Application of Competency Management System in Safety Performance: A Case Study of a Canadian Structural Steel and Erection Industry

by

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Abstract

The construction industry is the most hazardous industry because of the nature of its tasks and insufficient proactive approaches confronting the incidents. A safe work environment is needed for workers as they are the key components of the construction industry and should not be exposed to the unpredictable situations on the jobsite without significant attention to their safety. Therefore, safety practices should be an integral part of the construction processes right from the onset. Despite advancements in occupational health and safety practices, accident rates in the construction industry remain high. Previous research studies examining human resource management introduced the concept of competency as the skills in which individuals know or learn to perform tasks. While the competency management approach has been examined from an industrial psychology perspective, studies have yet to examine the ability of competency management to improve safety performance in construction practice.

This thesis focuses on developing a novel framework for examining the relationship between competency management and safety performance on construction sites. Two novel methodologies are presented in this thesis.

The first methodology contributes to the existing knowledge by (i) newly identifying a relationship between competency management and safety performance in construction, (ii) describing the features of competency program implementation at a construction company, (iii) detailing a procedure for determining the correlation between the penetration rate of a competency program and safety indicators, (iv) comparing the differences in safety performance prior and subsequent to the implementation of a competency program, and (v) analysing the cost benefit of applying a competency program as a consequence of improvements in safety performance. To demonstrate the application of the proposed methodology, a statistical correlation analysis has been conducted. Data from safety performance and competency management system are provided by a steel fabrication company in Alberta, Canada. The results show a strong correlation between safety performance indicators and competency management and suggest that competency knowledge may improve safety performance.

The second methodology proposes a system dynamic approach for examining how the competency management process contributes to the incident occurrence over time. Firstly, the competency hierarchy for performing construction tasks is introduced. Then, a causal loop diagram (CLD) for visualizing the relationships between the competency management and the incident rate is developed to understand the cause and effect of competency management and safety performance. Given the data available for modeling the relationships in the CLD, a stock and flow diagram (SFD) model can be developed to simulate the safety performance over time. To show the practical application of the developed approach, a case study was conducted in the same steel fabrication company to verify the significance of competency management approach in safety improvement. The simulation results prove that the incident rate decreases with job trainings. A sensitivity analysis also reveals that on-the-job training is one of the most important types of training for improving construction safety performance.

Preface

This thesis is an original work by Fahimeh Emami. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Application of competency management at a steel fabrication company", No. 70976, 25/09/17.

To my dear Mom

And my loving husband, Ali,

Without whom none of my success would be possible.

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Chapter 1: Introduction

1.1. Background

Competency management systems are human resource management models that identify the skill gaps of employees in terms of the organization's specific business goals and strategies (Homer 2001). Competency has been described as "behavioural patterns of an employee related to effective and/or superior work performance, acting both at an individual and collective level, and that provide the organisation in which they are implemented and applied with sustainable competitive advantage" (Vakola et al. 2007). From a human resource perspective, competency approaches provide a basis for integrating key human resource activities such as selection and assessment, performance management, training, development and reward management, thus developing a coherent approach to the management of people in organisations (Lucia and Lepsinger 1999).

The use of competencies in human resource management is not something new. During the last decade, competency management models had been used to focus on individual job performance, identify the competencies needed to perform effectively in the future work, analyze the gaps between current high and average performance, and investigate the skills required for long-term future success. Competency approaches, therefore, can be seen as a forward-looking and proactive approach for translating strategy into job-related and individual skills and behaviours that people can understand and therefore implement in support for change. All competency approaches help organizations attract and develop talented employees, identify the right person for a job position, perform succession planning, training analysis, and other core human resources functions (Draganidis and Mentzas 2006a). A substantial growth in the integration of competency management system to human resource systems and practices can be seen since the introduction of competency management system in 1959 by White and as the advantage of this system becomes more evident (Markus et al. 2005a).

Safety subject at workplace is a complex phenomenon in construction industries (Sawacha et al. 1999). Due to the high risk of fatality in construction industries—which is five times higher compared with the manufacturing industries and its injury rate, which is two and half times higher—construction industries remains as the most hazardous industry. The majority of accidents are due to an unsafe act committed by a worker involved in the accident. So, a management system is needed to investigate the workers' abilities and knowledge associated with the operations.

Construction incidents have been defined as "any observable, unplanned, and undesired human activities that may cause injury, illness, or property damage and permit inferences and predictions to be made about the person performing the act" (Hollnagel, 2016). To eliminate construction accidents, companies must develop competency-based management method to raise overall organizational performance and overall employee capability. To do this, companies need to identify patterns of order in the behaviour and develop highly productive workers to distill the core competencies that characterize top performers and differentiate them as a group from average performers (Kochanski 1997). Competency management systems assess how prepared an employee will be for all working conditions, assure that the job gets done correctly, on time, every time, with a strict adherence to safety standards. However, competency management is now recognized as a key process in ensuring and identifying individuals (re)training plans linked to the companies' objectives, the impact of competency approaches on safety performance needs to be explored.

As such, a method that examines the dependency of the competency management system and safety performance in construction industries must be developed. The aim of this research study is to quantify the impact and significance of competency programs from a safety perspective.

1.2. Problem Statement

Construction industry is the most hazardous industry in terms of personal safety and health. In order to improve safety performance in construction industries, management requires certain prevention methods to eliminate jobsite hazard. A review of the literature shows adequate research on developing human resource management tools and guidelines to assist the management in identifying the accident causation in construction industries and safety improvements. Competency management system as a system of managing and evaluating human resources has been introduced in the last ten years. Although different studies have discussed the significance of competency management system from an industrial psychology perspective, no study has been done on the impact of competency systems on improving safety performance in construction industries. Moreover, the impact of competency approaches on safety cost benefits has not been identified. In spite of the fact that many factors are involved in the accident occurrence at a construction site, no study has been developed to measure the contribution of competency factors in improving jobsite safety. Therefore, a research study is required to bridge the gap in the existing body of knowledge and determine the effect of competency management approaches on construction safety performance, and identify the required competency factors in having a safe workplace.

1.3. Objectives

This thesis work aims to investigate the impact of competency management system on safety performance in construction industries. The following outlines the objectives of this thesis:

1. Identify the safety indicators quantifying the safety performance of the company.
2. Propose a strategy to quantify the workers' involvement in competency management system developed in a steel fabrication company in Alberta.
3. Introduce a statistical analysis to figure out the impact of developing competency program on the safety performance of the company and safety cost benefit.
4. Identify the factors in competency management system affecting safety performance and build a conceptual diagram to visualize how different variables in a system are interrelated.

5. Develop a statistical simulation model to understand how the competency elements affect the safety performance. The developed simulation model assists to analyze the feedback process in order to investigate the dynamic behaviour of the system.

1.4. Methodology

The objectives outlined above will be achieved using the following methodology:

a) To achieve the first objective, the safety indicators such as lost time frequency rate (LTFR), injury frequency rate (IFR), and total frequency rate (TFR) were chosen to measure the safety performance. Data were collected from the company's safety databases on a weekly basis before and after the implementation of the competency management system. The collected data were used to measure the values of the safety indicators.

b) The second objective was achieved by going through the workers' profile in competency management system. By reviewing these profiles, a penetration rate, which shows workers' participations in competency evaluations, has been defined. To calculate this rate the number of workers with evaluations were divided by the whole workers in a specific period of the time.

c) To achieve the third objective, Pearson correlation analysis was conducted to measure the strength and direction of the safety indicators with the workers' penetration rate. The safety indicators have been recalculated for workers who have participated and who did not participate and correlated with the penetration rate to understand the significance of competency management system on safety performance.

d) In order to fulfill fourth objective, a causal loop diagram (CLD) diagram was developed in Vensim software to show the interactions between competency elements and safety performance. All of the factors in this CLD have been defined in an in-depth investigation through literatures and validated by the expert opinion.

e) The fifth objective was accomplished by building a stock and flow model in Vensim software to simulate the safety performance over time under the application of competency management system. The interactions between variables have defined by equations. The values and equations in the model determined through company databases and literature reviews.

1.5. Thesis Organization

The remainder of this thesis is organized as outlined below:

Chapter 2 provides a thorough literature review on the importance of safety performance in the construction industry. Safety approaches for eliminating safety problems are reviewed, and the application of a competency management system as a potential approach for improving safety outcomes is discussed. Moreover, a comprehensive review is carried out on the application of risk analysis methods for improving safety performance. Finally, reviews of the system dynamics (SD) methods in safety area which consider the interactions among system components are reported.

Chapter 3 describes a method for examining the relationship of the safety performance and competency management program. A correlation analysis quantifies the importance of competency management system in improving safety performance. Analysis, results discussion along with the existed competency management system is explored through the presentation of a case study in a steel fabrication company in Alberta.

Chapter 4 discusses the application of SD models for analysing industrial incidents. A simulation model using Vensim software investigates the dynamic cause and effect relationship between the competency management variables and safety performance in order to highlight the importance of competency program in safety improvement.

Chapter 5 recapitulates the academic and industrial contributions of this study, provides the conclusions of the current thesis, and offers recommendations for future research.

Appendices A provides the detail of one construction incident and explains the impact of competency management approach in eliminating the incident happening.

Appendices B provides all the feedback loops in the developed causal diagram.

Chapter 2. Literature Review

2.1. Introduction

The main aim of a literature review is gathering information related to the research topic to get a wider picture of the research problem, its objective, and its importance for investigations. Keyword search terms and descriptors included the following: competency management, safety performance, injury rates, lost time injuries, severity rates, recordable cases, frequency rates, workplace injury, incident rates, occupational safety, employee health, safety climate, safety communication, zero-injury technique, safety training, incident reduction, inspection, safety hazards, unintentional injuries, occupational health, occupational injury, behaviour based safety, safety programs, training and development, organizational learning, training, safety performance, causal loop diagram (CLD), and system dynamics (SD).

The main sources of this research are from journal papers, conference articles, paperwork and reference books as it is mentioned in the bibliography. The study begins with a detailed literature review on the competency management approaches in improving performance in construction industries. Subsequently, an overview of the competency definition along with the previous researches on competency management program is discussed. Thereafter, the focus would be on the need to improve the process of health and safety in the construction industries. An overview of the approaches taken to solve safety problems is discussed. Following the safety improvement techniques, the cause and effect methods, which investigate the relationships between competency management approaches and safety performance, in addition to the reviews of the SD approach for analysis of safety conditions in construction industries are introduced. Lastly, a summary of the literature review is discussed at the end of this chapter.

2.2. Competency Management

The competency approach to human resources management is not new. The early Romans applied competency profiling to figure out the attributes of a "good Roman soldier" (Wang

2012). The application of competency-based approaches initiating from 1970 has been rapid in the corporate environment (Draganidis and Mentzas 2006b). Researchers in competency management gave the following definitions for competency: Marrelli (1998) introduced competencies as human capabilities that are measurable and required for effective work performance demands. Dubois (1998) pointed out competencies as the combination of characteristics, knowledge, skills, mindsets, thought patterns, and the like that result in successful performance.

Competencies are defined as underlying causally characteristics of an individual, which means changing in one variable causes change in another with regard to an effective job performance (Boyatzis 1982) . Selby et al. (2000) described competency as a behavioural ability. The National Vocational Council proposed competency as the ability to perform roles or jobs based on the standards required in employment. The Treasury Board of Canada Secretariat (1999) argued competencies are the key employee-related levers such as knowledge, skills, abilities, and behaviours, which are useful for achieving results relevant to the organization's business strategies. LeBoterf (1998) denoted that competencies are not the resources of knowing how to act or how to do; rather, they integrate such resources. Milkvoich et al. (2003) defined competencies as the required skills, knowledge, abilities and other characteristics to perform a job effectively. Intagliata et al. (2000) pointed out that competencies define specific behavioural terms with regards to the leaders' desire and are consistent with the company's culture to produce more significant results. Hoonakker et al. (2010) suggested that the implementation of the competency management system in construction industry is crucial to overcoming the barriers to safety performance improvement in construction, which is addressed by ISO 10018. Perrenaud (2000) proposed competency as "a capacity to mobilize diverse cognitive resources to meet a certain type of situation." Competencies are defined as measurable knowledge, skills, abilities and other characteristics for differentiating the high level of performance from average performance (Mirable 1997). Athey and Orth (1999) introduced competencies as any observable knowledge, skills, attitudes, and behaviours linked to the individuals or any collective team, process, and organizational capabilities linked to high performance. Vakola et al. (2007) discussed and analyzed the core competencies in addition to the skills and behaviours needed for supporting competencies in measuring an individual's differences in banking sectors. Competencies are also defined as a "combination of motives, traits, self-concepts, attitudes or values, content knowledge or cognitive behavioural skills; any individual characteristic that can be reliably measured or counted and that can be shown to differentiate superior from average performers" (Spencer et al. as cited in Shippmann et al. [2000]).

Competencies can be classified as technical competencies, defined as "firm specific technologies and production related skills" (Walsh and Linton 2001), and as behavioural competencies, defined as "a mixture of knowledge, skills, abilities, motivation, beliefs, values, and interests" (Fleishman et al. as cited in Shippmann et al. [2000]).The Employment Department's Standards programme defines competence as the performance requirements of job positions such as the actions and outcomes that someone must be able to demonstrate, rather than the jobholders themselves, which means it is expressed in terms of the job purpose and the standards of performance expected to be achieved (Training Agency 1988). However, this perspective effectively determines the push for skill in job performance rather than understanding and fixing the output standards that regulate education and training (Burgoyne 1988).

Competency assessment process was initially developed for industrial psychology by McClelland (1973). Over the last 30 years, the utility and usefulness of the McBer job competency assessment methodology was found through a number of studies. These studies comprise of the identification of those criteria defining effective performance, the identification of a criterion sample group of superior performers, and a comparison group of average employees, data collection through behavioural event interviews, and the identification of competencies that distinguish superior from average performers (Spencer and Spencer 2008a). Serpell and Ferrada (2007) defined competency management system as a tool for achieving the required competencies for the inadequately trained workers who are dealing with site supervisors and help companies implement more training programs. Worker-oriented and work-oriented approaches are used by Chen et al. (2008) for measuring competency management. The first approach measures the employees' skills and abilities, and personal traits (Veres III et al. 1990; Chen et al. 2008), whilst the latter treats is definable in terms of the technical requirements of work tasks (Holmes and Joyce 1993) and is independent form the worker. Three unique classifications for competency measurement are introduced by Crawford (2005) and Ahadzie et al. (2008): input competencies, output competencies, and personal competencies, which measure competency based on the knowledge and skills of a person brought to a job, the demonstrable performance that a person exhibits at the job place, and the core attributes underlying a person's capability to execute a job, respectively.

