SAFETY ACTIVITY ANALYSIS FRAMEWORK TO EVALUATE

SAFETY PERFORMANCE

IN CONSTRUCTION

by

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ABSTRACT

The construction work environment remains one of the most hazardous worldwide. As a result of dangerous working environments, construction workers often face safety and health risks throughout the construction process. However, it is worth noting that an emphasis on construction safety has increased mainly in the aspect of safety performance, and efforts are required to not only monitor but also seek to improve safety performance. The main objective of this research is to assess safety performance on construction sites using safety activity analysis technique. A safety activity analysis framework as well as a safety activity analysis tool are developed to facilitate the collection and analysis of the safety activity data for continuous evaluation of safety performance. Additionally, a case study is carried out to implement the framework and tool on an active construction project. Activity observation is used to continuously collect data of safe behaviors and conditions, along with unsafe behaviors and conditions on construction sites for analysis and decision making. It is expected that the observation results can be used to set improvement targets and provide continuous feedback so that construction workers can adjust their performance accordingly. The findings of the case study show that the safety index of the construction site ranged from 37.0% to 62.8% with an average of 53.8%. Results obtained also indicate that the stage of a construction process can affect the safety performance of a project. It was recommended that well-informed decisions and far-reaching efforts have to be made to ensure the safety index is brought as close as possible to 100% by reducing the unsafe behaviors and conditions on the construction site.

DEDICATION

This thesis is dedicated to my dear parents Mr. Olusegun Lucas Awolusi and Mrs. Modupe Juliana Awolusi for their unflinching support.

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CHAPTER 1

INTRODUCTION

This chapter presents an overview of safety in the construction industry along with background to the study of the evaluation of safety performance in the construction work environment. The goals and significance of measuring construction safety performance are discussed. The existing approaches being adopted in the measurement of construction safety performance are highlighted. The motivation and objectives of the research, as well as the research contributions, are also presented.

1.1 Overview and Background to the Study

Globally, the construction industry experiences one of the highest rates of occupational injuries, illnesses, and fatalities when compared with other industries (Brunette, 2004; Bansal, 2011; HKOSH, 2013; HSE, 2014; BLS, 2015a). The global importance of the construction industry in producing facilities that support various economic activities and contribute to the delivery of social and environmental needs of a nation makes construction safety a crucial subject of concern (HSE, 2009). Still, the construction industry remains one of the most hazardous and unsafe industries with fatality and incidence rates considerably higher than the all-industry average in many countries (HSE, 2009; Che Hassan et al., 2007; Zou & Sunindijo, 2013; BLS, 2015a).

In the construction industry, workers are exposed to hazards that are difficult to quantify for reasons closely associated with the way construction work is performed. Not only do work locations for any group of workers often change, but each work site evolves as construction proceeds, changing the hazards workers face on a weekly and sometimes even daily basis (McDonald et al., 2009). Poor safety on construction sites affects workers and their relatives in physical and psychological ways that impact the project financially by increasing direct and indirect costs (Bansal, 2011). Besides managing the triple bottom line of time, cost, and quality, project personnel also have an important role in managing safety risks in construction projects (Zou & Sunindijo, 2013; Che Hassan et al., 2007). The statistics of incidents in the construction industry clearly show an immediate need to reduce the prevalence of fatal and non-fatal injuries in construction (Seo, Han, Lee, & Kim, 2015) and thus a need for continuous measurement of safety activities to evaluate safety performance on construction sites.

The primary purpose of measuring safety performance is to create and implement intervention strategies for potential avoidance of future accidents. Recognizing signals before an accident occurs offers the potential for improving safety; many organizations have sought to develop programs to identify and benefit from alerts, signals, and prior indicators (Grabowski et al., 2007). Traditional measures of safety performance rely on some form of accident or injury data (Choudhry et al., 2007), with actions being taken in response to adverse trends in injuries (Hallowell et al., 2013). Fearnley and Nair (2009) also noted that the original response from organizations was to assess safety by monitoring and investigating accidents and incidents to determine root causes in order to target actions that could reduce the risk of a repeat event. Alternatively, safety-related practices can be measured during the construction phase to trigger positive responses before an injury occurs (Hallowell et al., 2013). Another technique is behavior sampling, which requires one or more trained observers to observe workers on-site to determine whether they are working safely or unsafely (Choudhry et al., 2007).

In order to achieve a zero incidents, proactive methods of safety management should also occur during the construction phase (Hallowell et al., 2013). Current safety performance and potential risks in the operation or in the facility can be predicted in advance, and one can take proactive actions to avoid or reduce the occurrence of an incident (Chen & Yang, 2004). According to Hallowell et al. (2013), there is need to identify and define predictive indicators of safety performance that can be measured and monitored during the construction phase. These predictive indicators are referred to as leading indicators because they can be measured and adjusted as the project progresses in order to monitor and improve safety performance. Reiman and Pietikainen (2012) also acknowledged that an increased emphasis has recently been placed on the role of leading indicators in providing information for use in anticipating and developing organizational performance, as opposed to the commonly used lagging indicators which measure outcomes of activities or events that have already happened.

The finding that safety climate perceptions will not necessarily match actual levels of safety performance strongly suggests that the industry should focus its primary safety improvement efforts on changing unsafe situations and conditions, as well as people's safety behavior at all organizational levels, rather than concentrating on improving people's attitudes, beliefs, and perceptions about safety (Cooper & Phillips, 2004). Behavioral approaches to safety management are commonly implemented within organizations in order to improve safety and reliability. These interventions are based upon the principle that modification and change of safety-critical behaviors can facilitate safety improvements and reduce accidents (Cox & Jones, 2006). It is reduction in the frequency of unsafe behaviors and their antecedents (i.e., unsafe conditions or situations) that reduce the opportunity for accidents to occur, not perceptions about how safety is operationalized (Cooper & Phillips, 2004). To avoid unsafe acts, workers need to be guided in a proactive manner and management needs to reinforce the value and importance of safety among operatives. Workers are required to change their attitudes towards safety by obtaining training and knowledge about their jobs and should not behave unsafely if they want to be accident-free (Choudhry & Fang, 2008).

1.2 Motivation and Research Objectives

Many construction organizations rely heavily on failure data to monitor performance. The consequence of this approach is that improvements or changes are only determined after something has gone wrong (HSE, 2006). In most cases, the difference between whether a system failure results in a minor or catastrophic outcome is purely a matter of chance. Despite the potential benefits of using leading indicators (such as workers' unsafe actions and unsafe conditions) for safety improvement, behavior measurement (e.g., field observation) has not been actively carried out on a construction site because it is a manual, time-consuming task and a large amount of samples is necessary to avoid biases (Han & Lee, 2013).

Effective management of major hazards requires a proactive approach to risk management, so information to confirm that critical systems are operating as intended is essential. Switching the emphasis in favor of leading indicators to confirm that risk controls continue to operate is an important step forward in the management of major hazard risks (HSE, 2006). Accurate safety performance measurement facilitates the evaluation of ongoing safety management and the motivation of project participants to improve safety (Han & Lee, 2013).

With the current surge in the measurement of leading indicators in the construction industry, continuous data collection and analysis has the potential to positively impact decision making in safety management (Pradhananga & Teizer, 2013). If data would be more rapidly updated, safety personnel could take faster preventive actions and prevent hazardous conditions before they occur. Therefore, the safety goal should be to put adequate efforts in place to achieve zero injuries, because all serious injury to workers can be successfully prevented (Hinze 2002; Huang & Hinze, 2006).

This research uses activity observation or activity sampling (Glendon & Litherland, 2001; Jenkins & Orth, 2003; Cooper & Phillips, 2004; Gouett et al., 2011; Zhang & Fang, 2013) to continuously collect data of safe behaviors and conditions, as well as unsafe behaviors and conditions on construction sites for analysis and decision-making. The activity observation (or activity analysis) results can be used to set and implement improvement targets, and then provide continuous feedback so that construction workers can adjust their performance accordingly. This study takes advantage of the benefits of activity analysis by developing a safety activity analysis framework and tool to continuously assess safety performance on construction sites.

1.3 Contributions

The fundamental focus of this research is to provide a continuous and functional approach for evaluating safety performance during the construction phase. The activity sampling procedure is used to collect data that serves as predictors of safety performance and how they may be used to proactively measure, monitor, and control safety hazards on construction sites. The following are the major contributions of this research:

- A safety activity analysis framework to effectively measure safety performance through the systematic collection and analysis of safety activity data on construction sites;
- A safety activity analysis tool to facilitate the collection and analysis of the safety activity data;

- Scientific evaluation data from a case study that implemented the created tool for safety performance assessment on an active construction project;

1.4 Thesis Organization

This thesis describes an investigation into the use of activity analysis to evaluate safety performance on construction projects. The following is an outline of how this thesis is structured.

Chapter 1 gives an overview of construction safety and background to the study. The motivation for the research, as well as the research objectives, is presented. The research contributions are also given.

Chapter 2 provides a review of safety statistics and current safety practices in the construction industry. A detailed discussion on the measurement of safety performance is given together with the indicators used in measuring safety performance in the construction industry. The concept of human behavioral observation is also discussed extensively.

Chapter 3 presents the research method adopted for the study. The procedure for safety activity analysis is described together with the categories of measurement. The safety activity analysis framework developed in this research is presented along with the safety activity analysis tool created for the easy and efficient collection and analysis of safety activity data. A case study to implement the activity observation technique used for the collection and analysis of safety data on a construction project is also presented.

Chapter 4 presents the results of the research. It gives the analysis and discussion of the results obtained from the case study.

Chapter 5 concludes the research and gives the closing remarks. It also discusses the limitations of the research and areas of further research.

CHAPTER 2

LITERATURE REVIEW

The construction industry continues to rank as one of the most hazardous work environments, recording the highest rates of occupational injuries, illnesses, and fatalities when compared with other industries. Although, a good amount of research work has been carried out to reduce these unwanted situations, much effort is still needed to enhance safety performance on construction sites. Consequently, continuous measurement of safety activities to evaluate safety performance on construction sites is required. This chapter contains a review of relevant literature with respect to safety performance in the construction industry. Construction safety statistics and current safety practices in the construction industry are reviewed. The measurement of safety performance and the metrics used are extensively described. A review of the different methods of observing human behaviors on construction site is also presented. Finally, the end of this chapter includes a research needs statement derived from the findings of this literature review and background to the study.

2.1 Safety Statistics in the Construction Industry

When compared to other industries, the construction work environment is one of the most dangerous in the world (HKOSH, 2013; HSE, 2014; BLS, 2015a). In the United States, construction remains the most hazardous industry in terms of the aggregate number of fatalities (BLS, 2015a). The construction industry has consistently maintained this trend of having the highest rate of occupational injuries for more than a decade when compared with three other major industries, as shown in Figure 2.1. Although the number of fatalities experienced some decrease in the past, it has been increasing in recent times, as can be observed from year 2011 through 2013 in Figure 2.1.

