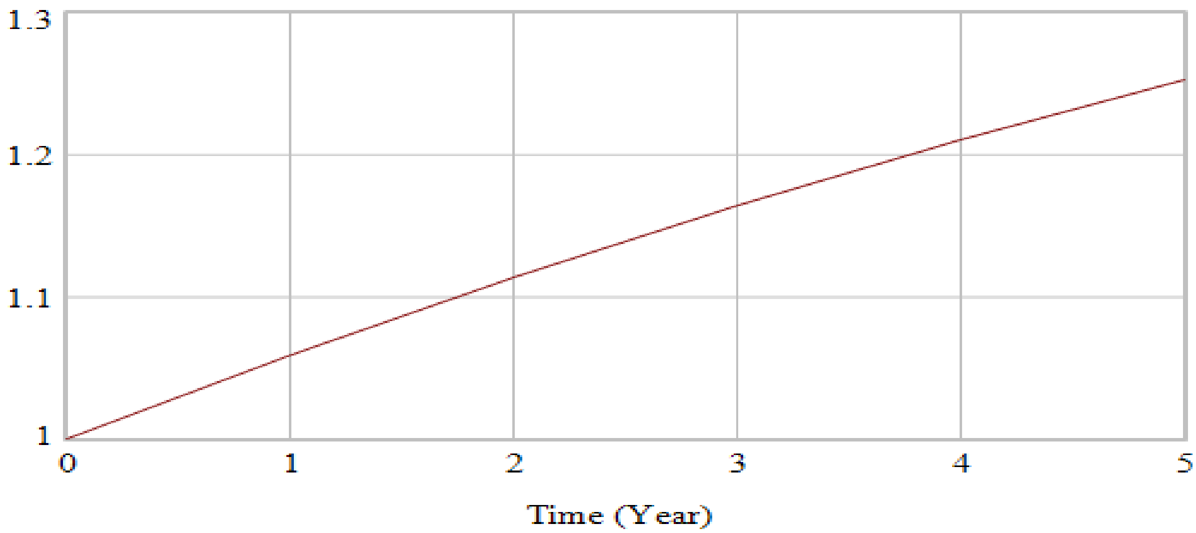

Figure 27: Lack of personal protective equipments – Simulation Graph

Furthermore, *knowledge regarding appropriate hazard* gradually decreased during the 5 year period maily due to negative effect of *environmental issues* although factor like *quality workers and managers* was positively complimenting the *knowleage reagrding appropriate hazard* but the overall effect was coming out to be negative due to the negative influence of *environmental issues.*