2.3. Previous Research Studies in Competency Management Approaches

A summary of the previous work conducted in the area of competencies is explained below.

Sparrow (1995) described "management competence," "behavioural competence" and "technical competence" as three main approaches for measuring organizational competencies through different levels of the organization. The "management competence" approach measures effectiveness within an organization whereas the "behavioural competence" approach evaluates individuals across different occupations. The third approach, "technical competence", identifies the capabilities and resources that are connected to the overall performance of the organizations. Sparrow concluded that re-integration of the three approaches in companies and its human resources management system is essential.

Markus et al. (2005b) investigated that applying competencies model in organizations will benefit Human Resources (HR) systems and practices. So, three approaches have been mentioned for modeling competencies: the educational approach, psychological approach, and business approach. The focus of the educational approach is the role analysis based on "role outcomes, or knowledge, skills and attitudes, or both, required for role performance" (Markus et al. 2005b); whereas, the purpose of psychological approach is identifying competencies based on "the skilled behavioural repertoires of recognized star performers within particular organizations" (Markus et al. 2005b). The purpose of business approach is to assess organizational competencies including core competencies, capabilities, and practices communication and interpersonal skills. In addition, he found that construct, model and predictive validity are three fundamental issues related to competencies modeling. The construct validity asks for measuring actual competencies and the reliability of the competency assessment. Model validity or validation of the model is another issue in competencies modeling because “competencies describe normative production-related competencies and individual behaviours” (Markus et al. 2005b). Predictive validity is related to the lack of evidence for benefits resulting from adopting a competency approach. The underlying assumption of all competency initiatives is that the production-related competencies and individual behaviours will lead to improved job performance.

A core competency framework measuring the competency of cost estimators in construction projects was proposed by Alroomi et al. (2011a). This framework investigates the importance of each competency and its associated gap between the ideal and actual level of competency. He identified 23 core estimating competencies classified into skills, knowledge, and personal attributes competencies. The relationship between corporate level competencies and market return as a performance measure was done by Hitt and Ireland (1986) through a regression analysis. An “Iceberg Model” considering the individual’s qualities, knowledge and skills was developed by Spencer and Spencer (2008a) to highlight the importance of personal and professional competencies of individuals in measuring the level of competency. Draganidis and Mentzas (2006a) identified the various definitions of competency-based management in human resources management systems from previous research. In addition, a list of competencies needed to improve work performance was derived by observing the performance of the experienced employees in a specific occupation. Ultimately organizational competencies and individual-related abilities were found to be the common features in competency management system.

The relationship between managerial competencies and performance was identified with the use of factor analysis and regression analysis by Levenson et al. (2006a). Factor analysis was performed to classify competencies whereas regression analysis was performed to identify the relationship between the grouped competencies and performance. A strong relationship between management competencies and organizational strengths and weaknesses were identified because of applying structural equation modeling by Isik et al. (2009). Martone (2003) introduced competency-based performance-management as a formalized way of establishing employees' skills and behaviours, informing employees of company expectations, and setting employees to a clearly defined path toward achieving specific goals. Following elements are the key elements in designing and implementing a competency-based performance-management system that was identified by Martone (2003). The first key element is establishing competencies. The employer must specify the cultural and organizational competencies that employees are expected to demonstrate as well as the skills that must be measured. Setting goals and performance expectation is the second key element in designing the competency management system. Goals which are within the scope of an employee's responsibility should be selected to result in a great benefit to the organization. The third key element is monitoring performance and feedback. There should be a monitoring and feedback processes tied to the competencies that can provide ongoing guidance, measurement and feedback. Completing employees' profiles is the other key element in a competency management system for summarizing skills, experience, education, and strengths and for developing areas for each employee to begin succession planning, which is the last key element for implementation of competency-based performance-management.

Kululanga et al. (2001) identified competencies in terms of general knowledge and skill elements essential for developing project management competency through a survey of project managers in the construction industry. He mentioned that "professional competency in project management is attained by the combination of knowledge acquired during training, and skills developed through experience and the application of the acquired knowledge". Dingsdag et al. (2008) argued that clarification, improvement and standardisation of the safety competency within the industry can be an efficient way to provide consistency in the managing occupational health and safety (OH&S) and developing safety culture. This research has sought to define the most at risk of injury or death positions, the actions needed to be undertaken to be effective in driving OH&S performance on-site and to investigate the most practical way of defining OH&S competency. Core competencies associated with the role of construction management along with the development of a predictive model used for informing human resource selection and development decisions within large construction organizations is identified by Dainty et al. (2005). The methodology adopted in this research is the McBer job competency assessment process, which comprises the identification of effective performance criteria, comparison of the superior's performers with the average employees, data collection through interviews, identification of competencies for separating superior from average performers, validation of the competency model, and application of the model to a range of human resource management functions (Spencer and Spencer 2008a). Müller and Turner (2010) examined the leadership competency profiles of successful project managers by developing leadership development questionnaire to profile the intellectual, managerial and emotional competences of project managers of successful projects.

Moore et al. (2002) introduced a number of inconsistencies in the terminology and interpretations of the competency terms between the USA and UK approaches to competency assessment. The first inconsistencies arose between the McBer consultancy operated for the American Management Association and the Employment Department's Standard from UK over the term competency. McBer defines competency as "an underlying characteristic of a person which result in effective action and/or superior performance in a job" (Boyatzis 1982). In contrast, the UK Standards Programme defines competency as "a description of an action, behaviour or outcome which a person should be able to demonstrate" (Training Agency 1988).

Debrah and Ofori (2005) found that acquiring both occupational and organizational competencies are needed for Tanzanian construction professionals. In this study, the need for post-experience training is highlighted as a primary basis to compete with foreign companies for projects and being successful in a commercial environment.

The comparison of managerial competencies of female with managerial competencies of male project managers was done through a questionnaire by Arditi and Balci (2009) to find out the reasons for women's exclusion from the industry. The study concluded that there is not much difference between female and male managerial behaviours except that women perform better under the "sensitivity," "costumer focus," and "authority and presence" categories.

Crawford (2000) studied the importance of the project manager's competency in successful delivery of projects. In this study, knowledge, skills and personal attributes of project managers are found to be critical factors for success of the project. An inventory of the 75 types of competencies was established by Egbu (1999). In the context of this study, “leadership, communication (oral/written), motivation of others, health and safety, decision making, and forecasting and planning” were found as the six most important competencies. In addition, a comparison of the importance of management skills for refurbishment and general construction works was done showing that “the skills/knowledge associated with forecasting and planning, managing conflict and crisis, tenant welfare, team building, and decision making are higher than in general construction management; reflecting the uncertain nature and the relatively higher levels of risks associated with refurbishment works” (Egbu 1999). Zhang et al. (2013) adopted a well-established model to examine the social competencies of construction project managers via the use of a structural equation modelling approach. He investigated “working with others, stakeholder management, leading others, and social awareness” as four dimensions of social competencies which contribute towards a better performance for construction project managers.

Ahn et al. (2012) developed a survey asking the recruiters to rate the following 14 competencies: ethical issues, problem-solving skills, interpersonal skills, leadership, adaptability, collaborative skills, safety issues, interdisciplinary application, practical awareness, technical skills, computer skills, estimating/scheduling skills, communication, and environmental awareness to figure out the key significant competencies for construction graduates and clustering these competencies by doing a descriptive statistics and exploratory factor analysis. Factor analysis revealed that “ethical issues, problem-solving skills, and interpersonal skills” are the key competencies construction graduates whereas “communication and environmental awareness are ranked lowest.” Moreover, these 14 competencies were classified in four classes: (1) general competency, (2) affective competency, (3) cognitive competency, and (4) technical competency (Ahn et al. 2012).

2.4. Safety Management

Over the decades, the construction industry continues to be one of the industries with the poorest safety records (Siu et al. 2004; Huang and Hinze 2006). Construction sites have been described as ‘crawling with hazards,’ which affect the health of construction workers (Marsicano 1995). Lack of “provision of personal protection equipment”, “regular safety meetings", "safety training" and "reckless operations" are the main factors that makes construction industry as the most hazardous industries (Rowlinson 2004). Internationally, construction workers are two-to-three times more likely to die on the job than workers in other industries while the risk of serious injury is almost 3 times higher (Safe 2000). Although the incidence of injuries and fatalities has decreased by more than 50% during the last 30 years, the number of accidents, injuries and deaths continues to remain unacceptably high.

Zohar (1980) mainly addressed how the role of management, rather than the worker, affects safety in organizations. It is mandatory for all firms to provide a safe working environment for their workers (Lin and Mills 2001). Prescribing and enforcing "defenses" is considered as an approach that reduces the workers' exposure to hazards (Mitropoulos et al. 2005). Under this perspective, accidents occur because the prescribed defenses are violated due to lack of safety knowledge and commitment. This perspective has a limited view of accident causality as it ignores the work system factors and their interactions that generate the hazardous situations and shape the work behaviours.

In order to reduce and eventually eliminate construction accidents, researchers have explored techniques associated with company and project safety success. Significant factors associated with these successes are summarized in the following: Levitt and Parke (1976) introduced company managers' awareness of safety problems as a method to reduce construction accidents. Hinze (1978) pointed out safety impact identification on new workers and turnover rates as another approach for improving safety performance. Hinze and Pannullo (1978) proposed that increased job control leads to better safety performance. Hinze and Parke (1978) argued investigation of superintendent characteristic as a way to define the level of safety improvements. Hinze and Gordon (1979) suggested investigation of supervisor-worker relationships and its effect on injury rate as a way for measuring safety improvements. Hinze and Harrison (1981) identified that the safety program practices associated with the reduced injury frequency rates is an important factor in reducing construction injuries. Samelson and Levitt (1982) introduced owners' guidelines identification for selecting safe contractors as a significant indicator for safety performance. Hinze and Raboud (1988) proposed the identification of appropriate means of achieving or maintaining acceptable safety performance as an indicator for measuring safety. Liske et al. (1993a) pointed out zero accident techniques for investigating the safety status.

Although several research studies relating to improving jobsite safety proposed different approaches for safety improvement identification, the key elements of effective safety management and a crucial determinant of successful safety performance depends on the organizations' human resources. As a result, enterprises must be able to manage and develop the skills of their employees, recruit the most appropriate candidates, make effective succession planning and employee development plans by the implementation of a core human resource tool to tackle the safety problems (Draganidis et al. 2006) to undertaking the shortage of improvements in safety area. Investigations, shedding light on the lack of framework to face with minor improvements in safety, prove the necessity of a management system to have an overview on the safety performance. In the following the details of some of these techniques will be discussed.

2.4.1. Reported Literatures for Improving Safety Performance—Behaviour-Based Safety (BBS)

Behaviour-based safety as a continuous four-step improvement process has been succeeding in organizations nationwide and throughout the world more than a decade. (1) Defining certain target behaviours, (2) observing certain safe or at-risk behaviours, (3) intervening in an attempt to increase the occurrence of safe behaviour or decrease the frequency of at-risk behavior, and (4) testing in order to refine or replace a behaviour-change intervention are the four main steps for improving safety performance in the behaviour- based method (Geller 2005). Komaki et.al (1978) applied behavioural techniques to industrial safety focusing on the personal communication and giving posted and verbal feedback to the workers based on the systematic observations.

Goal setting and posted feedback (Chhokar and Wallin 1984; Reber et al. 1984), observation and posted feedback (Komaki et al. 1980), and observation, verbal feedback, data analysis, and problem solving (Krause and Hidley 1990) are the important components of behaviour-based safety performance improvements that necessitate various behaviour modification programs. The common features of these programs are employee training, observation, and feedback. Kopelman (1986) reported that it is crucial to develop a safety action plan to take corrective actions when feedback revealed a performance deficit. Informational feedback on performance has been shown to be a simple, effective, and durable method for promoting safety (Fellner and Sulzer-Azaroff 1984).

Sulzer-Azaroff (1980) showed a dramatic and consistent decrease in the number of hazards in 30 university materials research laboratories when the supervisors were provided with a copy of the observation form. Although behaviour-based safety programs improve the safety condition, there are a number of criticisms on its execution. Firstly, safety programs are doomed to fail unless they are supported by a powerful company management system. Secondly, these programs are highly dependent on adherence to the behaviour-based safety principals of observation and reporting by employees and miss-criticisms management system that helps employees report hazardous exposures and observations without fear of reprisal. Third, some opponents believe that since in BBS programs many injuries will not be reported, this program provides a counterproductive to risk management efforts and it is more practical to correct a hazardous condition in comparison with change human behaviours.

2.4.2. Reported Literatures for Improving Safety Performance— Safety Climate

Safety climate is a concept encompasses the safety ethic in an organization. It is a reflection of employees' view about safety and is an index for predicting employees' actions towards safety in workplace (Williamson et al. 1997). With the introduction of safety climate many of the limitations of traditional safety measures, such as reporting biases and after–the-fact measurement, were solved. Ojanen et al. (1988) claimed that changes in organizational safety behaviour can be measured through the safety climate. Schroder (1970) introduced the level of maturity of employees' safety attitude as an important part of the safety climate in decreasing unsafe behaviour. In safety climate approach, more safety staff, safety committees, and safety training result in less incident rates (Smith et al. 1978).

Simonds and Sahrai (1977) introduced management involvement, promotional efforts, employees' specifications, and physical conditions as factors contributing to injury frequency which are indispensable parts of safety climate. Neal et al. (2000) argued that safety climate is a mediating variable between organizational climate and safety performance and can be measured through self-reports of compliance with safety regulations and participation in safety-related activities. Dedobbeleer and Beland (1991) mentioned that workers' involvement and management commitment to safety are the two key factors impacting the safety climate. Safety climate also refers to the shared perceptions, beliefs, attitudes and behaviour of the worker, regarding safety in their workplace (Cheyne et al. 1998). Ngowi and Mothibi (1996) who studied 30 construction sites in Botswana argued that the major reason for viewing safety procedures differently is the cultural differences and therefore a safety climate can be portrayed as a temporal measure of culture.