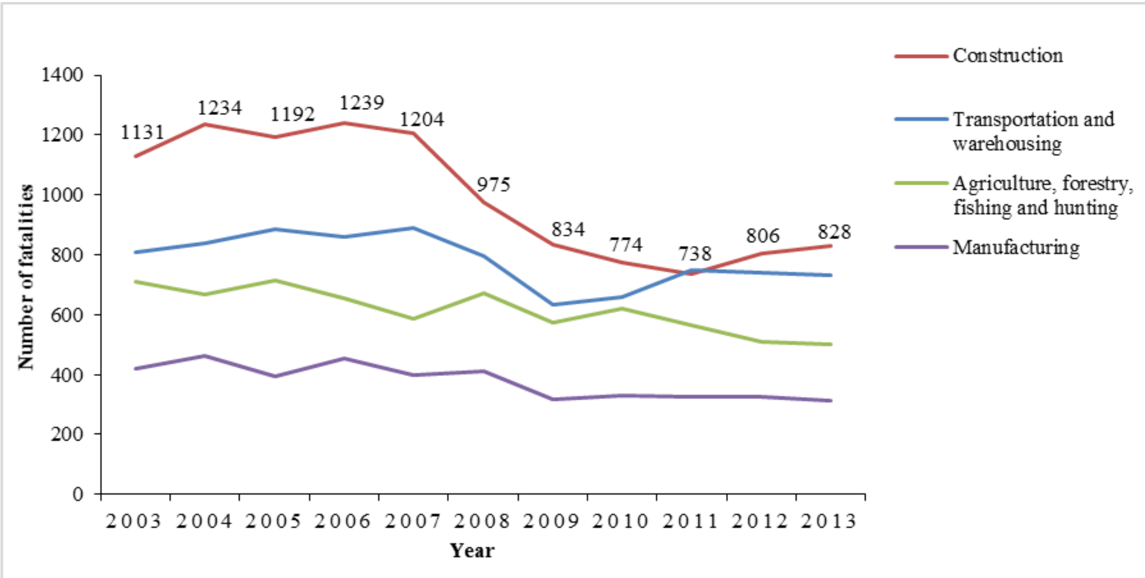
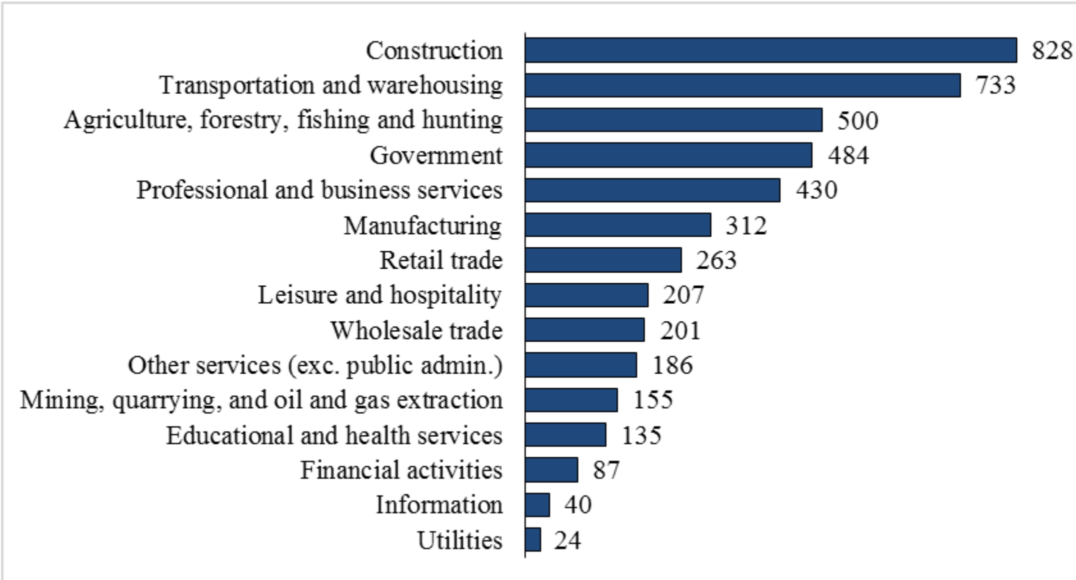


Figure 2.1: Number of Fatal Work Injuries in Major Industries, 2003-2013 (BLS, 2015a)

From the U.S. Bureau of Labor Statistics 2015, construction had the highest count of fatal injuries in 2013, recording 828 injuries (see Figure 2.2), or almost 18% of total fatal work injuries (4,585 injuries). Out of the fatal work injuries experienced in 2013, 16% involved contractors while 35% of those who died while employed in the construction industry were actually contracted to another industry, such as government or the financial sector, when the fatal injury occurred (BLS, 2015b). Construction sites are extremely active places where the working environment is ever changing and difficult to predict before or during construction (Bansal, 2011). Due to hazardous working environments at construction sites, workers frequently face potential safety and health risks throughout the construction process (Seo et al., 2015).



Number of Fatal Occupational Injuries, by Industry Sector, 2013 (BLS, 2015b)

Construction is always risky due to factors such as outdoor operations, work-at heights, and complicated on-site plant equipment operations, as well as workers' attitudes and behaviors towards safety. The nature of the construction industry's rapidly changing conditions, associated work hazards, and the characteristics of construction organizations further aggravate the situation (Choudhry & Fang, 2008). Inadequate safety planning and the ever-changing environment of construction sites often lead to accidents which negatively impact people, project economics, aspects of social life, and associated legal liabilities (Bansal, 2011). Therefore, it is imperative for the construction industry to manage its safety risks and improve its safety performance (Zou & Sunindijo, 2013).

2.2 Current Safety Practices in the Construction Industry

In the construction industry, the protection of workers is of great concern because construction workers often face a high possibility of fatality or injury. As stated by Seo et al.

(2015), the unique, dynamic, and complex nature of construction projects likely increases workers' exposure to hazardous working environments. Construction site safety is one of the project's success factors, along with time, cost and quality (Bansal, 2011). In view of the importance of safety, countries such as the United Kingdom, Singapore and Hong Kong have adopted a self-regulatory approach to safety, whereby proprietors (including contractors) are required to develop, implement, and maintain safety management systems to identify potential hazards at an early stage so as to help avoid unnecessary losses in life and cost (Ng et al., 2005).

On construction projects, the site management teams learn from safety policies and safety management systems while the workforce learns more from toolbox talks and morning site safety cycles (Choudhry & Fang, 2008). In a market-driven society, it is common for construction stakeholders, especially those at the lower end of the supply chain, to concentrate exclusively on completing projects to the required quality standard with the minimum time and cost. Safety is, therefore, regarded as a secondary concern (Ng et al., 2005). Thus, there is a huge need and responsibility for project personnel to also manage and mitigate safety risks on construction sites.

2.3 Measurement of Safety Performance

In recent years, the emphasis on construction safety has intensified, particularly in the aspect of safety performance. Certain firms in some sectors of the construction industry have evolved from being firms that monitored safety performance to firms that proactively sought to improve safety performance (Hinze, 2005). Safety performance has traditionally been measured by "after-the-loss" type of measurements, such as accident and injury rates, incidents and costs (Grabowski et al., 2007). However, most of these methods are reactive or subjective methods in the sense that accident statistics only show the performance of the safety management in the past

(Dagdeviren et al., 2008). The fundamental goal of measuring safety performance is to intervene in an attempt to mitigate unsafe behaviors and conditions on construction sites.

The term “indicators” is used to mean observable measures that provide insights into a concept that is difficult to measure directly; a safety performance indicator is a means for measuring the changes over time at the level of safety as the result of actions taken (OECD, 2003). An indicator is a measurable and operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality. According to Reiman and Pietikainen (2012), an indicator can be considered any measure (quantitative or qualitative) that seeks to produce information on an issue of interest. Safety indicators can play a key role in providing information on organizational performance, motivating people to work on safety, and increasing organizational potential for safety. Often, hindsight has shown that if signals or early warnings had been detected and addressed in advance, the unwanted event could have been prevented. Recognizing early warning signs through the use of proactive safety indicators will reduce the risk of major accidents (Oien et al., 2011).

Performance measurements can either be reactive monitoring or active monitoring (HSE, 2006). The former means identifying and reporting on incidents, and learning from mistakes, whereas the latter provides feedback on performance before an accident or incident occurs. Safety metrics fall into two categories: 1) leading indicators, which are measurements linked to preventive actions; and 2) lagging indicators, which are linked to the outcome of an injury or accident (Toellner, 2011). Because these traditional approaches measure historical events of safety, the terms reactive, downstream or lagging indicators are used in construction (Hinze, 2005; Mohamed, 2002).

As illustrated in the Heinrich's safety pyramid (see Figure 2.3), the probability of injuries or accidents is a joint outcome of unsafe conditions (i.e. hazardous conditions), unsafe actions (i.e. at-risk behaviors), and chance variations. The safety pyramid depicts the concept that a multitude of minor incidents (such as hazardous conditions and at-risk behaviors) are required for one major incident to occur (OSG, 2009). Data from these minor injuries or leading indicators (Figure 2.3) can be evaluated to determine safety performance and can help avert major injury or fatality.

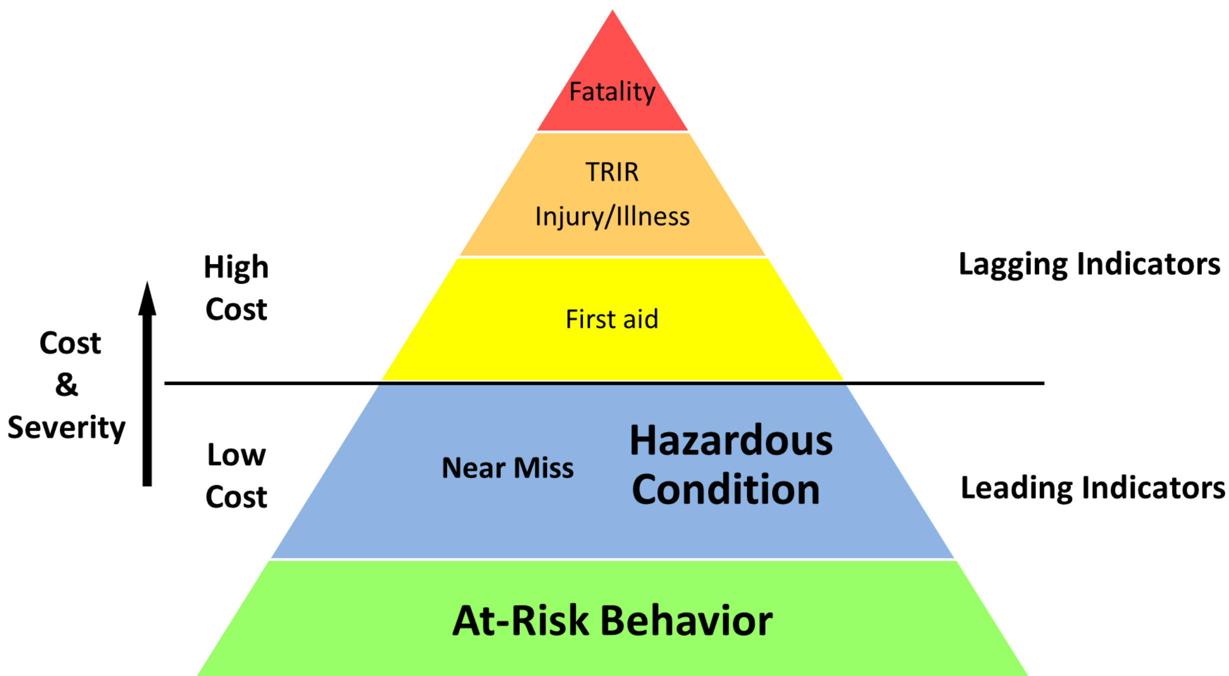


Figure 2.3: Heinrich's Safety Pyramid (OSG, 2009)

According to Radvanska (2010), the main idea of the safety pyramid shown is accident causation, which states that unsafe acts lead to minor injuries and, over time, to major or even fatal injury. Heinrich's original theory has been modified several times over the years to create a more accurate and quantifiable image of the accident incidence, as it is shown in Figure 2.3. Safety research has been focused on the upper part of the injury pyramid, but there is merit focusing on the lower part of the pyramid (Teizer et al., 2010). Currently, few firms record statistical data on incidents that occur in the lower part of the pyramid. Information from these leading indicators can be very beneficial in accident prevention, thereby increasing safety performance.