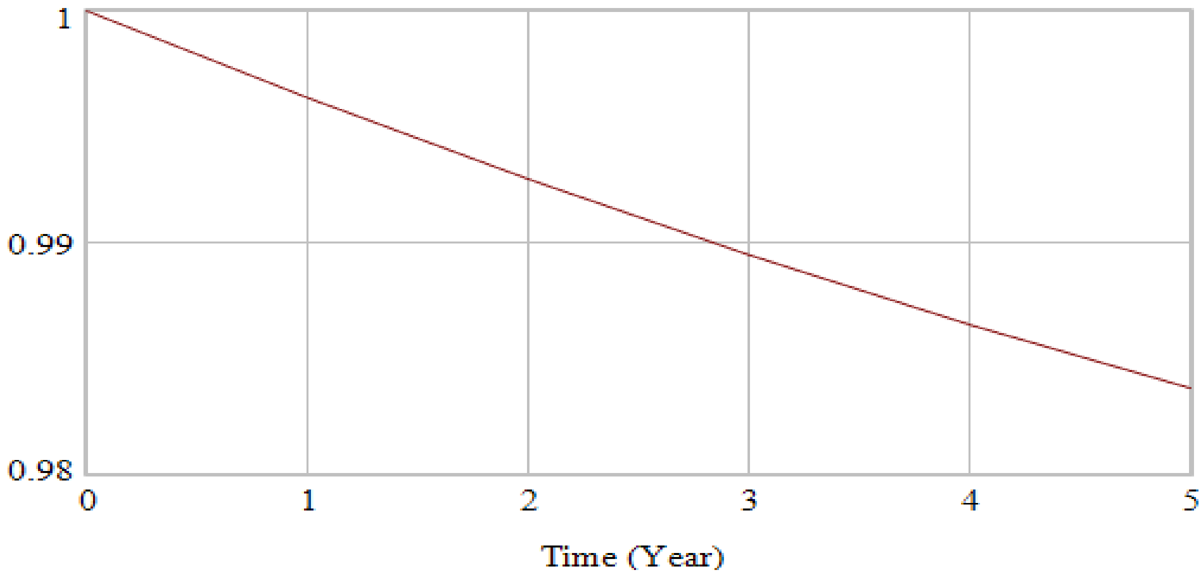

Figure 28: Knowledge regarding appropriate hazard – Simulation Graph

The Simulation graph of *innovative technology on safety measures* showed an increase in a linear direction. This was due to the positive influence of *knowledge regarding appropriate hazard* and *unforeseen circumstances* on *innovative technology on safety measures* due to which it showed an increase in linear direction.

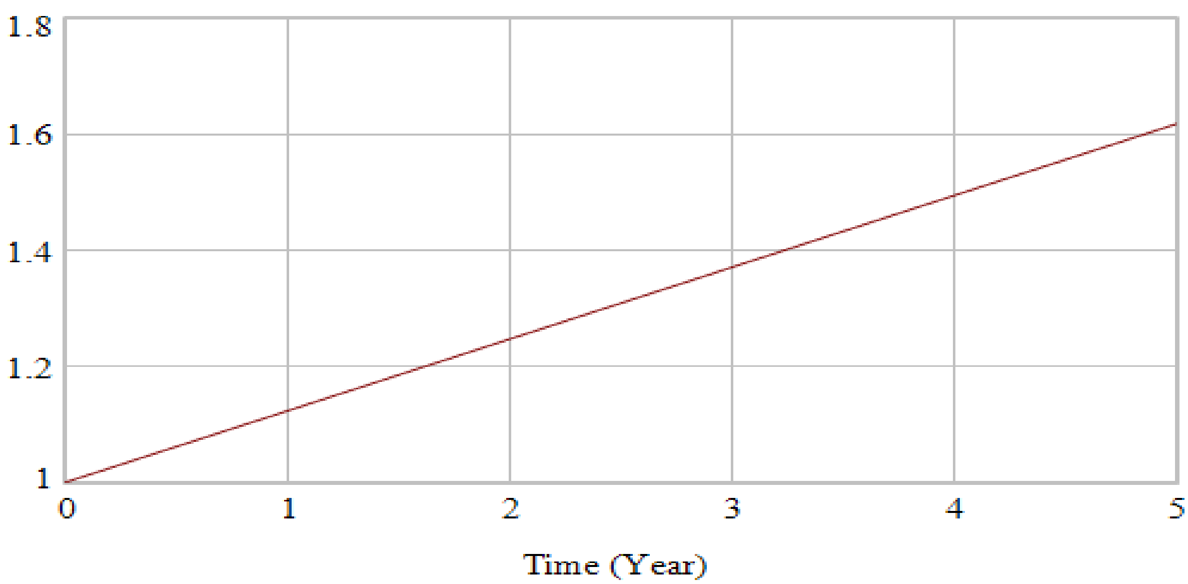

Figure 29: Innovative technology on safety measures – Simulation Graph

Lastly, the simulation graph of *Safety Hazards* which took input from all the five stocks also showed an increasing trend over the period of five years' time duration which was very logical and understandable as the reinforcing loops and the positive influences were dominating throughout due to such an impact the *Safety Hazards* increased over the period of time.