2.4.3. Reported Literatures for Improving Safety Performance—Leader-Based Verbal Safety Communication

Organizational safety culture is largely determined by the effectiveness of safety communication (Williams and Solutions 2006). Leader-based verbal communication focusing on social exchange theory and measuring the quality of exchanges has a significantly positive and lasting effect on the level of safety (Hofmann et al. 2003; Hofmann and Morgeson 1999). A proactive leader-based safety intervention method, focusing on adjustment of supervisory monitoring, was developed by Zohar (2002) and Zohar and Luria (2003) to encourage superintendents to prioritize safety communication during daily informal exchanges with workers. Studies have shown that foremen/supervisors have stronger influence on construction workers' safety attitudes than the workers' colleagues (Dingsdag et al. 2008). The safety intervention method, which is leader based rather than worker based, is used to change the managerial safety practices in addition to the workers safety practices (Kines et al. 2010). As the behaviour-based intervention aims to target the worker level, the aim of leader-based approach is to prioritize safety because of the complexity of the contributing factors to adverse events (Kines et al. 2010). However, the positive effects of leader-based verbal safety communication are tangible and undeniable; people pay more attention to the actions and nonverbal cues accompanying words that are said, so verbal safety communication without any effective safety improvements actions cannot be considered as a powerful method and sometimes make misinterpretations due to clouded judgment of the employees.

2.4.4. Reported Literatures for Improving Safety Performance—Zero Injury Technique

Construction Industry Institute (CII) introduced the zero injury technique in the construction industry to improve occupational safety and reduce accidents by convincing owners, contractors and managers of the importance in having a powerful safety program (CII 1993). Based on the CII finding, five high impact techniques must be utilized to achieve zero accident rates in construction projects: (1) pre-project planning for safety, (2) safety orientation and training, (3) written safety incentive programs, (4) alcohol and substance abuse programs, and (5) accident/incident investigations (CII 1993; Hinze and Wilson 2000). The importance of zero injury techniques for improving safety was examined by Hinze and Wilson in 1998, which validated the importance of the five, high-impact techniques in safety performance.

In 2003, after the revision of the aforementioned techniques, management commitment, staffing for safety, pre-planning, safety education, worker involvement, evaluation and recognition/reward, subcontract management, accident/incident investigations, and drug and alcohol testing were argued as the developed methods for fulfilling the idea of zero injury technique. Owner involvement is an essential requirement for this technique (Huang and Hinze 2006). In the research conducted by Liske et al. (1993b) and colleagues, the involvement of owner in pre-project planning and day-to-day project safety activities is considered as a prior condition in safety performance excellence. Suraji et al. (2001) developed an accident causation model showing that owners' responses to reducing the project budget, adding new project criteria, changing project objectives, and accelerating the design or construction efforts of the project to the constraints and the environment on construction projects play an essential role in having less or zero injury rate

2.4.5. Reported Literatures for Improving Safety Performance—Workplace Training vs. Education

Occupational safety and health administration (OSHA) instructs workers in recognizing hazards and using available method for protection (Waters et al. 1994). Workers' training not only prepares them to deal with potential hazards and unexpected situation but also help them become better informed about the actions for eliminating the hazards. Differences between workers' training and education are highly depending on the role; i.e. if the role is narrow, the best instruction for workers is training, and, as it becomes broader, education is more crucial (United States Congress 1985). Workers in the construction industry need to be trained and educated in the hazard recognition instructions, emergency procedures and use of personal protective equipment (Sulzer-Azaroff et al. 1990). Deming (1982) emphasized adequate training and employee involvement as a method for continuous improvement in safety performance. Cohen et al. (1998) revealed a need for greater effectiveness of workplace training. Their literature search focused on reports of training intervention efforts designed to enhance worker knowledge of workplace hazards, affect behaviour changes to ensure compliance with safe work practices, or prompt other actions aimed at reducing the risk of occupational injury or disease. Training was used as an intervention to reduce the risk of work related injury and disease.

2.4.6. Reported Literatures for Improving Safety Performance—Management Responsibility

Krause and Hidley (1989) mentioned the significance of management role in construction site safety. Management as the key component of a successful business performance controlling training resources, developing policies and procedures, regulating spending for equipment, selecting and deploying employees have the most significant impact on the safety performance. Geller (2016) described management's responsibility as arranging workers' safety discussion through the safety audits and group problem solving as an approach for developing action plans for safety improvements. The goal of the safety-auditing program is to achieve safety incident rate reduction at the first line of defense, and at the observable exposure stage before hazardous incidences occur.

2.4.7. Reported Literatures for Improving Safety Performance—Participants Involvement, Particularly Designers

Research has shown that the early involvement of all participants, particularly designers, in the construction worker safety effort has great potential for reducing exposure to hazards and potential hazards. The consequence of this early involvement potentially results in the reduction of accidents, injuries and fatalities (Gambatese 2000a; Hinze and Wiegand 1992; Gambatese et al. 1997; Gambatese 2000b; Lorent 1999; Hinze et al. 1999). By including construction workers as users, designers have the potential to consider their particular requirements and the performance required to meet them during the pre-design and design phases of construction (Hinze 2000).

2.5. Cause and Effect Relationship between Competency Management Approaches and Safety Performance

Traditionally, risk analysis methods and organizational methods are commonly used approaches for identifying risk elements contributed to incident occurrence. Risk analysis methods are the common methods for identifying risk elements, and subsequently develop mitigation plans to improve safety performance in construction industries. These methods describe accidents using sequential models that represent the linear succession of a series of events linked by cause and effect (Nicolet–Monnier 1996).

Although the sequential models such as Hazard and Operability Study (HAZOP), Failure Mode Effect Analysis (FMECA), and Preliminary Risks Analysis (PRA) are applied to the construction industries to improve safety performance, there are two main problems with these models. Firstly, the interactions among components in sequential models are not considered. Secondly, the impact of human and organizational factors is not highlighted. To solve the second problem, organizational methods that explain the presence of failure factors as the contributing factors in accident occurrences have emerged. System Action Management (SAM), Technical Analysis, Human and Organizational Security (ATHOS), and Cognitive Reliability and Error Analysis Method (CREAM) are the organizational methods that pinpoint the impact of the organizational environment on human and technical factors (Nicolet–Monnier 1996).

The main difficulty with the organizational models is that they present a static model of a system; i.e. they do not consider interactions among components and do not take into account feedback effects (Garbolino et al. 2009a). To consider the interactions among components, the impact of human and organizational factors, and constructing a dynamic model of safety condition in analysing incident occurrences a system dynamic approach was developed by Forrester in 1950. He introduced the following steps to create a system dynamics model in 1997; i.e. defining the purpose of modeling and identifying model's variables and interactions, developing a causal diagram that represent the causal relationships between these variables, building a quantitative model that consists of three types of element (stock [or level] elements [also called state variables], flow elements, and auxiliary variables and constants) (García and Sterman 2006).

Investigation through literatures sheds light on the application of system dynamics in diverse area. There is few research in economics (Tauheed and Wray 2006; Meadows et al. 1972), hospital systems (Koelling and Schwandt 2005), and engineering (Bagheri and Hjorth 2005). The system dynamics method has also been applied to complex managerial problems such as the development of inter-organizational networks (Akkermans 2001), optimizing the allocation of marketing resources (Graham and Ariza 2003), management of multiple projects in research and development (Repenning 2002), the prevention and management of crises in organizations (Rudolph and Repenning 2002), and innovations in process implementation (Milling 2002). Nepal et al. (2006) developed a causal diagram to illustrate the effects of the schedule pressure on construction and trade-offs in scheduling. A framework incorporated into the system dynamic model was proposed by Lee et al. (2005) for project planning and control in design and construction processes. This framework enables the assessment of the effects of changes and rework on schedule and quality performances. Love et al. (1999, 2002) developed a conceptual causal loop model to reduce the cost and effect of rework, to understand the causal structure of rework and to identify effective strategies for the prevention of rework. In the following, previous research studies on the application of cause and effect approaches in analyzing industrial accidents are discussed.

2.6. Previous Cause and Effect Approaches in Safety Management

Cooke (2003) described the relations and conditions that created a fatal explosion in a Westray mine by developing a system dynamic model. The model highlights the complex labyrinth of causes that can lead such a disaster and provide valuable lessons for organizational learning. The causal system dynamic of the Walkerton Water Contamination Accident is discussed by Leveson et al. (2003). Kyung and Jae (2005) analyzed the reliability of a nuclear power plant in addition to the evaluation of the boundary conditions of a nuclear power plant while under operation using system dynamic. A methodology was been proposed by Garbolino et al. (2009b) to simulate the functioning of a chlorine storage and distribution unit based on technical dimensions by the application of system dynamic method. This methodology contains four integrative steps: (1) using the systematic theory terms to model the system, (2) implementing of the model into a Dynamic System platform for the simulation, (3) using different scenarios to estimate the consequences of these deviations in the simulation model, and (4) assessing the barriers efficiency. System dynamic model has been applied to formalize causal interdependencies between technical, organizational, and human safety factors such as modeling the activity of the industrial system in system dynamic's software (Bouloiz et al. 2013) and identifying managerial tools in both organizational and human factors to improve safety (Yu et al. 2004). Bouloiz et al. (2013) used a systemic approach to assess the safety of a storage unit located in Morocco; however, Yu et al. (2004) explained that the interactions among organizational and human factors in a nuclear power plant contributing to nuclear safety.

To model the impact of workers' behaviour on incident occurrence, Han et al. (2014) examined the impact of production pressure on safety performance over time by identifying the feedback process. A CLD was developed to analyze the relationships between the schedule delay and rework and the variables of safety program such as workers' safety perception, safety training, safety supervision, and crew size. They found that schedule delay and rework are the critical factors of incident occurrence.

Shin et al. (2014) developed a SD model to mimic workers' mental process to analyze safe behaviour. They found that the model can help to prevent unsafe conditions and examine the effectiveness of safety improvement policies for eliminating unsafe acts (e.g., incentive for safe behaviour, increased level of communication, and immersion in accident). Shin et al. (2014) developed a system dynamic based model of construction workers' mental processes to analyze the feedback mechanisms and the resultant dynamics regarding the workers' safe behaviours as they found that there are dramatic improvements in preventing unsafe conditions, however, there are not yet any significant improvements in eliminating unsafe acts. The developed model examined the effectiveness of the safety improvements policies such as "incentives for safe behaviours, and increased levels of communication and immersion in accidents" (Shin et al. (2014)) to provide a better understanding of eliminating unsafe acts.

2.7. Summary of the Literature Review

The construction industry functions as a system-of-systems comprised of multiple people and processes. Without a comprehensive safety management system, this industry will continue to be characterized by poor safety performance. Although various approaches for improving safety performance in construction have been reported, due to their limitations in scope and effectiveness, an organization's human resource characteristics, particularly in terms of their competency level, may also be a determinant of effective safety performance when performing particular work tasks. So, a comprehensive competency management system as a function for measuring safety improvements is a necessity in the construction industries. Measuring safety performance against competency standards has formed the dominant performance management paradigm (Dainty et al. 2004). According to the ISO 10018, the overall performance of a management system and its processes in safety performance ultimately depends on the involvement of competent people and whether they are properly introduced and integrated into the organization, which can result in achieving an outcome consistent and aligned with organization's strategies and values.

The CII includes site-specific safety programs and implementation, auditing, and incentive efforts to embrace the mindset that all accidents are preventable. However, while CII's programs are considered best practices, a complementary practice or management system is required to assess the competency of people who will be adhering to these best practices. The CII has compared the total number of practices implemented on projects with safety performance (Hinze et al. 2013), yet the quantification of the impact of these practices on safety performance has yet to be studied. The relationship between construction competencies and performance indicators could not be found in previous investigations (Omar and Fayek 2014) as a result of the definition of competency as "performance" in past research (Fayek 2012). In addition, all the mentioned competency systems considered competency management as a skill management system rather than a learning management system. The aim of competency as a learning management system is creating a framework that handles all aspects of the learning and training process to eliminate safety problems through the improvement of workers' abilities, confidence and reliance. The existing body of knowledge provides a solid foundation for competencies identification (CII 2005; International Project Management Association and Caupin 2006); however, further investigation is required to investigate the different competencies, their measurement, and their relationships to performance indicators for construction projects to provide a continuous improvement tool for construction companies, helping companies measure and improve their competitiveness and facilitate the process of decision making by viewing competence not only as an attribute-based phenomenon, constituting a specific set of generic and context-independent attributes, but also as a practical competence in accomplishing work. In the present research study, the importance of competency management is examined from the novel perspective of safety improvement. In addition, system dynamic approach has been used to demonstrate the way which competency management system can improve safety performance.

Chapter 3: A Competency Driven Approach towards Improving Construction Safety Performance

3.1. Introduction

Competency management systems are human resource management models that are used to improve hiring practices and overall workforce performance (Tripathi and Agrawal 2014). Competency has been described as "people's underlying characteristics that indicates ways of behaving or thinking that can be generalized to one situation or another and which are maintained for a reasonably long time" (Guion, cited in Spencer and Spencer [2008b]). From a human resource perspective, competencies are any measurable skill or ability that relate to job performance. Competencies are not only associated with job performance success but are also associated with the investigation of knowledge, skills, and behaviours that are required to successfully perform critical work functions or tasks in a defined work setting.

The last ten years have observed a large expansion in the use of competency models and management systems to improve both individual job performance and overall organizational effectiveness (Vazirani 2010; Campion et al. 2011; Ashkezari and Aeen 2012; Wang 2013). Competency management, therefore, can be seen as a reference framework for a system that designs the inputs of an organizational plan and delivers outputs in the form of employee-centered performance. In these models, activities and attributes required for optimal job performance are identified and assessed. If assessment results are unsatisfactory, workers are proactively (re)trained. By improving employee and organizational performance through competency management and cultivation, companies may be able to prevent failings and deficiencies before they occur. Indeed, the use of competency management systems have considerably expanded since their introduction by White in 1959 and have now become a staple of many human resource systems and practices (Markus et al. 2005a).

During the past decades, the construction industry has been criticized for its poor safety performance (Alarcon and Ashley 1992; Forbes 1993; Kanji and Wong 1998; Loushine et al. 2006; Nesan and Holt 1999; Oglesby et al. 1989; Siu et al. 2004; Huang and Hinze 2006). Due to humanitarian considerations, the rising cost of workers' compensation, and occupational safety and health administration (OSHA) fines, the health and safety of workers remains a fundamental concern in construction practice (Jaselskis et al. 1996). The hazardous nature of the construction industry has been attributed to a lack of workers' perception of their abilities, poor safety meeting and training, and reckless construction operations (Rowlinson 2004).