The construction industry has in recent years been experiencing a movement away from safety measures based on retrospective data or lagging indicators such as accident rates and compensation costs (Mohamed, 2002; Hinze, 2005). Accident costs tend to be reactive or after the event and are relatively infrequent. This focus on safety results often means that the success of safety is measured by levels of system failure (Choudhry et al., 2007). However, there is a growing consensus among safety professionals and researchers that lagging indicators, which require that an accident must occur or a person must get injured before a measure can be made, may or may not provide the necessary insights for avoiding future accidents (Grabowski et al., 2007).

Many modern approaches promote a shift to using proactive measures and upstream or leading indicators such as hazard identification and observed percent safe behavior (Cooper & Phillips, 2004). These approaches are focused on current safety activities to establish the safety performance of a system rather than system failure. Six main stages are needed to implement a process safety measurement system (HSE, 2006). These stages are outlined and further illustrated in Table 2.1.

Table 2.1: Overview of the Six Steps to Setting Performance Indicators (HSE, 2006)

Step 1	• Establish the organizational arrangements to implement the indicators	▪ Appoint a steward or champion ▪ Set up an implementation team ▪ Senior management should be involved
Step 2	• Decide on the scope of the measurement system • Consider what can go wrong and where	▪ Select the organizational level ▪ Identify the scope of the measurement system: • Identify incident scenarios - what can go wrong? • Identify the immediate causes of hazard scenarios • Review performance and non-conformances
Step 3	• Identify the risk control systems in place to prevent major accidents • Decide on the outcomes for each and **set a lagging indicator**	▪ What risk control systems are in place? ▪ Describe the outcome ▪ Set a lagging indicator ▪ Follow up deviations from the outcome
Step 4	• Identify the critical elements of each risk control system, (i.e. those actions or processes which must function correctly to deliver the outcomes) and **set leading indicators**	▪ What are the most important parts of the risk control system? ▪ Set leading indicators ▪ Set tolerances ▪ Follow up deviations from tolerances
Step 5	• Establish the data collection and reporting system	▪ Collect information - ensure information/unit of measurement is available or can be established ▪ Decide on presentation format
Step 6	• Review	▪ Review performance of process management system ▪ Review the scope of the indicators ▪ Review the tolerances

Glendon and Litherland (2001) used a behavior sampling technique to evaluate the safety performance of each construction crew. The observer counted the safe and unsafe key behaviors, then the percentage of safe behavior was calculated. Leading indicators, such as unsafe behaviors or conditions, are safety-related practices or observations that can be measured during the construction phase, which can activate positive responses. For instance, Chen and Yang (2004) developed a predictive risk indicator (PRI) based on unsafe acts or conditions in a petrochemical plant. The unsafe observation results are quantified by a simple rating based on estimates of probability of danger (PD), frequency of work exposure (FE), number of persons at risk (RN) and maximum of probable loss (MPL).

2.3.1 Reactive Measurement (Lagging Indicators)

Reactive monitoring involves identifying and reporting on incidents to check that controls in place are adequate, to identify weaknesses or gaps in control systems and to learn from mistakes (HSE, 2006). Lagging indicators are related to reactive monitoring and show when a desired safety outcome has failed, or when it has not been achieved (Oien et al., 2011). When a lagging indicator of safety is used, the information is by definition historical in nature. If the number of injuries is unacceptable, a response is generated that will hopefully prevent or reduce the number of future occurrences. Despite such efforts, they are implemented only after injuries have already occurred (Hinze, 2005).

Lagging indicators do not provide further insights on the existing safety conditions once an accident has occurred. According to Toellner (2001), the most common lagging indicators (such as total recordable index, lost-time index, and number of days restricted) used by U.S. industries are largely driven by OSHA recordkeeping requirements. However, due to variations in interpretation and application of these guidelines, these indicators may not consistently reflect performance over time or between competing work areas. The most commonly used lagging indicators, such as accident rate, lost workday injuries, medical case injuries, and experience modification rate (EMR), are described in Table 2.2.

Table 2.2: Lagging Indicators used in Construction

Lagging Indicators	Description
Accident Rate	• It is a requirement by OSHA for construction companies to measure safety performance by numbers of accidents. • Considered to be an unreliable basis of evaluation in which some contractors may truthfully report accidents while others may not
Medical Case Injury Frequency Rate	• Mandated with the passage of the Occupational Safety and Health Act of 1970 • Means of comparing safety performances between different firms or construction projects • The U.S. Bureau of Labor Statistics maintains records of medical case injury frequency rates. • These rates have shown a sustained decline over the past decades.
Lost Workday Injury Rate	• Compares safety performances using the frequency of lost workday injury cases and the number of days that injured workers are away from work • Computed according to the number of lost time cases (lost time injury rate), number of days lost for all lost time cases (severity rate or lost work day rate), and number of fatalities, injuries and illnesses with or without lost workdays (recordable injury rate) • The accuracy of lost workday rate depends on how honest a contractor is in revealing the reportable accidents, illnesses, fatalities and injuries.
Experience Modification Rate (EMR)	• Widely used in the construction industry as a measure of a company's safety performance • It is essentially the ratio between actual claims filed and expected claims for a particular type of construction. • The EMR reflects the cost companies have to pay for workers' compensation insurance. • Inappropriate for measuring safety performance for all types of companies • Cannot truly reflect the current safety performance of companies because it is based on running average results over several years

2.3.2 Active and Proactive Measurement (Leading Indicators)

Leading indicators are a form of active monitoring which determines that risk control systems are operating as intended (Fearnley & Nair, 2009). Active monitoring provides feedback on performance before an accident or incident (HSE, 2006). Leading indicators are simply those metrics associated with measurable systems or individual behaviors linked to accident prevention.

These indicators focus on maximizing safety performance by measuring, reporting, and managing positive, safe behaviors (Toellner, 2001).

Leading indicators of safety performance are used as predictors of safety performance to be realized. They are used as inputs that are essential to achieve the desired safety outcome (Oien et al., 2011). These indicators require systematic checks if activities are carried out as intended (Oien et al., 2011). While lagging indicators are safety measures of performance on past projects, leading indicators are directly related to the project that is to be undertaken and are concentrated on safety management process (Hinze, 2005). A proactive measurement requires the adoption of a safety approach that is not dependent on the monitoring of injuries after they occur.

Leading indicators give the probability that a safe project will be delivered by providing the opportunity to make changes as soon as there is an indication that the safety program has a weakness. Because the measurement of leading indicators has recently become more popular in the construction industry, adding continuous data collection and analysis has the potential to impact decision making in safety management and much further (Pradhananga & Teizer, 2013). One huge advantage of these active leading indicators is that they are more subject to change in a short period of time and can be used to improve safety performance as a project proceeds. For instance, worker safety observation records such as unsafe behaviors and conditions can be analyzed to determine the need for jobsite changes in the job safety program. The common leading indicators used in construction are described in Table 2.3.

Table 2.3: Leading Indicators used in Construction

Leading Indicators	Description
Near Miss Reporting	• Defined as an incident where no property damage and no personal injury were sustained, but where, given a slight shift in time or position, damage and injury easily could have occurred • Near misses are measurements of processes, activities and conditions that assess safety performance and can predict future results. • Near miss reporting is used as a safety management tool in many other industries within the U.S. private sector.
Project Management Team Safety Process Involvement	• Demonstration of leadership and commitment via active management walking around • Senior management and supervisors are encouraged to participate in site safety walks. • Management plays a key role in promoting a positive safety culture. • Allocating resources, time, and inspections
Worker Observation Process	• Common techniques used to evaluate ongoing tasks in construction • Unsafe conditions and acts that contribute to injury, property damage, or equipment failure can be identified, recorded and used to monitor and predict safety performance.
Job Site Audits	• Systematic measurement and evaluation of the way in which an organization manages its health and safety program against a series of specific and attainable standards • Conducted to identify problem areas including unsafe conditions and unsafe behaviors • The results can predict trends to show that safety is improving or that jobsite safety is degrading.
Housekeeping Program	• Helps achieve a further reduction in the occurrence of jobsite accidents • The level of housekeeping at a given site is an indicator of safety at that site.
Stop Work Authority	• Workers are expected to stop any work they consider to be unsafe until they feel it is safe to proceed. • Stop work authority is to be clearly communicated to workers in initial orientation and at regular intervals throughout each project
Safety Orientation and Training	• Helps workers become aware of project hazards • The nature of the orientation will help to determine the probable success of delivering a safe project. • The orientation training should be provided to all individuals who will be working on site, including the field employees, subcontractors' employees, and all salaried personnel on site.

2.4 Human Behavioral Observation

According to Choudhry (2014), behavior means the observable actions or reactions of persons or things in response to external or internal stimuli. One can know about someone's attitude by conducting observations of how they behave and what they convey on-site. Observations are often made on categories of exposure, and the proportion of time recorded for each exposure category is the ratio of the number of observations recorded for the category to the total number of observations (Paquet et al., 2001). For construction safety and health, continuous monitoring of unsafe conditions and action is essential in order to eliminate potential hazards in a timely manner (Seo et al., 2015). A behavioral approach addresses how people behave on the job (Choudhry, 2014). Through observing and rectifying others behavior while your own behavior is observed and rectified by others, human safety behavior and safety consciousness can be enhanced (Ismail et al., 2012).

The most effective method of dealing with unsafe human behavior is Behavior Based Safety (BBS). BBS advocates believe that unsafe behavior is the main accident cause; accident frequency could be decreased by correct behavior (Ismail et al., 2012). Furthermore, they believe that behavior can be measured and improved by methods such as observation, analysis, and feedback. Observation regarding workers' safe and unsafe behaviors is conducted by safety managers or assistants during the later stage of an intervention cycle (Zhang & Fang, 2013). Observers are supposed to conduct two rounds of observations in every cycle to ensure the reliability of records. In each round of observation, observers mark individual behaviors as either "safe" or "unsafe" by using a behavior checklist, which should be developed by safety managers.

Behavior-based safety starts by defining one or more critical behaviors to target (DePasquale & Geller, 2013). Thereafter, the behaviors are observed and recorded in particular work settings. When a relatively stable baseline measure of the frequency, duration, or rate of behavior is obtained, an intervention is implemented to change the behavior in beneficial directions. The typical implementation of a behavior-based safety program usually involves four well-defined steps (Ismail et al., 2012): 1) identification of critical safety behavior that contributes to injuries and losses, 2) observation or sampling of identified behavior over a certain period of time, 3) application of feedback reinforcement to increase desired behavior and decrease undesired behavior, and 4) presenting feedback on performance to the relevant audiences within the organization. Some applications of human behavioral observation found in literature are described as follows.