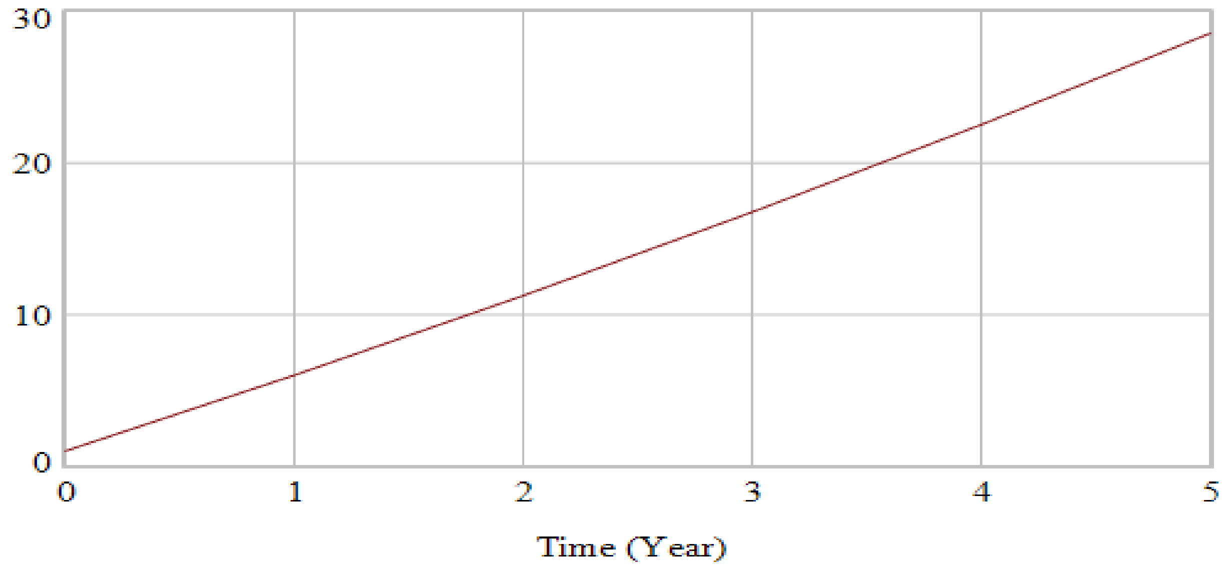

Figure 30: Safety Hazards – Simulation Graph

4.5.2 Model Validation

In the field of system dynamics, model validation is seen as a critical stage. There is a significant connection between a model's validity and its "purpose".The model's purpose will not be met until it is confirmed. As previously stated, the model's primary goal is to investigate factors that influence construction site safety hazards. As a result, the step to model validity is developed in order to demonstrate that it is critical for its main purpose. Boundary adequacy test, Structure verification test, and Parameter verification test are some of the tests used to validate the model (Qudrat-Ullah & Seong, 2010).

4.5.2.1 Boundary Adequacy Test

A boundary adequacy test was performed to see if the model's essential ideas for solving the problem are endogenous, and if the model's behaviours change dramatically when the boundary assumptions are loosened (Sterman, 2000). The system dynamics model incorporates all of the variables gleaned through a thorough literature research, which were then confirmed by expert opinions. As a result, the variables were discovered to be endogenous to the model. Furthermore, the model's behavior did not alter as the boundary conditions changed.

4.5.2.2 Parameter Verification Test

The system was mathematically linked based on field responses, which proved to be empirical proof for the sound model structure (Sterman, 2000).

4.5.2.3 Structure Verification Test

The goal of this test is to see if the model's structure matches up with the system's relevant descriptive information (Sterman, 2000). The model's structure is represented by the interrelated variables in the numerous loops. All of the variables in this model were selected through a thorough literature research, and field specialists subsequently verified the presence of interrelationships between variables. This aided in the creation of a coherent and understandable causal loop diagram. As a result, the model structure closely resembles the actual industry system.