To reduce construction accidents, enterprises must manage and develop the safety knowledge and skills of their workforce, recruit the most appropriate candidates, and create effective succession and employee development plans by implementing a human resource tool to tackle safety problems (Draganidis et al. 2006). Many competency management systems include a documented set of safety-focused competencies that are used to assess the safety-related skills and knowledge of an employee. Although identifying and subsequently (re)training employees with unsatisfactory safety-related competency measures may prove to be effective at reducing incident occurrence, the impact of competency management on safety performance has yet to be explored.

As such, a method capable of examining the relationship between competency management program implementation and safety performance has yet to be developed. The primary objective of this research study is *to develop a novel method for quantifying the importance of competency management from a safety perspective*. In the following, a methodology which describes a method for correlating safety performance indicators with competency program participation will be proposed. The existing competency management system, statistical analysis, and discussion of the results are explored through the presentation of a case study. Conclusions, along with implications for performance improvement and recommendations for further research, are also presented.

3.2. Methodology

The proposed methodology was used to examine the relationship between implementation of a competency management program and several safety indicators, namely lost time frequency rate (LTFR), injury frequency rate (IFR), and total frequency rate (TFR).

3.2.1. Competency Sample Characteristics

Since competencies required for delivering particular tasks vary considerably, competencies must be precisely identified and categorized to ensure that the behaviours, abilities, and strengths of each individual worker are appropriately assessed and that (re)training programs result in actual performance improvements.

For example, the ironworkers for steel fabrication are responsible for handling and installing steel members, unloading and stacking prefabricated steel, hoisting steel by attaching cables to the steel from a crane or derrick, positioning steel with connecting bars and jacks, checking the vertical and horizontal alignment, and bolting or welding steel pieces permanently in place.

Example competencies used to assess ironworkers fabricating steel members were identified from various sources including expert subject matter opinion, company safety manuals, and operations schedules and are provided as follows:

- Ability to read and understand blueprints;
- Ability to unload and stack steel units for hoisting;
- Ability to inspect all rigging devices for damage;
- Ability to position steel units, align holes, and insert temporary bolts;
- Ability to direct operations safely with hand signals or radios.

Implementation of a competency management program at a company is a progressive process. Rather than assessing the competency of all employees immediately, participation in these programs often occurs progressively, with a small group of individuals passing through the assessment program each day. Here, the level of worker participation in competency evaluations, also referred to as the penetration rate of competency management, is calculated by Equation (3.1).

$$\text{Pentration rate of competency management} = \frac{\text{Workers participated in competency assessment} \times 100}{\text{Total number of workers}} \quad (3.1)$$

The present methodology exploits the progressive nature of this implementation process to examine the relationship between competency management and safety performance. Rather than assessing safety outcomes prior to (penetration rate = 0%) and after complete implementation (penetration rate = 100%), safety outputs are compared to the penetration rate to examine if increasing employee participation is associated with changes in safety outcomes. Notably, this approach allows for a dynamic examination of the relationship between these variables that can be applied in conditions where program implementation is incomplete or unattainable.

3.2.2. Safety Sample Characteristics

Traditionally, safety performance has been measured by metrics such as the OSHA's recordable injury rates; days away, restricted work, or transfer injury rates; or the experience modification rating from workers' compensation. These metrics assist construction companies to assess their safety performance and strengthen their prevention management system, if needed. Here, definitions of safety indicators, such as LTFR, IFR, and TFR were adopted from the OSHA's safety rates.

Data of medical aid injuries (which require medical treatment prior to returning to work) and lost time injuries (which require restricted work or employee absence) were collected weekly before and after implementation of the competency program. Data were extracted from a company's safety database. IFR and LTFR values were determined using Equations (3.2) and (3.3), respectively. The TFR value was determined based on both medical aid and lost time injuries (Equation 3.4).

$$\text{Injury frequency rate (IFR)} = \frac{\text{Medical aid injuries} \times 200{,}000}{\text{Total working hours}} \tag{3.2}$$

$$\text{Lost time frequency rate (LTFR)} = \frac{\text{Lost time injuries} \times 200{,}000}{\text{Total working hours}} \tag{3.3}$$

$$\text{Total frequency rate (TFR)} = \frac{(\text{Medical aid injuries} + \text{Lost time injuries}) \times 200{,}000}{\text{Total working hours}} \tag{3.4}$$

3.2.3. Data Analysis

The Pearson correlation coefficient (PCC), developed by Karl Pearson, is used to measure the strength and direction (decreasing or increasing) of a linear relationship between two variables (Ahlgren et al. 2003). The PCC (r) is defined in Equation (3.5), where $\bar{x}$ and $\bar{y}$ denote the means of the two variables. Correlation coefficients range from −1 to 1. A value of 1 implies a strong positive relationship between two components with all data points lying on a straight line where y increases as x increases. However, a value of −1 implies a strong negative relationship between two components where y decreases as x increases. In this research study, correlation analysis was used to measure the linear dependence between the program penetration rate and the specified safety metrics.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{3.5}$$

The impact of competency involvement on safety indicators was also examined by comparing the safety metrics of employees that have participated in the program to employees who have not.

3.3. Case Study

A practical case study at a steel fabrication company is used to demonstrate the functionality of the proposed methodology and to examine the consequences of competency management system implementation on safety performance and safety-associated costs. The following subsections (i) introduce the features of the existing competency management system at this company, (ii) examine the correlation between competency management and safety performance, (iii) compare the differences in safety performance between employees participating and not participating in the competency management program, and (iv) estimate the safety-associated cost-savings resulting from the implementation of a competency program. It is important to note that, as competency knowledge varies between specialty trades, the scope of this case study is limited to ironworkers.

3.3.1. Existed Competency Management System

The main objective of the existed competency management system is to measure and improve the performance of employees and increase their future potential and value to the company. A competency-based performance-management system is a way of establishing the specific skills and behaviours that are expected from each functional group of employees to be/become successful in their present roles and for future growth in their organizations. It is imperative that construction industries define their long- and short-term goals, both for individual employees and the organization, and then determine the skills and behaviours that every employee in the organization should demonstrate to achieve individual and organizational success. In order to establish a comprehensive framework for measuring competency, there is a need to know the importance of competency.

3.3.1.1. Importance of Competency Management Approaches

The competency based approach has a number of advantages for the employee, the company, and the clients:

(1) Employee advantages:

- Common understanding of the knowledge, skill, ability and behaviour being measured;
- Consistent objective method;
- Eliminate biases by evaluating competence against best practices/ procedure;
- Identifies areas requiring development assisting both the supervisor and the employee to maintain focus;
- Outlines employee development and advancement paths within the organization: provide an opportunity for career development;
- Encourage ongoing conversations with leaders and employees regarding safety and quality;

- Effectiveness of training can be measured through performance, quality, and safety;
- Provides an opportunity for career development.

(2) Company advantages:

- Training will be effectively monitored and used to increase the competence of our employees;
- Promotes the development of our leaders and employees organically;
- Promotes consistency in quality and safety on site;
- Gains respect within the industry as a leader to promote a competent workforce;
- Employee development will relate more closely to corporate objectives and strategies;
- Employees that demonstrate multiple skills and capabilities are easily identified;
- Development of profiles link more closely to expectations, performance, and competence;
- Increased employee retention;
- Easier recruitment of qualified individuals;
- Continuous improvement and development thus creating a work and learning environment.

(3) Client advantages:

- Promotes a safe worksite;
- Promotes a competent workforce which allows for better cost control, scheduling, and health, safety, consistent environmental, and quality control;
- Promotes a positive public image relating to the safety and quality of the projects;
- Enhances quality of final product with trained and competent workers;
- Enhances knowledge of required competence which results in increased productivity on projects;
- Fully managed program to ensure workers are safe and ready for work.

3.3.2. Elements of the Existed Competency Management System

The following elements need to be addressed and considered to build ongoing snapshots of the overall knowledge capital and skills portfolio of the workforce.

3.3.2.1. Automation and Transparency

Automation and transparency are two important concepts within the competency management system. The potential of automating competency tasks, such as job search, skill gap analysis, and training plan preparation across cultural barriers is enormous and extremely valuable for performance improvements. Competency management systems must have transparency, where the purpose of measuring skills and abilities must be obvious to all employees. Employees must understand that a company expects them to be competent in their job.

3.3.2.2. Focus on advancement

Competency management allows employees to realize their key strengths, skills, and behaviours, in addition to those that need to be developed. They will also understand how their strengths complement those of other employees and why that is important in order to achieve individual and collective success. By utilizing the strengths of individuals and teaching them to work cohesively, a company's management will then be able to focus on developing the skills and behaviours that employees need to be successful in the marketplace.

Another benefit of establishing a competency-based performance-management system is that the organization delineates the performance criteria for each level so that employees know what competencies must be mastered in order to be considered for advancement. Competencies describe the skills, knowledge, behaviours, personal characteristics, and motivations associated with success in a job. Moreover, by applying a systematic approach of measuring individual competencies, it may be possible for an organization to build ongoing snapshots of the overall knowledge capital and skills portfolio of its workforce. Furthermore, organizations may be able to utilize this information to perform individual and organizational analysis, reduce education costs, improve hiring practices, improve retention, improve human resources performance and developmental planning processes, and deploy its human capital more effectively.

3.3.2.3. Rating scale

A rating scale method offers the structure for appraisers to evaluate each employee's trait or characteristic on a scale, which usually has several points ranging from "poor" to "excellent" and helps differentiate the abilities and strengths of each individual. Rating scales increase the speed of employee evaluation regarding the competencies relating to their position to ensure them having the correct understanding and proper knowledge of the skilled required. Since these rating scales are consistent, structured and standardized, the process for rating can be easily compared and contrasted. In addition, each employee is subjected to the same basic appraisal process and rating criteria, which encourages equality for all appraisals and imposes standard measures of performance. Both appraisers and appraisees have an intuitive appreciation for the simple and efficient logic of such a scale. The result has been widespread acceptance and popularity for this approach.

3.3.2.4. Assessments and frequency

The competency assessment processes must be tied to the skills, knowledge, behaviours, personal characteristics, and motivations associated with success in a job and provide ongoing guidance, measurement, and feedback. A fundamental component of successful companies is ongoing, regular quantitative and qualitative feedback of its employees, which highlights the importance of a prototype tool to produce employees' personal profiles. In addition, a skill gap analysis needs to be performed on a desired competency profile. The secret to a successful performance-monitoring and feedback process is to make this a regular part of the employees' activities, which can keep the senior executive informed and updated and allow them to know whether people are working on the right things and whether goals for the organization will be attained. Daily, weekly, and monthly informal assessment supplemented by a formal quarterly or, at minimum, a semi-annual process must be conducted to fulfill the frequency needed for the competency measurement system. The least successful way to administer a performance-monitoring and feedback process was found to be a once-a-year process with no feedback provided until delivering the year-end appraisal.

3.3.2.5. Motivating superior performance

A competency management system motivates superior performance by the workers. Through the application of a competency management system, employees understand what is considered as superior performance in an organization. As most people strive to be superior performers, a competency measurement process provides them with a relatively objective means of evaluating where they actually are and where they must be to achieve superior performance.

3.3.3. Designing a Competency Management System

The overall competency management system consists of self-assessment, witness competence, employees' (competencies') evaluation, training and development plan, and reassessment evaluation. **Self-assessment**, an employee's evaluation of his or her own performance during the specified performance period, is popular because it is easily administered. Self-evaluations are a vital activity that can help make performance appraisal process more effective and give serious consideration to the employees regarding how he or she has performed in meeting expectations.

Employee self-evaluations can provide several key benefits to the organization including employee engagement in the performance appraisal process, providing managers with a broader perspective, flagging differences in perception before the review meeting, promoting more effective discussions about performance, and prioritizing and managing challenges. The benefit of self-assessment includes increasing the workers' involvement in the process of assessing strengths, identifying discrepancies of performance between the employee and supervisor, and conducting a more constructive evaluation meeting; thus increasing commitment to career and performance planning.

Employees must be given the opportunity to complete the self-assessment regularly. For various reasons, many employees forgo the opportunity to conduct a self-assessment for the performance review and development process. In doing so, the employee abdicates his/her right and responsibility to take an active role in the feedback session and the final performance review session. Whether the employee agrees or disagrees with the supervisor's performance assessment of the employee, the self-assessment will always open channels of communication and play an important role in having a successful performance review and development process.

3.3.3.1. Witness competence

Witness competence is an outline that supervisors can verify employees' level of skills in a certain job regardless of their behaviour, gender, age, culture, race, and religion and they can only focus on the skill components of the employees and make it as objective as possible, removing all subjective issues in measuring competency level. Using this model will enable managers to easily manage employees' talent pool, perform succession planning, and build bench strength for the future.

3.3.3.2. Employee's evaluation (competency evaluation)

Competency management system is the process of examining and evaluating the performance of an individual. Evaluation is a legitimate and major objective of competency measurement system. Organizations must continually assess their employees' strengths and weaknesses. Employees' evaluations provide an assessment of the strengths and weaknesses for individual employees as well as the collective talents of employees by department or team, which enable employers to better match employee qualification to job assignments.

A complete evaluation, which gives the supervisor and the employee a chance to set goals and address any training outlined on the evaluation, needs to be conducted by the leader/supervisor/mentor of the employee with the applicable competency profile. The purpose of an employee evaluation is to measure job performance and provide employers with a metrics regarding the quality of employees' work. The importance of an employee evaluation is to determine whether an employee's skill set is appropriately matched to the employee's job, which is instrumental for the success of the employee. The importance of employees' evaluations to assess workers' skills is particularly significant in work force planning processes. Though organizations have a duty to conduct such evaluations of performance, many still recoil from the idea.

3.3.3.3. Training and development plan

Training plans must be issued to all construction and fabrication leaders/supervisors. This enables the leaders/supervisors to properly place employees with tasks and tools prior to starting the shift, and creates mentorship surrounding the training needs where on the job training is utilized to develop the employee. Assessing employee strengths and weaknesses is the first step in determining the type of training the employees need. Upon learning the employees' strengths and weaknesses, an employee evaluation decides what type of training is needed for the employee to perform his/her job tasks. An evaluation also sheds light on development programs, which benefit both the employee and employer. Competency management system can make the need for training more pressing and relevant by linking it clearly to performance outcomes and future career aspirations.