Behavioral observation checklists were developed for nine main departments in conjunction with the workforce of a packaging production plant. An employee from each workgroup within the departments was trained to be an observer. The observer monitored everyone within their respective work areas for 10–20 minutes every day they were at work. A behavior was recorded as safe only if everyone in a workgroup was performing that behavior safely. The observed percent safe scores recorded for the first four-to-six week shift rotations were used to establish baselines by which participative safety improvement goals could be set and future performance compared. Results showed statistically significant improvements in safety performance and decreases in accident rates (Cooper & Phillips, 2004).

A critical behavior checklist was developed for behavioral observation with a comprehensive consideration of the local regulations and specifications, major construction activities of the target sites and experiences of the site safety personnel. Nine categories of unsafe behaviors were identified within the checklist: personal protective equipment (PPE), manual handling, work platform and access, lifting operation, hot work, working at heights, plants and equipment, excavation, and traffic management. In order to ensure the consistency of performance measurement, the authors independently conducted a series of observations during the intervention phase, based on which result was generated. Observations were conducted one round per week during the baseline phase and one round per cycle during the intervention phase. In each round of observation, observers marked individual behaviors as either "safe" or "unsafe". When a specific behavior could not be observed, it would be marked as "not applicable" (Zhang & Fang, 2013).

A behavioral sampling technique was used to evaluate the safety performance of each crew in a road construction. This method of safety measurement involves observing samples of behavior at random intervals to determine safe performance. Percentage of safety behavior was calculated (Glendon &Litherland, 2001). The behaviors observed in the study are given in Table 2.2.

Table 2.4: Key Behaviors for Observation (Glendon & Litherland, 2001)

Personal protective Equipment	1. Safety helmets are to be worn in the vicinity of either a bridge site, when working with any plant in the crane mode, or when working in trenches. 2. When safety helmets are not required, reflective wide brim hats should be worn. 3. Reflective safety vests or jackets should be worn at all times. 4. Steel cap boots must be worn at all times. 5. Hearing protection should be worn when working with noisy machinery. 6. Thick gloves should be worn when dealing with chemicals or concrete. 7. Eye googles should be worn in any situation where damage to the eye as a result of flying particles may occur.
Traffic awareness	8. Watch for traffic before crossing the road. 9. When working in close proximity to traffic, one person should be watching the traffic. 10. Persons are not to walk in a machine's, or truck operator's blind spots. 11. Ensure that traffic is stopped before taking machinery onto the road.
House-keeping	12. Safety mesh should be erected around excavations 13. After using any tools or small machinery (e.g. jack hammer), store them in the correct place.
General	14. Use the correct procedure when lifting. 15. If an object is heavier than 40kg, two people should lift it, or use a lifting aid.

2.5 Research Needs Statement

As a result of the existing research, it is accepted that a sequence of unsafe behavior and unsafe conditions coupled with lack of implementation of adequate safety practices are elements that can lead to accidents on construction sites (Cooper & Phillips, 2004; Cox & Jones, 2006; Radvanska, 2010; Seo et al., 2015). A research need exists to create a framework which can measure and predict safety performance that can reflect the current status of safety activities in the workplace through continuous observation, recording, and analysis of unsafe behaviors of workers or unsafe conditions in workplaces.

CHAPTER 3

RESEARCH METHOD

This chapter explains the research methodology implemented for this study. A detailed description of what safety activity analysis entails with regard to construction is given, followed by a brief discussion on activity analysis for direct-work rate improvement in construction. The categories of measurement of safety performance are also described to establish the operational meaning of the concepts as applied in this research. A comprehensive description of the safety activity analysis framework to evaluate safety performance in construction is also given. The safety analysis activity tool (SAAT) developed to facilitate the collection and analysis of data in the safety analysis framework is presented. A case study aimed at implementing the created safety activity analysis framework is also described.

3.1 Safety Activity Analysis

Activities are the fundamental acts that are required to complete a task. A typical construction projects requires different interrelated activities which must be carried out safely to ensure the successful completion of the project. Choudhry and Fang (2008) pointed out that on a construction project, thorough evaluation and step-by-step job safety analysis followed by the development of written safe operating procedures can influence workers to improve their safety behaviors when performing work tasks. In conjunction with the Construction Industry Institute (CII) Research Team, the benefits derived from activity analysis were used to improve the direct work rate in construction (Gouett et al., 2011). The observation of unsafe acts and conditions were also implemented as a means for continuous improvement of safety management in a petrochemical plant (Chen & Yang, 2004).

A workface assessment method called activity analysis was developed to continuously improve productivity performance by efficiently measuring the time expenditure of workers on-site and identifying productivity inhibitors that management must reduce or eliminate to provide workers with more time for direct-work activities (Gouett et al., 2011). The research concluded that activity analysis, as a continuous performance improvement process, is feasible and when continually applied to a construction site, can significantly improve direct-work rates through the life of a project. This research seeks to continuously monitor safety performance of construction personnel on active sites by deploying safety activity analysis techniques. The categories of measurements are described in detail, followed by a comprehensive description of the safety analysis framework developed to evaluate safety performance on construction sites. The safety analysis tool created to implement this framework is also presented and described.

3.2 Categories of Measurement

The uniqueness of the construction industry dictates the need to customize many of the contemporary accident causation models and human error theories. According to an accident root causes tracing model (ARCTM), accidents occur due to three root causes: (1) Failing to identify an unsafe condition that existed before an activity was started or that developed after an activity was started; (2) deciding to proceed with a work activity after the worker identifies an existing unsafe condition; and (3) deciding to act unsafely regardless of the initial conditions of the work environment (Abdelhamid & Everett, 2000). The categories of measurements used for safety activity analysis are the safe behavior and condition, unsafe behavior, unsafe condition, and injury/illness. These categories of measurement are described as follows.

3.2.1 Safe Behavior and Condition

A safe behavior promotes a safe working environment and the combination of these two results in a workplace having a very high safety performance. Accidents at work occur either due to unsafe working conditions or unsafe acts (Aksorn & Hadikusumo, 2007). Safer behavior is reflected by good attitude. Many workplace accidents, especially on building construction sites, were due to inadequate adherence of workers to work procedures (Che Hassan et al., 2007). The long-term values of exhibiting safe behavior at work include employees being able to work without injury so they can continue to provide earnings for both the company and for their family (Choudry et al., 2007).

3.2.2 Unsafe Behavior

There is no general agreement on the definition of unsafe acts but notwithstanding, it has been defined as "unaccepted practices which have potential to contribute to future accidents and injuries" (Aksorn & Hadikusumo, 2007). Unsafe behaviors seem to be a combination of many factors, which include both the human and situational or environmental aspects involved in performing construction tasks (Choudhry & Fang, 2008). Safety problems are related to unsafe or careless employees that can be resolved by closely monitoring and changing their behaviors (DeJoy, 2005). A worker may commit unsafe acts regardless of the initial conditions of the work (i.e., whether the condition was safe or unsafe) (Abdelhamid & Everett, 2000). Examples of unsafe worker acts include the decision to proceed with work in unsafe conditions, disregarding standard safety procedures such as not wearing a hard hat or safety glasses, working while intoxicated, or working with insufficient sleep.

3.2.3 Unsafe Condition

An unsafe condition is a situation in which the physical layout of the workplace or work location or the status of tools, equipment, and material are in violation of contemporary safety standards (Abdelhamid & Everett, 2000). Examples of unsafe conditions include open-sided floors, defective ladders, improperly constructed scaffolds, protruding ends of reinforcing rods, protruding nails and wire ties, unshored trenches, defective equipment, overloaded tools or equipment, unprotected explosive material, ungrounded electrical tools and flying materials.

When an unsafe condition exists before or develops after a worker starts a construction task, the worker either succeeds or fails in identifying the unsafe condition (Choudhry & Fang, 2008). When the unsafe condition is identified by the worker, an evaluation of risk must be made and if the worker fails to identify the unsafe condition, the person will continue the work. In such cases, management is responsible to investigate unsafe conditions. Often, unsafe conditions are not easily identified by workers, hence management's dependence on engineers to identify and mitigate hazards in the processes, equipment, and materials they specify.

3.2.4 Injury/Illness

An injury is caused by an incident, which, in turn, is caused by unsafe acts or conditions. The occurrence of accident usually requires a combination of many unsafe acts and conditions (Chen & Yang, 2004). When workers are made to perform tasks that exceed human capabilities or that violate human factors, ergonomics, and industrial hygiene principles, the results are overexertion injuries and illnesses (Abdelhamid & Everett, 2000).

3.3 Safety Activity Analysis Framework

A safety activity analysis framework has been developed to utilize activity analysis to continuously evaluate safety performance on construction sites. The framework includes four main stages which are extensively discussed as follows.

3.3.1 Stage 1: Goal Definition and Action Planning

At this stage, the objective of safety activity analysis is properly defined to ensure that it is well understood by all the stakeholders in the organization. The various concepts (such as categories of measurement and sample population) involved in the process are defined. The process of defining and clarifying these concepts is accomplished through orientation and training of the stakeholders on the different categories of measurements that would be used to evaluate safety performance. The team required to champion the process is formed and this team should be comprised of safety personnel in the organization. A checklist of activities that can be identified in the different categories of measurement (i.e., safe behavior and condition, unsafe behavior, unsafe condition, and injury/illness) is prepared and agreed upon by the stakeholders in the organization.

Determining an appropriate sample size is also critical to the accuracy of the activity analysis study. In most industries an error of ±5% at a confidence level of 95% is generally acceptable (Gouett et al., 2011). Generally, activity analysis has more than two categories of which this study is not an exception and therefore, it is multinomial. The result for each category is subjected to the 95% confidence level and so has the potential to be wrong one time out of 20. However, there are several categories in which the results all have a probability of being wrong once out of 20 times. Therefore, the probability of reporting one result wrong in the entire study is significantly greater than 1 in 20 (Gouett et al., 2011). The sample size for a multinomial distribution is determined using Equation 3.1 (Thompson, 1987).

$$n_o = \max\left[\frac{\left(Z_{\left(1-\frac{\alpha}{2m}\right)}\right)^2 \frac{1}{m}\left(1-\frac{1}{m}\right)}{d^2}\right] \tag{3.1}$$

Where n_o = total number of observations, α = a simultaneous significant level, d = error, and m = number of categories of measurement. For a 95% confidence level and error of d = 0.05, and m = 4, $n_o \approx 470$ observations. This means that regardless of the category percentages, a total of 470 observations per study period is required to obtain a confidence greater than 95%. For m = 3 (i.e. 3 categories of measurement), $n_o \approx 510$.

3.3.2 Stage 2: Activity Observation and Data Analysis

This is the stage at which the workers on site are observed in order to identify critical safety behaviors and conditions. The observation is termed "snap-observation or snap-reading method" (Gouett et al., 2011). The checklist of unsafe behaviors and unsafe conditions is used to identify and record observations of the number of safe behaviors and conditions, as well as unsafe behaviors and conditions. This activity observation is carried out by a safety representative who has the required knowledge and training to professionally use the safety activity checklist to identify the different categories of measurement. However, the observation criteria should not be limited to the checklist provided because the list of safe and unsafe activities on a construction site is ever-increasing. Additionally, the checklist used at any particular time should always be reviewed and updated to reflect the current situation of the construction site and the knowledge gained in the process. Activities that cannot be categorized as neither unsafe behaviors nor unsafe conditions are identified as safe behaviors and conditions.