4.5.2.4 Extreme Condition Test

Because all exogenous variables were assigned unity values, or 100%, the existing system dynamics model was previously simulated at extreme conditions. As "Safety Hazards" (the convergence point of all five stocks in the model) rose under the provided system, the findings indicated that model behaviour is still relavent.

5. CONCLUSION AND RECOMMENDATION

The construction industry is one of the most dangerous in the world. The working environment, as well as the activities that must be completed, are both complex. On the whole, there are a lot of people working on the construction site. Heavy machinery and a labyrinth of pipelines, materials, and cables are always present. Furthermore, because construction sites are seldom "tidy," it's unsurprising that major injury rates are higher on construction sites than in other sectors. One safety hazard can always trigger another saety hazards in an increasing manner or decreasing manner due to which it needs to be studied in order to cope with with such factors that influence safety hazards at the construction sites. System dynamics was utilised as a technique to reflect systems thinking and, as a consequence, design a model to handle the complexity that resulted in construction site safety hazards.

Preliminary questionnaire survey and detailed questionnaire survey were used to obtain data. A preliminary survey was conducted to identify contributory elements that affected construction site safety hazards, and a detailed survey was conducted to identify the most relevant interrelationships between the components, as well as their polarity. In order to make the causal loop diagram intelligible and relevant to the construction sector, expert comments were also sought.

The research began with an evaluation of the literature to classify factors that influenced construction site safety hazards. From the literature, a total of 25 relevant factors that affected safety hazards were discovered. On the basis of these 25 contributing factors that influenced safety hazards, a preliminary questionnaire was constructed, in which respondents were enquired to score the influencing factors on a Likert scale ranging from 1 to 5. For the influencing factors, a normalized score was created for both the literature and the respondents, which was then blended using a 60/40 ratio. A total of ten factors impacting construction site safety hazards were shortlisted, with a cumulative normalized score of up to 50%. Lack of management interest, environmental issues, a lack of personal protective equipment, innovative technology on safety measures, and the nature of construction projects were identified as top 5 factors that influenced safety hazards at construction sites .

A detailed questionnaire was developed in order to develop systems thinking and causal loop diagram (CLD), in which respondents were asked to mark causal strength (low, medium, or high) as well as causal relationship (direct or indirect) of each factor that influenced safety hazard at the construction site on the other. Interrelations with a mean influence value more than or equal to 3.5 or a relative relevance index greater than or equal to 0.7 were used to create a causal loop diagram. The causal loop diagram was changed based on construction experts' expert judgments in order to make it more comprehensible and relevant to the construction industry. Five reinforcing and two balancing loops make up the causal loop diagram.

Finally, using VENSIM®, a system dynamics model was built based on modified systems thinking and CLD. The shortlisted causal influence scores were normalized for use in the system dynamics model, and a stock and flow diagram resulting in an SD model was created through simulation. The model is made up of five stocks: a **lack of managerial interest**, **unforeseen circumstances**, a **lack of personal protective equipment**, **knowledge regarding appropriate hazards**, and **innovative technology on safety measures**. One additional stock, in the shape of a safety hazard, was added, and all five stocks were merged on it to observe how they interacted.

Over a five-year period, the model was simulated. Throughout the simulation, the value of the exogenous variable, the nature of the construction project, was held at one (1). Under the effect of reinforcing interrelationships, all five stocks demonstrated rising behaviour. Because it is adversely supplemented by others, the simulation graph of the factor, lack of managerial interest, unforeseen circumstances, and knowledge of appropriate hazards declines with time. As a result of the convergence point of all five stocks, the "Safety Hazards" graph likewise showed a rising curve. This essentially represents the fact that, under the established system, safety hazards rise with time.

The outcomes of this study point the way for construction companies to build a culture/strategy for determining the factors that influence safety hazards and dealing with them in a timely and favourable manner, hence enhancing project performance. With the support of system thinking and behaviour throughout time, the CLD and SD model comprehensively explains factors that influenced safety hazards on construction sites. Future study might focus on putting the created model to use in the construction industry.

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