3.3.3.4. Reassessment evaluation

The purpose of reassessment is to fix the behaviour of employees who have poor behaviour, less than adequate performance or attitude problems. There is a need for regular on-going coaching and it cannot be replaced with an annual employee review and assessment. There are a number of positive benefits to an employee review and there are number of disadvantages as a result of not conducting routine reviews. These reassessments give the employee the opportunity to better understand expectations, standards and rules.

(1) Advantages of reviews:

- Gives the manager an opportunity to get to know the employee better;
- Gives the employee the opportunity to learn which behaviours and attitudes is needed to be improved or modified;
- Sends a message to the employee that company management cares about their performance as well as individuals;
- Helps the management of the company to chart a better course for the future of the employee;
- Helps the manager identify weaknesses and strengths that may not have surfaced on a day-by-day basis.

(2) Disadvantages of irregular or no reviews:

- Sends a message that the company management is satisfied with performance, attitudes and behaviour;
- Sends a message to the employee they are not important enough for the company to take the time for a review;
- Impedes improvements of the overall performance of the company.

3.3.4. Implementing a Competency Management System Understanding Obstacles

It is imperative to understand all of the barriers and obstacles to establish a comprehensive competency management system providing a continuous improvement tool for construction companies' performance. Arriving at a concrete definition of competency has proved to be challenging, which creates an initial barrier when trying to implement a competency management system. The evolving nature of the competency management system results in a school of thought which believes competency requirement cannot be generalized and the requirement of system will vary in different situations.

The second emerging critique is the concern expressed about the inadequacy of the concept of competency when defined in terms of skillful actions. This is because the skillful performance can be influenced by a variety of intervening variables such as comparing other employees' performance with one's own for individual motivation, which can be an ongoing challenge. From a management point of view, the most frequently conveyed problems include: lack of understanding by employees and a resistance to change, employees' fear of job losing; lack of confidence; being considered an inferior performer compared with other employees; loss of control, powerlessness or confusion when being asked to change; lack of competence because of not being able to make the competency transition well; lack of appreciation or reward system leading to lack of motivation to support the change over the long run; loss of support or support system as the competency management may shake confidence in their support system through working for a new supervisor, a new team, or on unfamiliar tasks because they fear that if they try and fail, there will be no one there to support them; lack of trust and support which leads to less resistance to change. On the other hand, from the employee's points of view, the most significant problem associated with a competency management system is that the explicit process of judgement can be dehumanizing and demoralizing and is a source of anxiety and distress to the workers. In addition, they agree that lack of commitment by management and lack of ownership and support by senior management can endanger their future work. Besides the problems that exist in convincing employees to participate in the competency evaluation, a lot of work need to be done by the evaluators for competency measurement, which are time-consuming in that a group of supervisors/leaders need to review and assess these measurements and teach the new system to their employees.

3.3.4.1. Creating culture

The competency program creates a culture that focuses on job training, identifying people who are competent, and ensuring this process functions properly. Prior to the emergence of competency, companies evaluated employee performance in terms of having a poor or great performance. With the introduction of competency management, focus is placed not only on employee's behaviour, but also on their skills and potential mentorship capabilities. The company culture transitions to one that is more collaborative and creates an ongoing learning culture that makes employees extremely employable. It transforms the entire culture of a company by promoting the idea of working together, rather than against each other, internally. As a result, competency management system as a system which contains training trailer, learning and development plan will help implanting the learning culture.

3.3.4.2. Educate employees, staff and users

Educating employees is needed when a competency measurement is established to improve the overall performance of the companies and benchmarks of the status of the firms' improvements. To help an employee to be eligible for a planned change in his/her role in the organization because of the introduction of the competency system, a comprehensive education system is needed. The reform and restricting of employees' education initially encouraged employees to place a premium on developing skills, which would enable them to manage their new responsibilities effectively. There are numerous reasons for training employees with the new learning culture of competency management. Chief among them are improved job satisfaction, motivation, process efficiency and increased capacity for new technology adoption.

3.3.4.3. Establishing competency management team

Competency management identifies the areas where coaching is necessary, encourages managers to take an active mentorship role, and highlights the importance of establishing a competency leadership team. Leadership team members are able to see—in a snapshot—if they have the appropriate people, in the appropriate roles, leading to a successful corporation. Competency-based performance systems also tie directly to recruitment and selection. Leaders and competency team must be able to determine which skills, experiences, and behaviours the company requires to select a candidate both for the immediate and the long-term success of the company.

3.3.5. Correlation between Competency Management and Safety Performance

The percentage of ironworkers involved in the competency program was determined as per the penetration rate defined in Equation (3.1). Safety statistics of the ironworkers were tracked based on the data provided by the health, safety and environment (HSE) department. Safety indicators of IFR, LTFR and TFR for companies' ironworkers were determined based on Equations (3.2−3.4). Associations between safety indicators and the penetration rate of the competency management program associated with the ironworkers were inferred from the correlations calculated using Equation (3.5).

The relationship between the ironworkers' penetration rate and the safety indexes are illustrated in **Figure 3.1, Figure 3.2**, and **Figure 3. 3**. For all three indexes, there was a strong negative correlation (r=−0.91 to −0.94) between the penetration rate and incident occurrence. These results demonstrate that as the number of participants increased, injury rates were reduced. Although conclusions regarding causality cannot be made from correlation analyses, these results support the hypothesis that implementation of a competency system can improve overall safety performance. **Figure 3.1** illustrates the relationship between the LTFR and penetration rate. LTFR was reduced to 0.33, or to one-third of its initial value, when the penetration rate reached 60%.

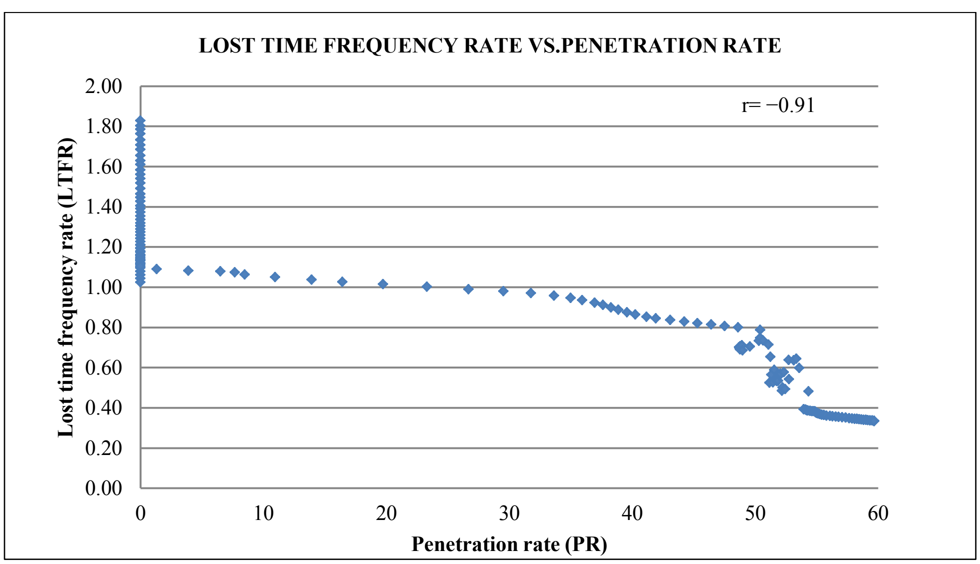

Figure 3.1: Ironworkers' lost time frequency rate versus penetration rate.

Figure 3.2 illustrates the relationship between the IFR and the penetration rate. The number of medical aids associated with the IFR decreased from 1.650 to 1.125 (i.e., −32 %) when the penetration rate reached 60%. Notably, the magnitude of the reduction was not as large as that observed for LTFR. However, organizations are generally less concerned with IFR since IFRs do not usually result in injury-associated employee absences or other irrecoverable problems.

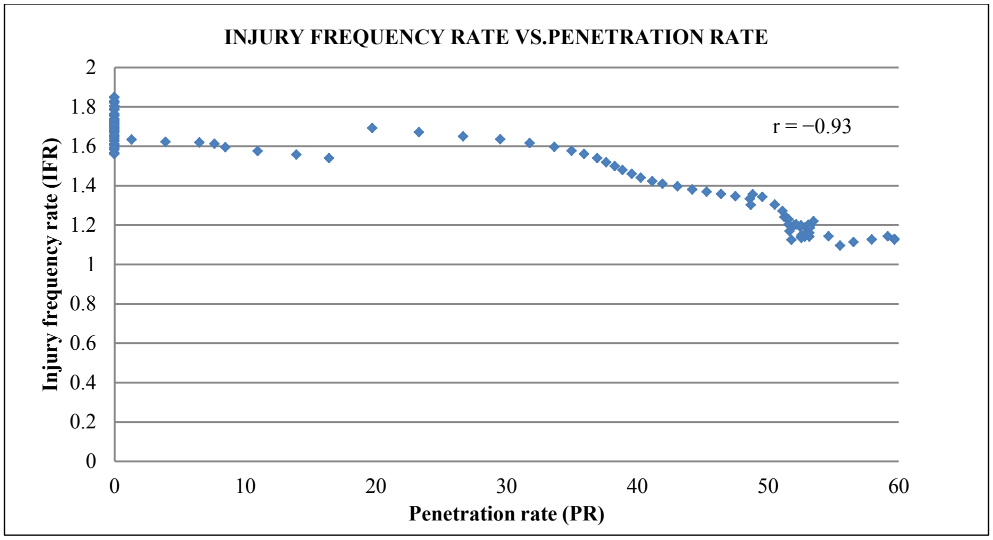

Figure 3.2: Ironworkers' injury frequency rate versus penetration rate.

Figure 3.3 illustrates the relationship between the TFR and the penetration rate. The penetration rate was strongly and negatively associated with reductions in TFR. These results demonstrate that implementation of the competency management system was associated with improved safety performance.

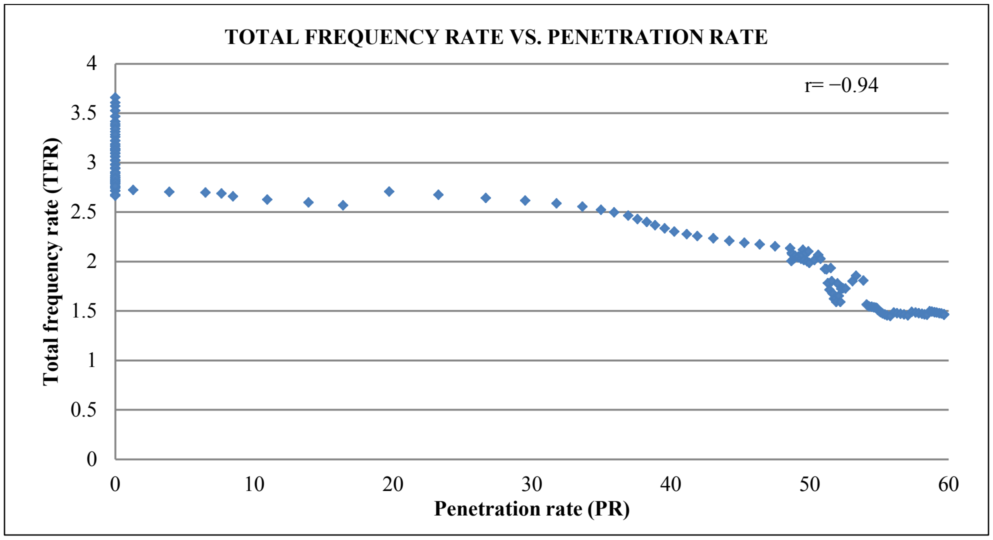

Figure 3. 3: Ironworkers' total frequency rate versus penetration rate.

3.3.6. Safety Performance Prior and Subsequent to Competency Program Implementation

To further examine the impact of competency management system implementation on safety performance, safety indicators for ironworkers who had or had not participated in the competency evaluation program were calculated and compared. The results of the LTFR per person-hour versus time and the IFR per person-hour versus time are illustrated in **Figure 3.4** and **Figure 3.5**, respectively. The LTFR was found to be twice as large for ironworkers who had not participated in the competency assessment program compared to the overall trend (0.62 vs. 0.33). In addition, the LTFR rate for ironworkers who had participated in the competency program was zero, indicating that the number of lost time injuries was been minimized, as shown in **Figure 3.4**.

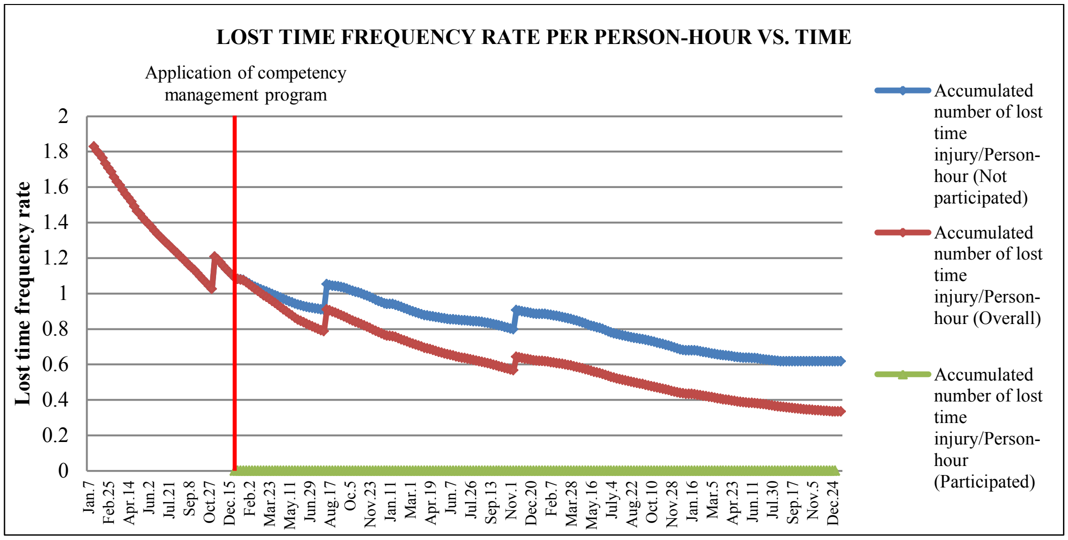

Figure 3.4: Lost time frequency rate considering ironworker participation.