Also at this stage, various computations are carried out on the observations using appropriate formulas to transform the observational data to useful information. The graphical presentation of the results are produced to reflect the measurements of safety performance on the construction site. These results are presented in the form of frequencies, probabilities, percentages, and trends on tables and with different types of charts. The equations used for the computation are as follows (Glendon & Litherland, 2001; Cooper & Phillips, 2004; Zhang & Fang, 2013).

$$\text{\% or P (Safe Behavior and Condition)} = \frac{\text{\# of Safe Behavior and Condition}}{\text{Total \# of observations}} \tag{3.2}$$

$$\text{\% or P (Unsafe Behavior)} = \frac{\text{\# of Unsafe Behavior}}{\text{Total \# of observations}} \tag{3.3}$$

$$\text{\% or P (Unsafe Condition)} = \frac{\text{\# of Unsafe Condition}}{\text{Total \# of observations}} \tag{3.4}$$

$$\text{\% or P (Injury/Illness)} = \frac{\text{\# of Injury/Illness}}{\text{Total \# of observations}} \tag{3.5}$$

Where # = number of observations and P = probability.

The overall safety performance on the construction site is measured using the safety index which is given by the percentage of safe behavior and condition observations. The safety index may vary from 0% to 100% (Laitinen et al., 1999; Cooper & Phillips, 2004; Zhang & Fang, 2013).

The results of the analysis are then interpreted by the investigative team of safety personnel. The actual level of safety performance on the construction site is known and the level of improvement required is also determined at this stage. Recommendations for improvements are also proffered by the investigative team.

3.3.3 Stage 3: Decision Making and Planning of Improvements

This is the stage at which decisions are made by the management of the organization based on the results of the analysis and the recommendations for improvements provided by the investigative team. Appropriate plans are made to implement the required improvements.

3.3.4 Stage 4: Implementation of Improvements

This stage involves the correction of the unsafe behavior and unsafe conditions by training the workers and making necessary changes on the construction site. This process is succeeded by updating the checklist and monitoring of the safety activities again through the activity observation and analysis. Results are tracked and feedback on performance is provided to the relevant audiences within the organization. The process continues through the decision making and planning of improvement stage and then to the implementation of improvements again. The process follows a continuous recurrent flow as shown in Figure 3.1.

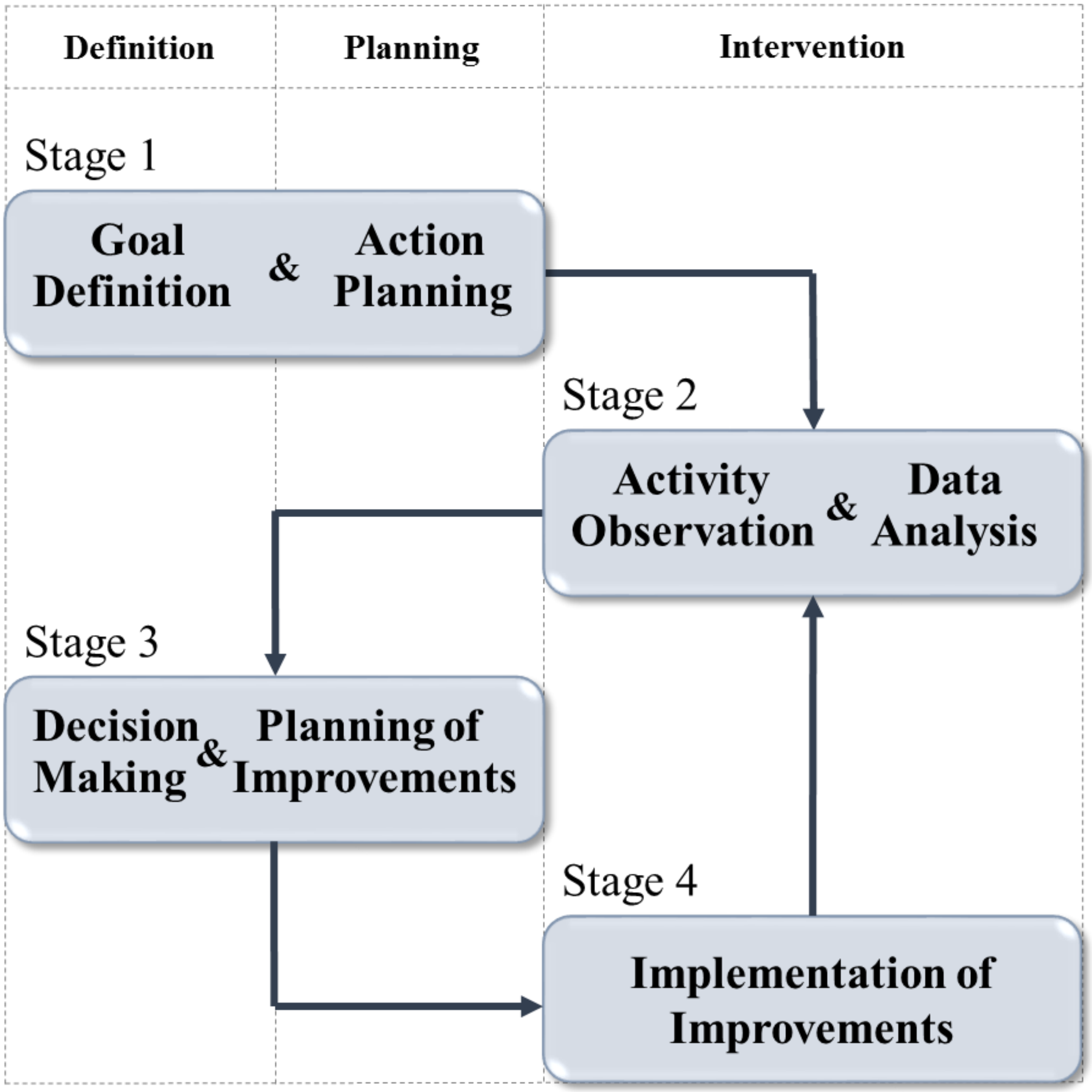


Figure 3.1: Overview of the Safety Activity Analysis Framework

3.4 Safety Activity Analysis Tool (SAAT)

The safety activity analysis tool has been designed to simplify the process of activity observation and data analysis during the intervention phase. The tool is a management information system which is expected to facilitate the collection and analysis of data and present the safety performance of a given construction project. Prior to the development of the safety activity analysis tool, system analysis tasks were carried out to understand the problems in the existing system, user expectations, opportunities for improvement, and the objectives of the system. The system design methodology was adopted in designing the safety activity analysis tool. This system design methodology included requirement definition, functional systems design, programming, testing, implementation, and maintenance. The description of the different stages as applied in the development of the safety activity analysis tool is given as follows.

3.4.1 Preliminary Design Documentation

First, the problems meant to be solved by the tools were identified and documented. The existing process was assessed and investigated by considering the different forms in which it has been applied to determine the intrinsic challenges and be able to proffer solutions. The findings of the critical review of existing situations in field observation and analysis of safety activities in construction show that the process of safety activity analysis is currently being carried out manually. Some of the shortcomings of the existing process are that it is time-consuming and the large amount of samples necessary to avoid biases are not easy to come by.

Different alternatives were evaluated to either improve the existing process or develop a management information system to get rid of the challenges of the existing approach. After a critical review of the different alternatives, a recommendation was made to develop a management information system called the Safety Activity Analysis Tool (SAAT) to facilitate the collection and analysis of safety activity data. The Hierarchical Input Process Output (HIPO) Chart for the Safety Activity Analysis Tool is shown in Figure 3.2.

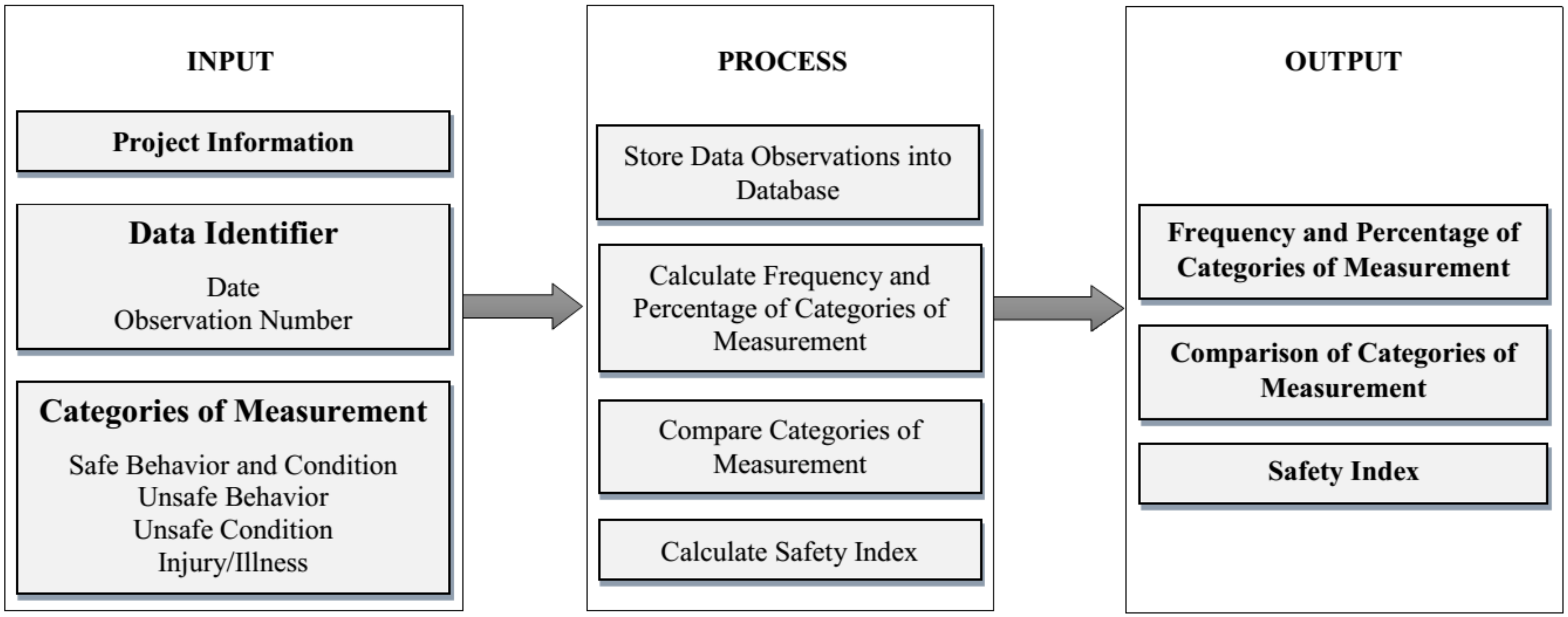


Figure 3.2: Hierarchical Input Process Output (HIPO) Chart for Safety Activity Analysis Tool

3.4.2 Requirement Definition

A detailed study of the existing process was carried out to ensure a clear understanding of the system is achieved in order to define the requirements of the system. The existing system involves walking around to observe construction workers and manually record observations of their safety activities via hard copy (i.e., paper-based files are created). After an adequate amount of data has been collected over a given period of time, the collected data is then analyzed and the results are presented.

From the existing system described above, it is clear that there is a huge need to transition from a laborious and ineffective manual method of data collection and analysis to a more effective computer-based method. The objectives of the systems design are expected to be met by adopting a computer-based system which will automate the data collection and analysis process and reduce the challenges faced in the current process.