Although the IFR was not minimized, the IFR declined from 1.33 to 0.80. Minimization of the IFR will likely require investigation into the causative factors involved in the occurrence of medical aid injuries. Notably, the IFR were only measured following implementation of the competency management program by one year, resulting in the delayed in reporting of injury frequency rates observed in **Figure 3.5**.

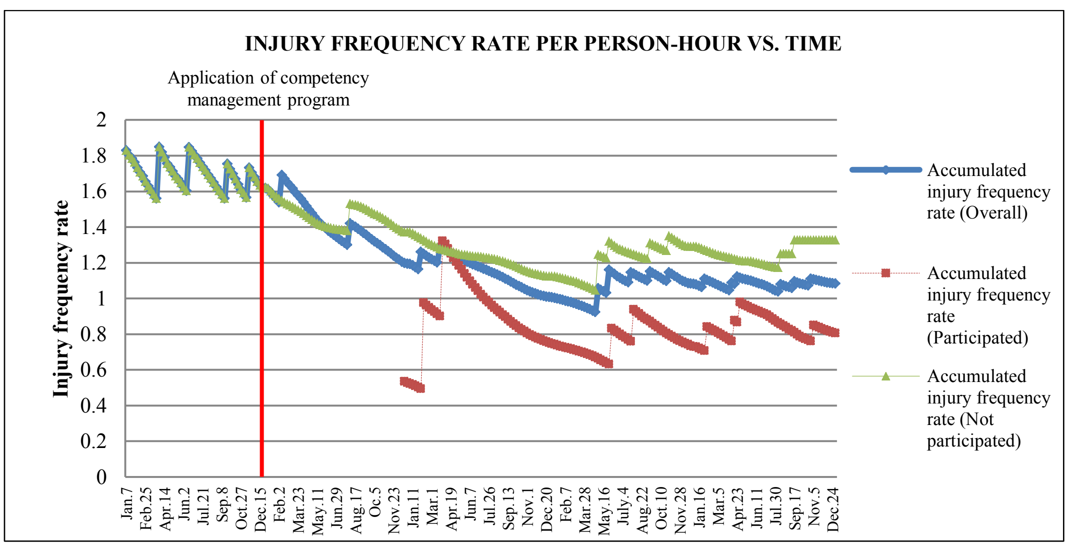

Figure 3.5: Injury frequency rate considering ironworker participation.

A root cause analysis was performed to investigate the root causes of medical aid injuries as shown in **Figure 3. 6**. It identifies the root causes of injuries along with the competencies that had been evaluated before the injuries occurred. Among the 17 workers with medical aid injuries, eight of them did not participate in competency evaluation and may have been predisposed to accident occurrence due to a lack of required knowledge. Notably, only three of the 17 workers involved in an incident were classified as competent. The remaining six incidents involved workers who participated in the competency program but who had been classified as not competent: four injuries were related to supervisory mistakes (supervisors failed to stop the work of two ironworkers who "need[ed] training" and failed to evaluate the identified competencies of two workers who were "not applicable to work"). In an effort to reduce supervisory errors, the competency management system was modified to include a front-line leader profile to ensure that supervisor competency was also evaluated. Two injuries were due to external causes and were considered "out of control" incidents as the cause of the incident could not have been pre-emptively mitigated by the workers, supervisors, or competency management system (The detail of the one of the incidents and its causes are discussed in Appendix A.)

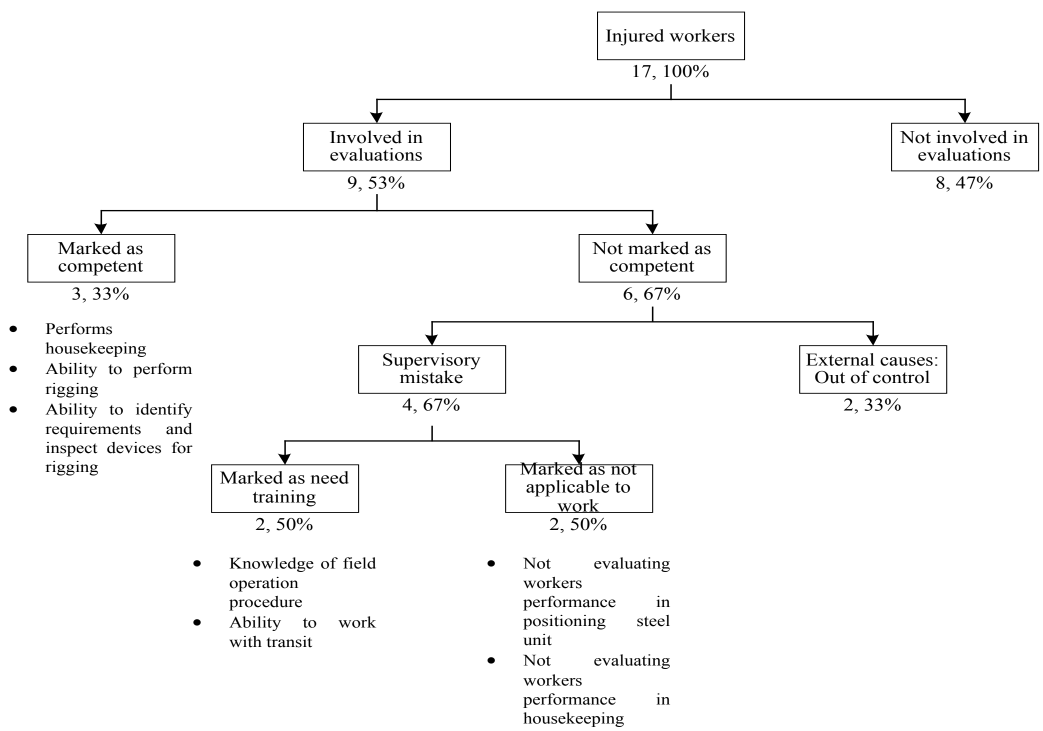

Figure 3. 6: Root cause analysis of medical aid injuries.

3.3.7. Safety Cost Benefit Analysis Following Application of the Competency Program

Both tangible and intangible costs contribute to safety-associated expenditures. The tangible cost related to lost time injuries were quantitatively estimated to examine the cost-benefit of implementing the competency program. To ensure a representative quantification of the total damages and costs resulting from an accident occurrence, various factors were considered including loss of production resulting from injured workers, transmission to the hospital, treatment, alcohol and drug testing, investigation of the incident, corporation and participation of the other workers to determine the cause of the incident, supervision, management, reassessment, and recovery of the injured worker to return to work. **Table 3.1** summarizes the average time and estimated cost allocated to lost time incidents. The total cost and hours of a lost time injury were estimated to be $39,050 and 160 hours respectively. These estimates are based on the effort involved in attaining treatment for the worker, completing the incident investigation, returning the worker to work, performing schedule enhancements to allow work continuation, and the lost time of the injured worker. Notably, these estimates do not include the worker's compensation board costs. Although difficult to quantify financially, intangible costs, such as loss of reputation and work opportunities, are often equally as detrimental to a company and should also be considered.

Table 3.1: Reported Average Time and Money for Lost Time Injuries

Cost description	Hours	Cost/hour		Total
		Paid to worker(s)	Loss of production	
Lost production injured worker (treatment/alcohol and drug testing)	10	$65	$90	$1,550
Investigation time (worker, supervision, management)	100	$100	$150	$25,000
Ready to wear effort / reassessments (injured worker, HSE advisors, leaders)	50	$100	$150	$12,500

Figure 3.7 illustrates the relationship between the lost time injury cost per person-hour versus penetration rate. To calculate the lost time cost per person-hour, the number of incidents that occurred was multiplied by the estimated cost for each incident. The results demonstrate that as ironworker participation increased, the estimated cost of lost time incidents was reduced.

When the penetration rate reached 60%, the estimated cost of lost time injuries per person-hour was reduced by ~61%, from 7.62 to 2.98.

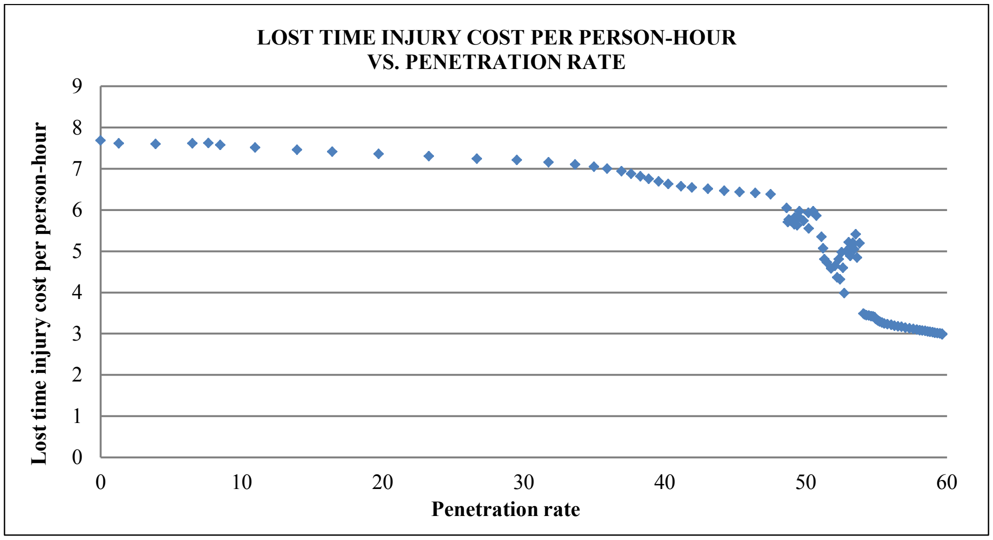

Figure 3.7: Ironworkers's lost time injury cost per person-hour versus participation rate.

3.4. Conclusions

This research study developed a new method to examine the impact of competency management knowledge on safety performance. This method was then applied to a case study to investigate the effect of implementing competency management and knowledge on safety performance at an industrial construction company. The overall aspects of an existing competency management system were detailed. The relationship between safety performance indicators (namely injury frequency rate, lost time frequency rate, and total frequency rate) and workers' participation in the competency evaluation program was examined using the Pearson correlation analysis. The impact of worker participation in the competency program on safety performance, as well as the resultant cost savings associated with reduced LTFR, were examined. Notably, a description of the importance of competency management implementation on safety performance, such as those detailed here, have yet to be reported.

Results of the present study suggest that implementation of a competency management program can reduce safety incident rates. The present study found a strong correlation ($r = -0.91$ to -0.94) between the penetration rate of the competency program and safety performance indicators and found that LTFR of ironworkers who had participated in the assessment program was approximately 50% lower than the LTFR of ironworkers who had not. Furthermore, the reduction in the occurrence of lost time injuries and medical aids was estimated to considerably reduce injury costs. These results not only shed light on the potential safety and safety-associated cost-benefits that may arise from the implementation of a competency-based performance management system in a construction company but represent novel findings with respect to the application of competency knowledge management.

Competency management knowledge encompasses multiple components of an organization's systems. The benefits of this knowledge, therefore, are expected to extend well beyond the safety effects reported here. Indeed, future research studies aimed at quantifying the impact of training duration, training type, and training outcomes on worker performance should be conducted. This will enable construction industries to better understand the relationships between competencies and related performance indicators such as safety. Moreover, a simulation study can also be conducted to predict business performance by capturing individual behaviour and competency levels of workers within the well-designed competency management system.

Chapter 4: A System Dynamics Approach to Understand the Impact of Competency Management on Safety performance in Construction

4.1. Introduction

The Construction industry is a main contributor to severe and fatal accidents (Dong et al. 1995; Brunette 2004; Waehrer et al. 2007; Sacks et al. 2009). The advancement of construction technologies increases the complexity of construction process and product such that the accident causation is dynamically changed in working environment. An important step in accident analysis, investigation, and prevention is to understand the incident occurrence mechanism. Unsafe acts and unsafe conditions are the primary reasons for incident occurrence. Unsafe acts include the deviation of a person's behaviour or activity from the normally accepted safe procedures whereas unsafe conditions are any hazard or unsafe mechanical or physical environment.

Competency, defined as a combination of characteristics, knowledge, skills, mindsets, and thought patterns (Dubois 1998), measures human capability required for effective work performance (Marrelli 1998). The competency level of a person defines the job performance (Boyatzis 1982) and specific behavioural terms to produce significant results concerning a company's desire and culture (Intagliata et al. 2000). The National Vocational Council emphasizes the importance of improving job performance through education and training (Burgoyne 1988). Competency management system was introduced as a tool for achieving required competencies for inadequately trained workers through job training programs (Serpell and Ferrada 2007). The main application of competency management system is to monitor workers' performance in order to minimize incident occurrence. However, no previous research study addressed the cause and effect relationships between workers' competency and safety performance.

A novel approach for investigating the causes of incident resulted from workers' competency is yet to be proposed in order to improve safety performance in construction. As such, the aim of this research study is to understand the cause and effect relationship between the competency management and safety performance in order to highlight the importance of implementing the competency management program in construction. To address this issue, the hierarchy of the competencies required in preforming construction tasks and the interactive relationship between competency management and incident rate should be examined.

A simulation approach, *system dynamics* (SD), is chosen to gain an in-depth understanding of how the competency management affects the safety performance over time. In general, the SD approach uses causal loop mapping and simulation modeling to analyze the feedback process for investigating the dynamic behaviour of entire system in a holistic manner (Sterman 2001). In the construction domain, previous researchers applied the SD approach for project planning and control (Love et al. 1999; Lee et al. 2005; Nepal et al. 2006). The *causal loop diagram* (CLD) can be developed to visualize the direct and indirect relationships between competency management process and incident rate. Based on the developed CLD, the *stock and flow diagram* (SFD) model can be developed to simulate the impact of competency management process on the safety performance.

In the following sections, a competency hierarchy for performing construction tasks is introduced. Next, a SD approach, along with a CLD, is proposed to analyze the cause and effect of competency management process and incident rate. A practical case study is conducted at a steel fabrication company to demonstrate its application. Given the data available from the company, the scope of the CLD and SFD is refined so as to highlight the importance of job trainings to increase workers' competency level and safety performance. Conclusion is drawn at the end by discussing the importance of competency management to improve safety performance in construction.