As opposed to the existing process, the new system uses a computer-based approach in which snapshots taken from an active construction site are used for the activity observations instead of the observer walking around. Furthermore, the observations are recorded in the tool instantaneously and the records are automatically stored in the database of the safety activity analysis tool. The analysis of the collected data is also carried out concurrently using the algorithm built into the tool and the results are presented in the tool. The results can also be printed out as a report from the tool.

3.4.3 Functional Systems Design

Since a computer-based program has been recommended, the hardware and software required to develop and run the system must be identified. The hardware is composed of the computer equipment and peripherals upon which software runs. The software chosen was Microsoft Excel, while the hardware required includes system unit, storage, mouse, keyboard, and monitor. The hardware could be in the form of a desktop or laptop computer. Other application packages were considered, but the final choices were limited to Microsoft Excel and Microsoft Access because of their ease of use and functionality.

After a critical review of the two alternatives, Microsoft Excel was chosen ahead of Microsoft Access because of its ability to store data, run data analysis, and present results of data analysis. Microsoft Excel is a spreadsheet program that has many advantages, including accessibility, cost, and graphical presentation. All these factors confirm the resourcefulness of Microsoft Excel in the collection and analysis of observational data and support its choice as the software for the design of the safety activity analysis tool.

The safety activity analysis tool was designed in the Microsoft Excel application software to allow the input of data into the tool for analysis. The input data that can be stored in the tool include the project information, data identifier (i.e., date and observation number), and categories of measurement of safety activities (i.e., safe behavior and condition, unsafe behavior, unsafe condition, and injury/illness). Interfaces were created in the form of data entry forms for inputting the required data. The Visual Basic (VB) program in the Excel software was also used to write codes (i.e., computer instructions) to execute the process of converting the inputs to the required outputs. Some of the outputs obtained when the computer instructions are executed are values of the frequency and percentage of different categories of measurement, the comparison of the categories of measurement, and the safety index on the construction site. The physical model for the proposed system is presented in Figure 3.3.

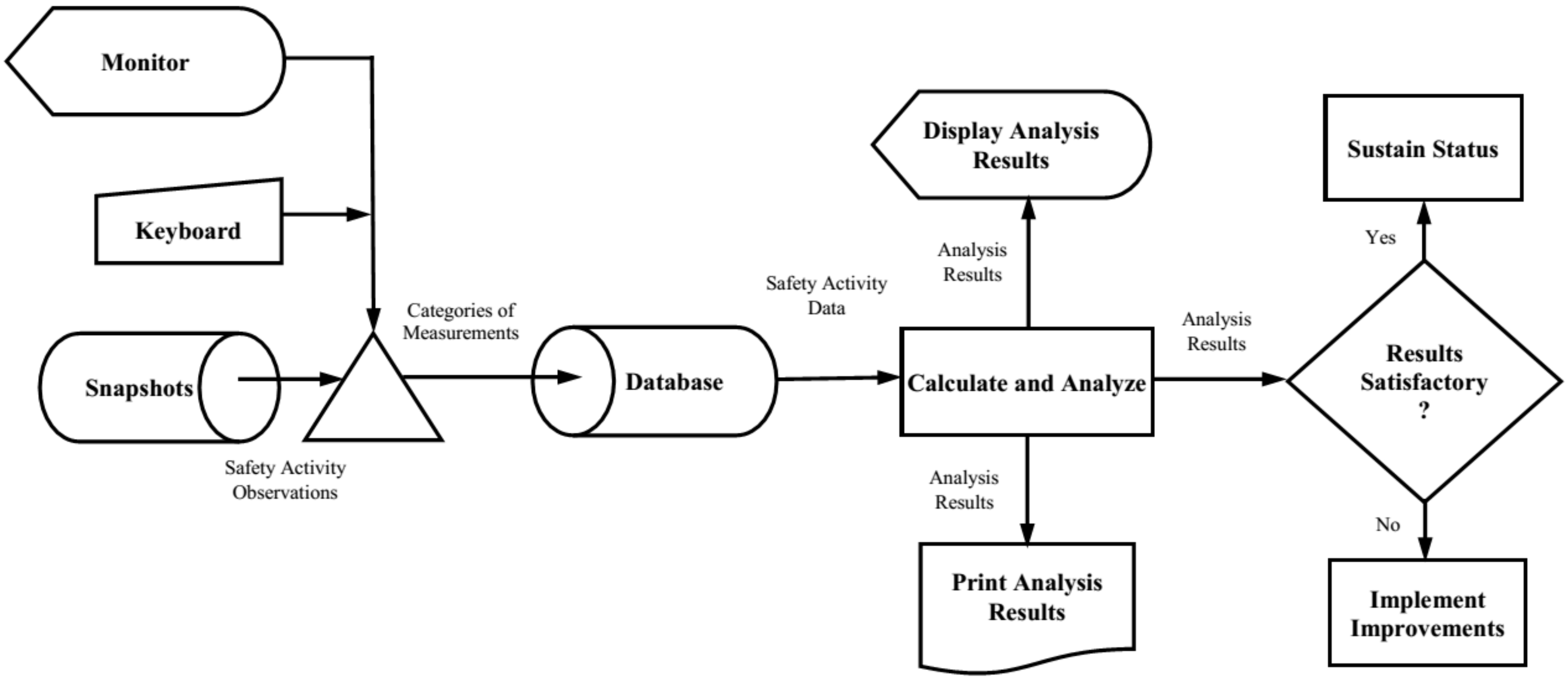


Figure 3.3: System Flow Chart for the Safety Activity Analysis Tool

The user interfaces by which users interact with the safety activity analysis tool to record safety activity observations, analyze safety activity data, and view/print analysis results are presented as follows.

Figure 3.4: Cover Page of Safety Activity Analysis Tool

The user interface of the tool presented in Figure 3.4 above allows the entering of the project information and other relevant details into the safety activity analysis tool. The project information reflected on the report reveal the results of the data collection and analysis. This is essential in order to know the specific construction project whose data is stored in the database and also to be able to correctly relate the results of the analysis to the right project. The interface allows navigation to other windows in the tool.

Figure 3.5 below shows the user interface for inputting activity observations into the tool. When any category of measurement is observed, the respective button can be clicked and the observation will be recorded automatically in the database. This user interface also permits movement to other windows in the tool.

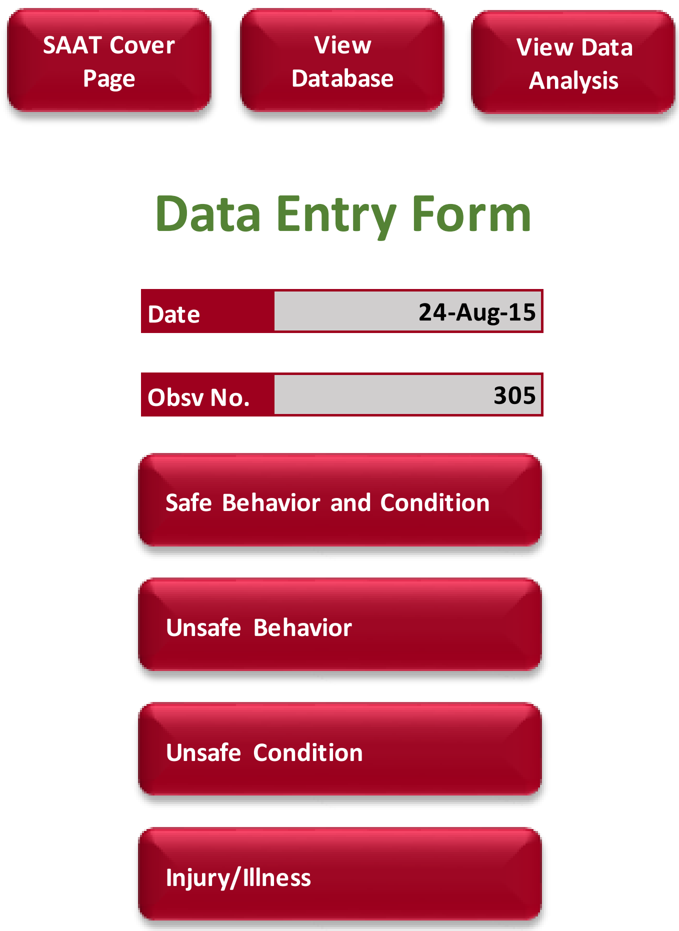


Figure 3.5: Data Entry Form of Safety Activity Analysis Tool

The layout of the database as contained in the safety activity analysis tool is shown in Figure 3.6 below. This user interface as well allows navigation to other windows in the tool.

SAAT Cover Page | Open Data Entry Form | View Data Analysis

Database

Date	Observation No.	Safe Behavior and Condition	Unsafe Behavior	Unsafe Condition	Injury/Illness
22-May-15	1	1	0	0	0
22-May-15	2	1	0	0	0
22-May-15	3	0	1	0	0
22-May-15	4	1	0	0	0
22-May-15	5	0	1	0	0
22-May-15	6	0	0	1	0
22-May-15	7	0	1	0	0
22-May-15	8	0	1	0	0
22-May-15	9	1	0	0	0
22-May-15	10	0	1	0	0
22-May-15	11	1	0	0	0
22-May-15	12	1	0	0	0
22-May-15	13	0	1	0	0
22-May-15	14	0	1	0	0
22-May-15	15	0	0	1	0
22-May-15	16	0	0	1	0
22-May-15	17	0	0	1	0
22-May-15	18	1	0	0	0
22-May-15	19	1	0	0	0
22-May-15	20	1	0	0	0
23-May-15	21	0	1	0	0
23-May-15	22	1	0	0	0
23-May-15	23	0	1	0	0
23-May-15	24	0	0	1	0
23-May-15	25	1	0	0	0
23-May-15	26	0	1	0	0
23-May-15	27	0	0	1	0
23-May-15	28	0	0	0	1
23-May-15	29	0	0	1	0
23-May-15	30	0	1	0	0

Figure 3.6: Database of Safety Activity Analysis Tool

Figure 3.7 below shows the layout of the data analysis interface of the safety activity analysis tool. This user interface also allows navigation to other windows in the tool.

Summary of Data			
Categories	Frequency	Percentage	Probability
Safe Behavior and Condition	128	42.1	0.42
Unsafe Behavior	98	32.2	0.32
Unsafe condition	67	22.0	0.22
Injury/Illness	11	3.6	0.04
Grand Total	304		

	May	Jun	Jul
Safe Behavior and Condition	35.0%	44.0%	46.0%
Unsafe Behavior	29.0%	32.0%	36.0%
Unsafe Condition	33.0%	20.0%	14.0%
Injury/Illness	3.0%	4.0%	4.0%

Figure 3.7: Data Analysis of Safety Activity Analysis Tool

3.4.4 Programming

The safety activity analysis tool was programed in the Microsoft Excel application system. The programing was carried out by the research student using the macro programming language (Visual Basic for Applications) in the Microsoft Excel application software. The macros and other Excel functions were used to implement numerical methods on the inputs in order to obtain the required outputs.