4.2. Methodology

This section introduces a hierarchy of four primary competency types required for performing construction tasks. Then, a SD approach, along with a CLD for simulation, is proposed to analyze the cause and effect of competency management process on incident rate.

4.2.1. Hierarchy of Practical Construction Competencies

Figure 4.1 categorizes the required competencies for performing construction tasks. The hierarchy divides the competencies into four types: general competencies, (ii) quality competencies, (iii) health, safety and environmental (HSE) competencies, and (iv) clinical competencies. Based on this hierarchy, all types of competencies are associated with both technical competencies and behavioural competencies. **Table 4.1** shows practical examples of the technical and behavioural competencies associated with particular competency type.

Technical competencies are classified as either internal or external technical competencies (Omar and Fayek 2014). To obtain internal technical competencies, practice and operational competencies are needed. Practice competency means a person should be familiar with the existing best practices to achieve better performance of the construction tasks. For example, the best practices can be innovation practice, worker improvement practice, and contract administration practice. On the other hand, operational competency means a person should be familiar with the new technologies. For example, the workers should be familiar with building information modeling, which may potentially increase resource utilization. External technical competencies can be identified by the relation of the construction tasks with the stakeholders such as workers' communication with different construction market stakeholders.

Behavioural competencies are characterized by personal knowledge, personal skill, and personal attribute (Alroomi et al. 2011b). For example, decision making, learning, leadership, engagement and motivation, self-control, assertiveness, relaxation, openness, creativity, result orientation, efficiency, consultation, negotiation, conflict and crisis, reliability, value appreciation, and ethics are considered behavioural competencies to enhance overall work performance (Trivellas and Drimoussis 2013).

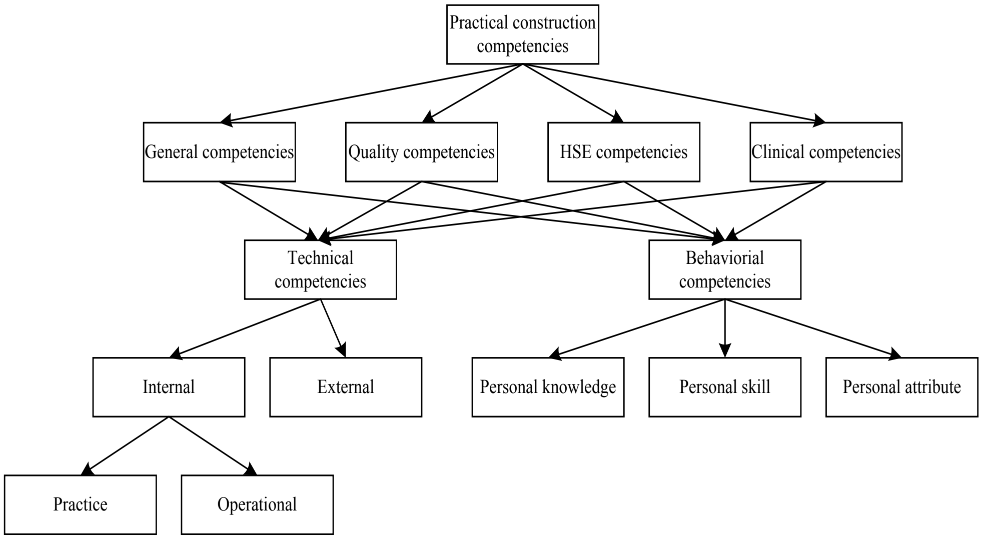

Figure 4.1: Hierarchy of competencies for construction practice.

Table 4.1: Practical Examples of Technical and Behavioural Competencies

Competency type	**Technical competencies**	**Behavioural competencies**		
		Personal knowledge related	**Personal skill related**	**Personal attributes related**
General competencies	Bolt torqueing	Apprentice training and experience	Hands on motor function	Safe working attitude
	Rigging	Apprentice and 3rd party training and experience	Hands on motor function	Safe working attitude
Quality competencies	Using instructions	Apprentice training and experience	Ability to read and comprehend	Integrity (the ability to do something right even when no one is watching)
	Visual inspections	Apprentice training and experience	Visual acuity	Attention to details
HSE competencies	Identifying hazards	Apprentice and 3rd party training and experience	Experience that the hazard exists	Proper risk tolerance
	Using safeguards	Apprentice and 3rd party training and experience	Ability to apply what is taught	Willingness not to take shortcuts
Clinical competencies	Alcohol and drug testing	3rd party training	No alcohol and drug dependencies	Discipline and integrity
	Fit for work	3rd party training	Conscious knowledge of work to be performed and be prepared for	Discipline and integrity

4.2.2. Causal Loop Diagram for Competency Management and Incident Rate

Since construction accidents could happen both as a result of events that are linked by cause and effect and also as a consequence of interactions within the system (Bouloiz et al. 2013), the CLD is chosen for visualizing the chains of cause and effect associated with the competency management process and the incident rate. Notably, the CLD is drawn based on Vensim simulation platform (Ventana Systems 2017).

A CLD diagram shows the relationship between a pair of variables. If the influence of one variable on another is reinforcing, the positive sign is used on the arrow. If the influence of one variable on another is balancing, the negative sign is used on the arrow. The application of CLD diagram makes the visualization of feedback loops possible. Loops in the diagram can be either balancing loop or reinforcing loop. In a balancing loop, a variable moves toward a desired or reference value; in a reinforcing loop, a variable continuously increases or decreases (Levenson et al. 2006b).

Figure 4. 2 shows the newly developed CLD for visualizing the direct and indirect causal relationships between competency management process and incident rate. Notably, the developed CLD consists of more than 40 interrelated feedback loops (**Appendix B**). In the following subsections, the four major reinforcing loops (R1, R2, R3, and R4) along with a major balancing loop (B1) are discussed.

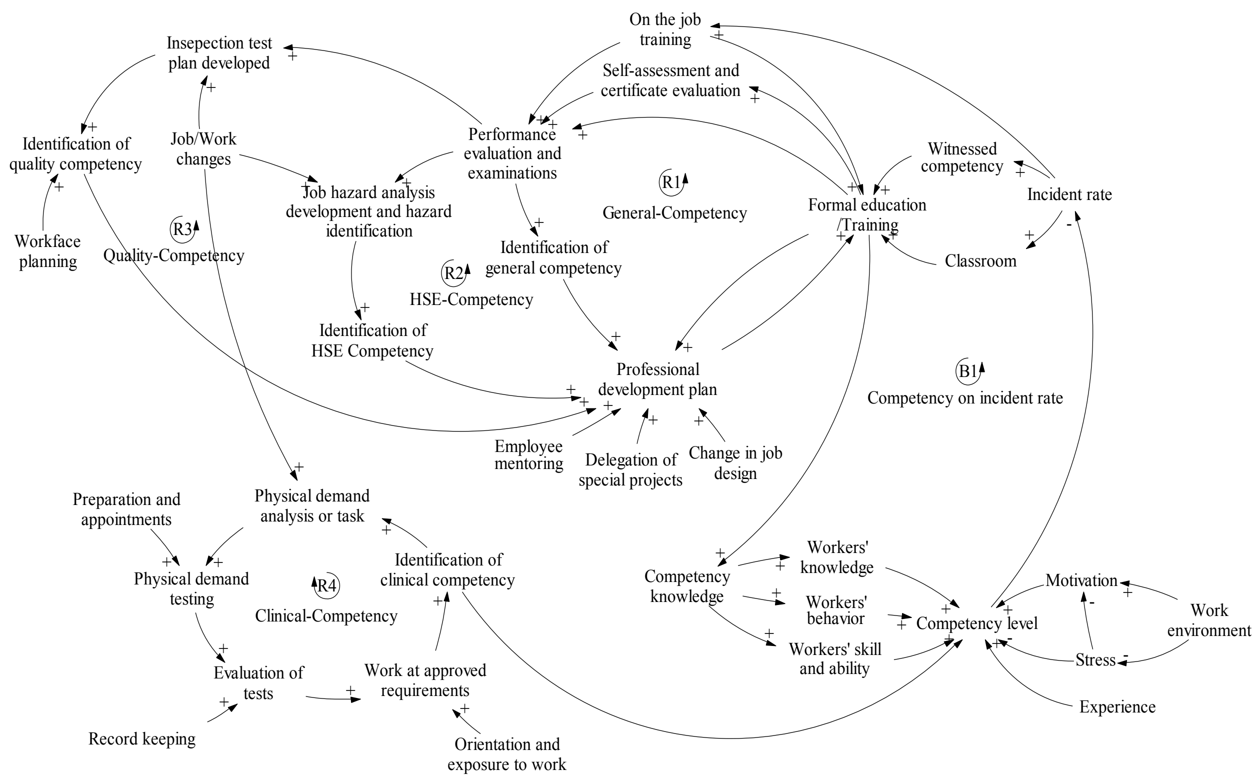

Figure 4. 2: Causal relationships between competency management process and incident rate.

4.2.2.1. General-competency reinforcing loop

Figure 4. 3 shows the general-competency loop (R1), which defines the continuous process of identifying the general competency. General competency contributes to the definition of a competent worker as the one who has sufficient skills to keep set production level.

Self-assessment and certification evaluation are conducted for each employee before evaluating his/her performance. After examining the performance, a professional development plan is developed in order to guide and assess employer's progress towards company career goal. Based on the development plan, the employee creates goals and action steps by scheduling a specific amount of time each day towards using development resources such as online course, continued education, informational interview with people, such that it is easier to identify the general competencies and plan the formal education/training. The cycle is continued after the employee is retrained.

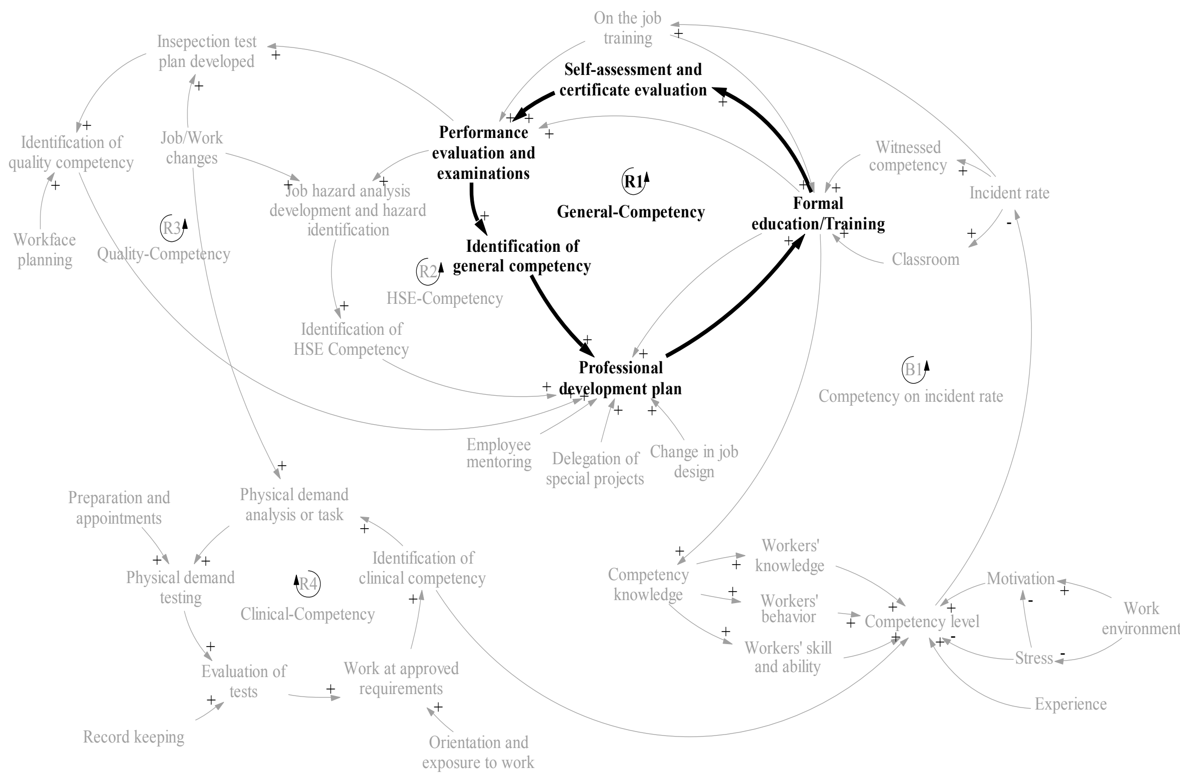

Figure 4. 3: General-competency loop.

4.2.2.2. HSE-competency reinforcing loop

Figure 4. 4 identifies the HSE-competency loop (R2), which defines the continuous process of identifying the HSE competency. HSE competency contributes to the definition of a competent worker as the one who is prepared to identify and handle surrounding hazards.

Education/training must be done for each employee before evaluating his/her performance. Based on the performance evaluations and job/work changes, job hazards must be identified and analyzed so as to identify the HSE competencies. The development plan for improving HSE competency for each worker must be developed and updated towards the company's future needs. The cycle is continued after the employee is retrained.