3.4.5 Testing

In the testing phase of the system development, program debugging was carried out to ensure that the codes (i.e., macros or computer instructions) used in the program execute as designed without errors. The verification process was carried out to ensure that the system was developed according to design specifications. The validation of the system was also carried out to determine if the developed system addresses the original problems. The process of debugging was performed by the programmer (i.e., the research student) and then the tool was passed on to a non-programming individual to carry out the quality assurance process (i.e., verification and validation). The quality assurance process was carried out through the development of acceptance testing plans based on the original requirements to confirm if the objectives are met by the system. The tool performed the function for which it was designed when tested for quality assurance by the non-programming individual and was accepted.

3.4.6 Implementation

The safety activity analysis tool was implemented on an active construction project to collect and analyze safety activity observations. Instead of the manual method of data collection and analysis, there was a transition to the computed-based system which automates the data collection and analysis process. With the aid of the new system, paper-based files can be converted to computer-based files and the output of the data analysis can also be printed out in form of a summary report if it is so desired. The tool has been incorporated with instructions to guide the users and thus, it is highly user-friendly and does not require special training or a training manual.

3.4.7 Maintenance

The tool can be evaluated continuously to prevent it from being rendered obsolete. The contents of the tool can be reviewed and updated and the application software can also be constantly updated to meet the current needs of the program.

3.5 Case Study

A case study was carried out to implement the safety activity analysis framework. A construction project located in southeastern United States was used as a case study. The project started in the Fall of 2012 and was completed in 2015. High-resolution cameras were used to capture activities completed on the construction site. There were three different cameras (with resolution of 12MP and update rate of 14 seconds) located at strategic positions to ensure that all the activities taking place on the construction site are captured. These pictures were used for the activity observations for eight months.

Some of the workers' unsafe behaviors and unsafe conditions of worksite observed were workers picking up a load without bending knees, workers not wearing hard hat, workers standing in an open and unshored excavation, and working in poor physical conditions. The observations were carried out using the snapshots (see Figure 3.8) taken at one-hour intervals from the construction site and the data was entered into the database of the safety activity analysis tool developed at the same instant of observation. A total of 1,280 pictures were used for the activity observation.

Figure 3.8: Snapshots from the Construction Site

3.6 Reliability of Activity Observation Method

In order to determine the reliability of the activity observation method, two other graduate students studying construction safety engineering completed the activity observation using fifty snapshots from the construction site. These other two graduate students together with the first observer were used as independent observers to determine the reliability by calculating the average error of their end results by formula: standard deviation of safety indexes multiplied by one hundred and divided by the mean of the safety indexes (Laitinen et al., 1999). The average percentage error was found to be 2% as shown in Table 3.1.

Table 3.1: Results of Reliability Test carried out on Activity Observers

	# of Observations	**Index (%)**
Mean	562	58.6
Standard Deviation	5	1.15
Average Error (%)	1	2

CHAPTER 4

RESULTS ANALYSIS AND DISCUSSION

This chapter presents the analysis and discussion of the research findings. The summary of the overall activity observations and the distribution of the periodic observations of safety activity on the construction project are displayed and described. The analysis and discussion of the percentage rates of the observation of the different categories of measurement are also presented. The percentage rate of observation of the different categories of measurement are further compared to give an assessment of safety performance of the construction project. Finally, the evaluation of safety performance on the construction project using the safety index is also presented and discussed.

4.1 Summary of Activity Observation

The summary and distribution of the activity observation process are presented in Table 4.1 and Figure 4.1. A total of 12,596 observations were made over a period of eight months from 1,280 pictures taken from the construction site used as case study. Workers observed to be working safely and in safe conditions were 6,760, amounting to 53.7% of the total observations, while workers exhibiting unsafe behavior had the second highest count with a total of 3,459 amounting to 27.5% of the total number of observations. Workers observed to be working in unsafe conditions were about 18.9% (2,377 unsafe condition observations) of the total number of observations. Table

4.1 also presents the probabilities of having the different categories of measurement on the construction site over the period of the activity observation.

Table 4.1: Summary of Activity Observation

Categories	Frequency (# of Observations)	Percentage (%)	Probability
Safe Behavior and Condition	6760	53.7	0.54
Unsafe Behavior	3459	27.5	0.27
Unsafe Condition	2377	18.9	0.19
Grand Total	**12596**		

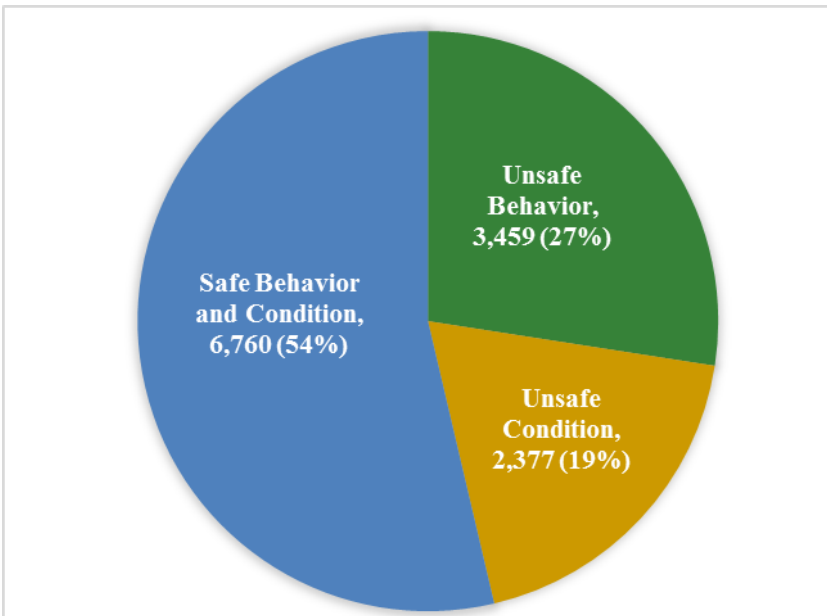


Figure 4.1: Distribution of Observations by Categories of Measurement

A general look at the distribution of the monthly observations (Table 4.2) shows that each month has an adequate amount of observations that can be used for data analysis (e.g. the number of observations are all greater than 510 required as the minimum sample size for 95% confidence) as determined in section 3.2.2 of this thesis.

Table 4.2: Distribution of Periodic Activity Observation by Categories of Measurement

Period (Month)	**Frequency**			
	Safe Behavior and Condition	**Unsafe Behavior**	**Unsafe Condition**	**Total # of Observations**
1	308	74	292	674
2	326	110	297	733
3	313	78	371	762
4	458	200	580	1238
5	812	368	461	1641
6	1344	791	284	2419
7	1633	924	78	2635
8	1566	914	14	2494
Total	**6760**	**3459**	**2377**	**12596**

Also from Table 4.2, it can be seen that the number of monthly observations increased progressively as the project moved on. This increase means that more workers were needed to execute the site operations as the project progressed. This is also an indication of the fact that more workers were required as the project was moving from excavation works mainly executed by heavy equipment to other labor intensive works.

4.2 Results of Categories of Measurement

The results of the categories of measurement computed using Equations 3.2, 3.3 and 3.4 are presented in this section. The percentage rate of monthly observation of the different categories of measurement are plotted against the period to draw out their respective rates of reoccurrence on the construction project. The percentage rate of monthly observation reflects the frequency in each of the categories of measurement per month.

4.2.1 Safe Behavior and Condition

As illustrated in Figure 4.2, the rate of occurrence of a safe behavior and condition on the construction site with respect to the other categories initially decreased at the inception of the project and then increased until it reaches a maximum of 62.8%. The lowest percentage rate, 37.0%, was observed in the fourth month. This result shows that safe behaviors and conditions have a strong tendency to increase as a project progresses and this trend can be made possible when the frequency of unsafe behaviors and conditions decreases. Reductions in the frequency of unsafe behaviors and unsafe conditions decrease the opportunity for accidents to occur (Cooper & Phillips, 2004). Thus, monitoring the safety activity of construction workers using the rate of change of safe behavior and condition can be taken advantage of to enhance safety performance.

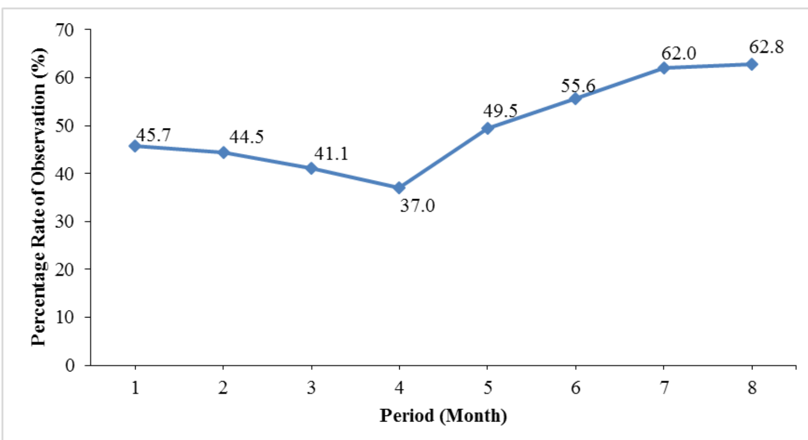


Figure 4.2: Percentage Rate of Safe Behavior and Condition Observation

4.2.2 Unsafe Behavior

The percentage rate of unsafe behavior observation was initially inconsistent, exhibiting a sudden increase and decrease in the early period and later increased steadily to reach a maximum of 36.6%. This outcome indicates that unsafe behavior by workers has more probability of increasing as a project progresses. Workers might behave unsafely consciously or unconsciously due to different factors (Choudhry & Fang, 2008). Proper intervention, therefore, needs to be put in place to prevent this occurrence. Zhang and Fang (2013) found that behavioral performance of two sites examined improved significantly from the baseline phase to the intervention phase in which workers were given feedback and proper coaching. A conscious effort is thus required to control and reduce the unsafe behaviors on a construction site in order to improve safety performance. Choudhry and Fang (2008) also recommended a strong need for behavior-based-safety intervention to strengthen the safety training, skill and safety knowledge of workers.

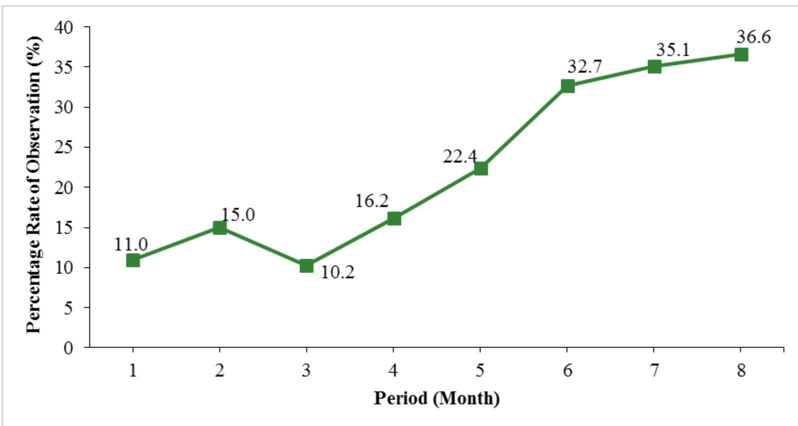


Figure 4.3: Percentage Rate of Unsafe Behavior Observation

4.2.3 Unsafe Condition

As observed in Figure 4.4, the percentage rate of unsafe condition in the activity observation started at a high value, experienced an irregular trend at the early stage and then decreased steadily as the project evolved. This could be a result of the fact that the project moved from mainly excavation works, which are characterized by more unsafe working conditions due to presence of open trenches and heavy equipment in close proximity to workers. Having workers in too close proximity to the operation of construction equipment has remained a key problem in the construction industry (Teizer, Allread, Fullerton, & Hinze, 2010). Statistical investigations from previous research show foundation excavation to be one of the construction activities most prone to hazardous conditions (Cheng, Ko, & Chang, 2002). This results also reinforce the need to implement proactive ways of monitoring and controlling the excavation conditions. More effort is therefore required at this stage and beyond to mitigate the effect of the unsafe condition in order to improve safety performance.

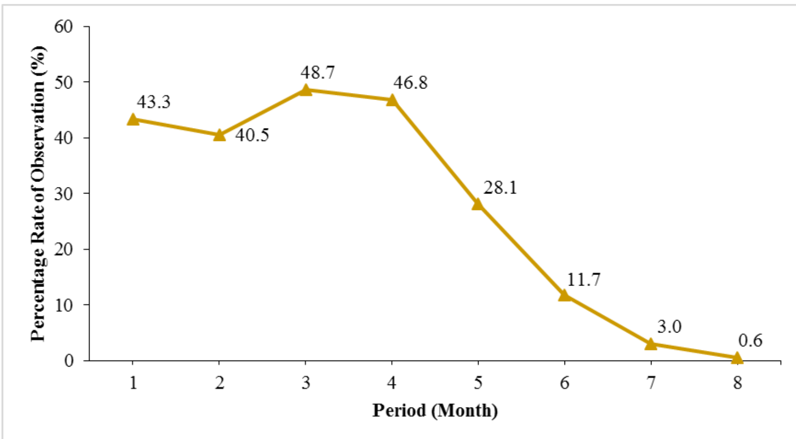


Figure 4.4: Percentage Rate of Unsafe Condition Observation

4.3 Safety Performance Measurement

The percentage rate of the observation of the different categories of measurement is used for the safety performance measurement as depicted in Figures 4.5 and 4.6. It should be noted that the more the percentage rate of safe behavior and condition over the percentage rate of unsafe behavior and unsafe condition, the higher the safety performance on the construction site. This means that the percentage rate of unsafe behavior and unsafe condition should be kept very low.

From Figure 4.5, it can be seen that an inverse relationship existed between the rate of safe behavior and condition observations when compared to unsafe condition observations after the fourth month (i.e. the percentage rate of safe behavior and condition increased with decrease in the percentage rate of unsafe condition). On the other hand, increase in the rate of safe behavior and condition experienced in the project was not as a result of a decrease in the rate of unsafe behavior as shown in Figure 4.5. Unsafe behavior rate increased even with increase in safe behavior and condition. This result shows that more work is required to reduce the unsafe behavior of workers so that an increased safety performance can be obtained.

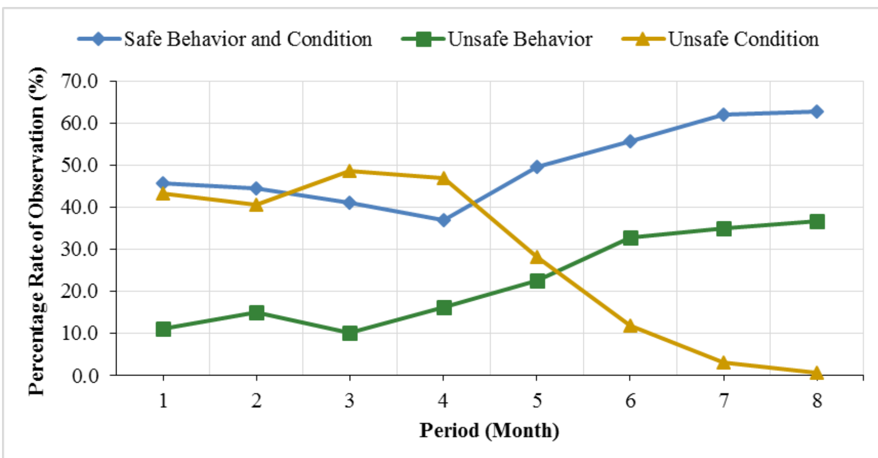


Figure 4.5: Comparison of Categories of Measurement for Safety Performance

The safety index for the construction project is shown in Figure 4.6. The safety index was determined using the percentage rate of safe behavior and condition on the construction site. Over a period of eight months, the safety index started at 45.7%, experienced a steady drop down to 37.0% at the fourth month and then increased steadily up to 62.8% in the eighth month. This results show that the stage of the construction process had significant effect on the safety index values.

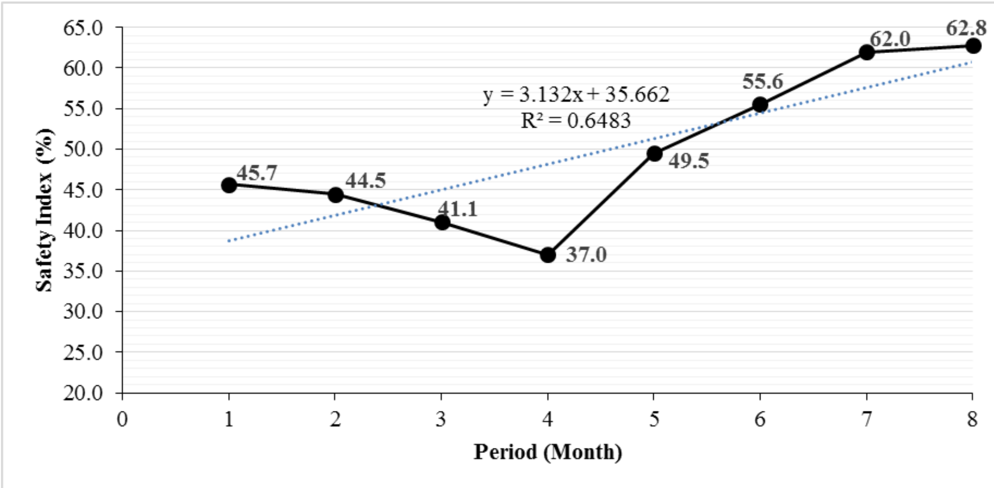


Figure 4.6: Safety Index on the Construction Site

A critical review of the stages of the construction project and their effects on the safety index shows that the safety index decreased with an increase in the amount of excavation work. The fourth month, which has the lowest safety index, also had the peak excavation work. This indicates that the huge amount of excavation work actually increased the unsafe condition on site which reduced the safety index. Furthermore, there was a clear trend in the safety index of the construction site after the fourth month. The linear regression curve (Figure 4.6) showed a steady increase in safety index as the project advanced in time. The value of the coefficient of determination, R^2, also shows that the regression model accounts for 64.8% of the variations in the values of the safety index. To an extent, this model can also be used to predict the safety index within this period.

In general, the safety index for the construction site for the period of eight months varied between 37.0% and 62.8% with the average being 53.4%. From these results, which indicate the safety index of the baseline, improvements and feedback can be implemented to increase the safety index. In previous research on two construction sites, the safety index rose from the baseline of

60% to 89% during the feedback at one site and from 67% to 91% at the other site (Laitinen & Ruohomäki, 1996). Therefore, well-informed decisions and far-reaching efforts have to be made to reduce the unsafe behaviors and unsafe conditions on the construction site in order to ensure the safety index is as close as possible to 100%. The probability of having safe behavior and condition on the construction site is 0.54 (i.e. 53.4%), which is the average of all the safety indexes over the eight-month period. This value can be used to predict the safe behavior and condition (i.e. the safety performance) of a similar project in the very near future.

CHAPTER 5

CONCLUSIONS

This chapter presents the summary of the research study and highlights the main results of the research. The contributions made in the research work with respect to the development of a safety activity analysis framework and tool are also reported. The conclusions, recommendations, and limitations of the research, as well as the areas of further research, are presented.

5.1 Concluding Remarks

Construction is not only a capital intensive activity, but also a labor intensive one in which workers play a very important role in the success of the various projects undertaken. Hence, the need to protect workers from accidents becomes a major consideration in any construction organization. It has been argued that measuring leading indicators such as safe behaviors and conditions, unsafe behaviors and conditions can be utilized in making predictions about the performance of a construction process.

The research developed a safety activity analysis framework that can be used to evaluate safety performance on construction projects. The framework established in one of its stages a goal definition and action planning process to set targets of reducing the numbers of injuries and illnesses on construction site to zero (or as close to that level as realistically possible). It describes the process of activity observation for data collection as well as the analysis of the collected data. The stage for the development and implementation of improvements to enhance safety performance in terms of continuous increase in safety index was also presented in the framework. A safety activity analysis tool was also created to simplify the process of data collection and analysis for the measurement of safety performance.

The case study carried out to implement the activity observation and analysis techniques also gave valuable results that can be used to continuously evaluate and predict the safety performance of construction projects. Over the eight-month period of the activity observations conducted on the project, the rate of occurrence of a safe behavior and condition on the construction site, with respect to the other categories, initially decreased from 45.7% at the inception of the project to a lowest value of 37.0% and then increased until it reached a maximum of 62.8%. This shows the existence of a trend in the safety behavior and condition and, thus, goals can be set to improve the percentage rate to as close as possible to 100%.

Although, the rate of unsafe behavior began with a low percentage at the start of the observation process, it increased steadily as the project progressed to a maximum of 36.6%. This value is not desired in a project, as it adversely affects the safety performance of a construction project and should therefore be reduced to a value as close as possible to zero in order to prevent the occurrence of unsafe behaviors that can result into an injury or illness. Then again, the percentage rate of unsafe condition started at a high level and decreased as the project progressed. This result points out that there is tendency for a high level of unsafe condition to be created when construction work is at the foundation or excavation level and should therefore be minimized to have an improved safety performance.

The findings of the case study demonstrated the use of a safety index in measuring safety performance on a construction site. The safety index of the site was 53.8% on average, the lowest index was 37.0% and the highest was 62.8%. These results can be used to set improvement targets and provide continuous feedback to increase workers' safety performance. The results also indicated that the stage of a construction process can affect the safety performance of a project. It was recommended that well-informed decisions and far-reaching efforts have to be made to ensure the safety index is brought as close as possible to 100% by reducing the unsafe behavior and unsafe condition on the construction site. The effort toward increasing safety index is expected to have a positive effect on the safety performance of the construction project. The percentage rate of safe behavior and condition also gives the probability of having safe behavior and condition, which is a measure of the safety performance on the construction site. This probability can be used to predict the safety performance (i.e. safe behavior and condition) of similar projects in the future.

5.2 Limitations and Further Research

The activity observation process still has some level of subjectivity in the sampling of unsafe behavior and unsafe condition. This subjectivity can affect the quality of the result in the sense that some inconsistency from the data collection can influence the results obtained. The case study made use of snapshots, which might offer limited information of the activities of the construction workers. The case study carried out in this research is also limited in the sense that it only presented the implementation of the data collection and analysis aspects of the safety activity analysis framework. The development and implementation of improvements were not carried out.

Further research can be carried out to decrease the subjectivity in the data collection (i.e. activity observation) process by engaging a panel of safety expert to create a standard checklist for the activity observation. The whole framework should be implemented on more than one construction project to confirm its validity and reliability. The activity observation and analysis carried out gave the baseline observation results that were used to determine the safety index of the baseline upon which improvements and feedbacks can be implemented. Research effort should also be made to test the improvements and feedback to determine if they are statistically significant.

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