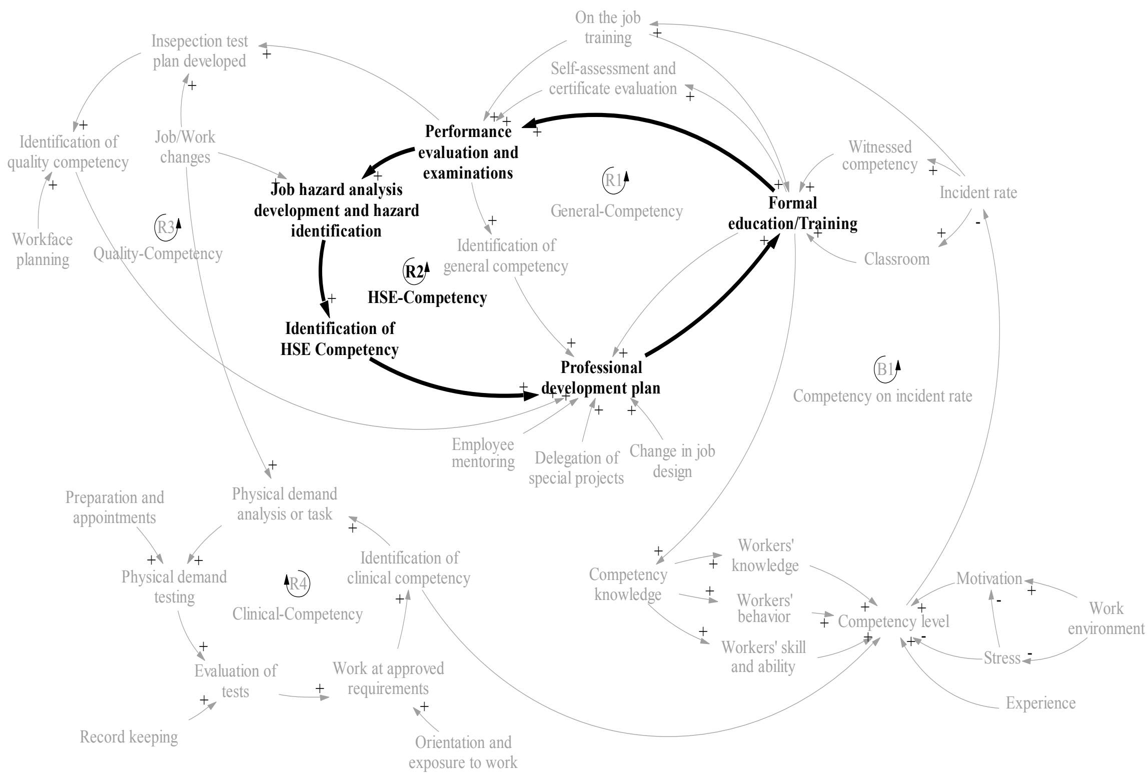

Figure 4. 4: HSE-competency loop.

4.2.2.3. Quality-competency reinforcing loop

Figure 4. 5 shows the quality-competency loop (R3), which defines the continuous process of identifying the quality competency. Quality competency contributes to the definition of a competent worker as one who is experienced to ensure that mistakes and errors are reduced or eliminated.

Each worker is trained to obtain the quality competency before evaluating his/her performance. After evaluating the performance, an inspection test plan is developed based on-the-job/work changes in order to identify the quality competencies. Based on the required quality competency, an individual's development plan must be developed for improving the performance. In accordance with the development plan, the education/training for each worker is provided. The cycle is continued after the employee is retrained.

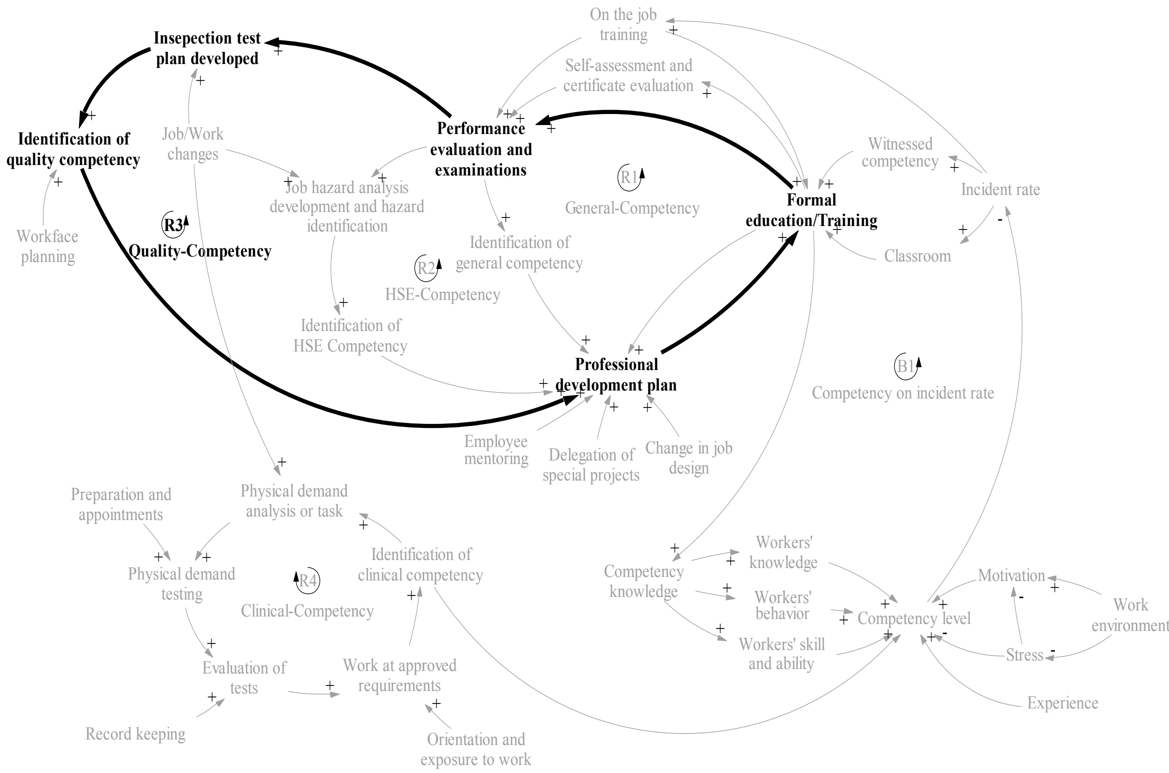

Figure 4. 5: Quality-competency loop.

4.2.2.4. Clinical-competency reinforcing loop

Figure 4. 6 demonstrates the clinical-competency loop (R4), which defines the continuous process of identifying the clinical competency. Clinical competency contributes to the definition of a competent worker as the one who is fit for work physically, mentally, and emotionally.

To check for the workers’ adaptation with the clinical requirements, physical testing, alcohol, and drug testing are required. The evaluation of the tests is needed to match the workers with their job responsibilities such that the workers can perform the tasks in accordance with the clinical requirements. Based on the tasks’ necessities, the clinical competencies associated with the tasks will be identified. Investigated clinical competencies in addition to the job/work changes result in continuing the process of physical demand testing.

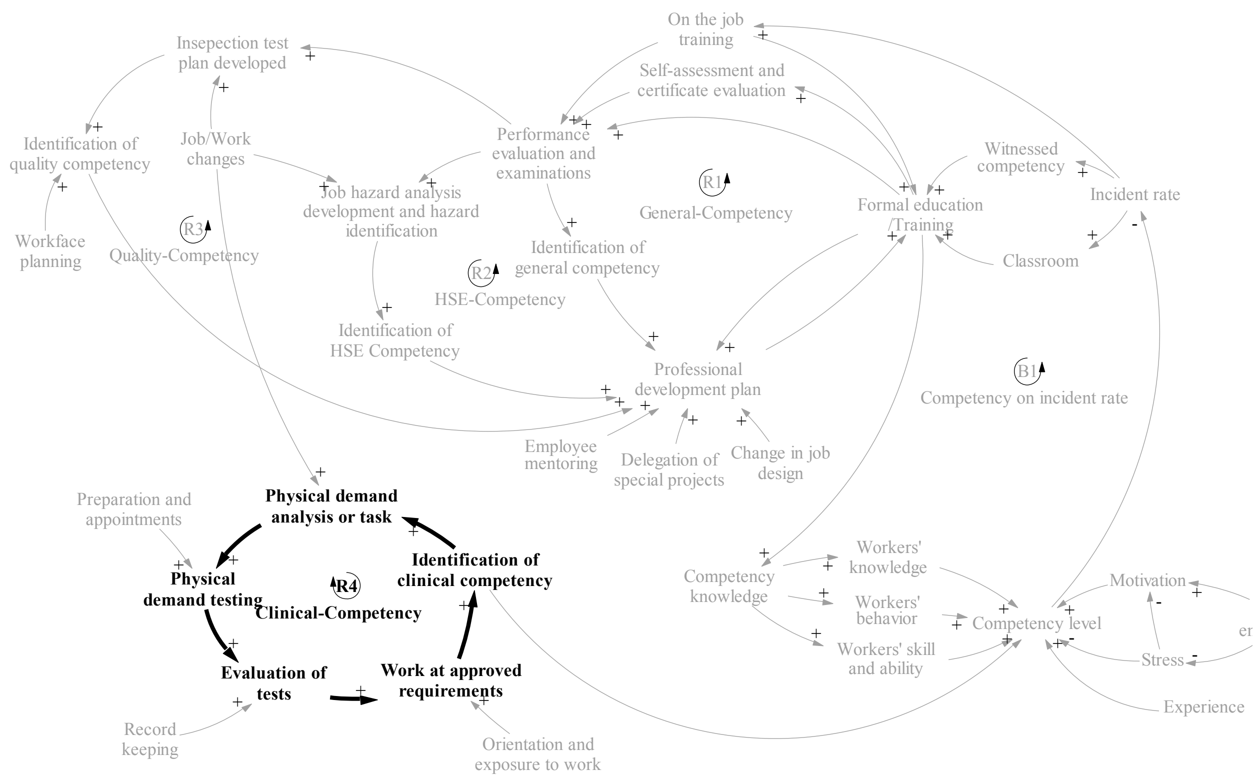

Figure 4. 6: Clinical-competency loop.

4.2.2.5. Competency on incident rate balancing loop

Figure 4. 7 demonstrates the competency on incident rate balancing loop (B1), which shows the impact of competency level on the safety performance. Formal education/training is the fundamental variable in the three main reinforcing loops (quality-competency, HSE-competency, and general-competency), as well as the balancing loop.

The education/training increases the competency level of workers and has a positive influence on their safety behaviour. This loop identifies the impact of education/training on the competency knowledge, subsequently leading to increasing competency level and decreasing incident rate.

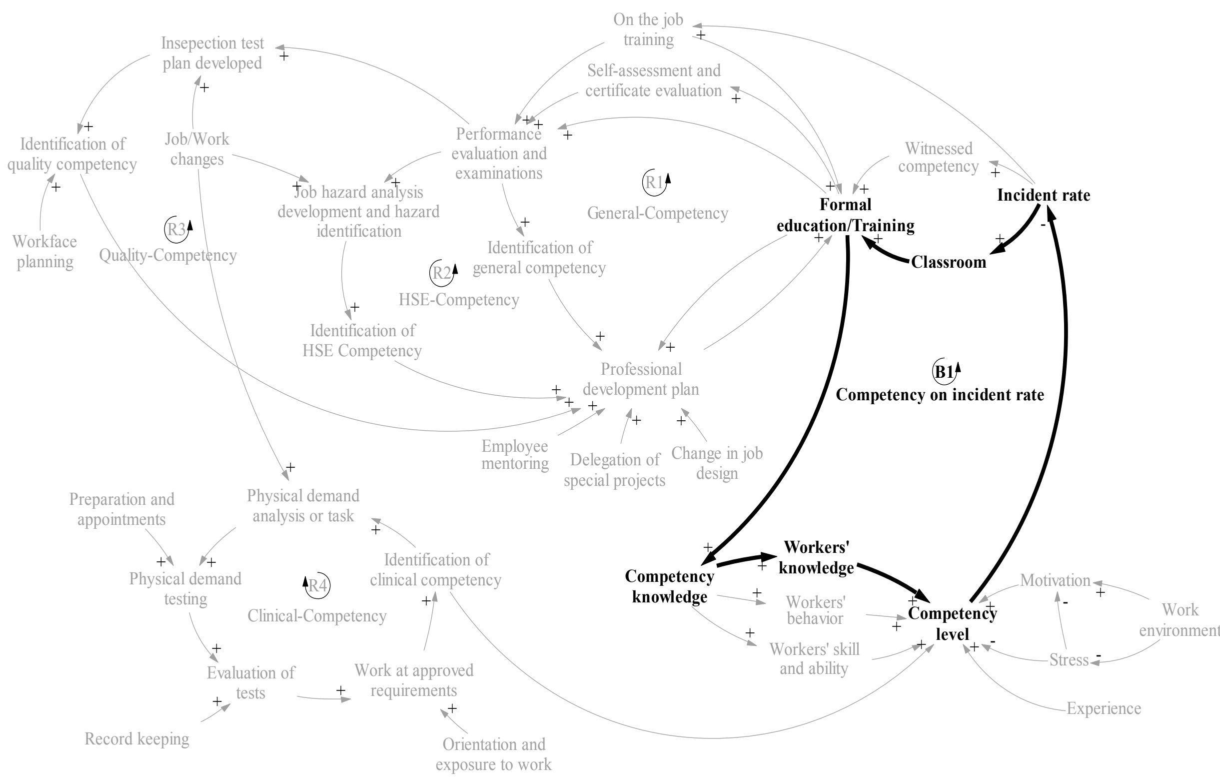

Figure 4. 7: Competency on incident rate balancing loop.

Figure 4. 8 shows the cause tree of the variable *competency level* associated with the CLD. The factors, including years of experience, clinical competency, motivation, stress, workers' behaviour, knowledge, skills, and abilities have a direct impact on the competency level and subsequently the safety performance. It shows that workers' behaviour, knowledge, skill, and ability are dependent on the competency knowledge that every individual has.

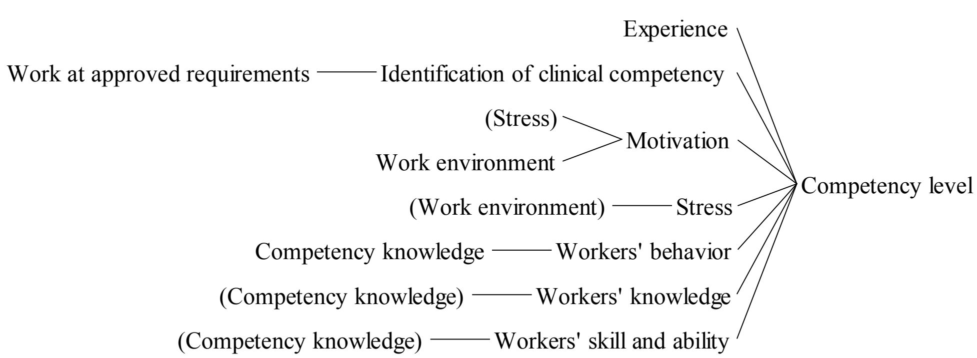

Figure 4. 8: Cause tree of competency level.

Figure 4. 9 shows the cause tree of the variable competency knowledge associated with the CLD. It demonstrates the application of formal education/training in improving competency knowledge. The training/education can be attained through classroom training, on-the-job training, professional development plan, and witnessed competency. Notably, the purpose of witness competency is to assist leaders/supervisors to witness workers' competency. Based on the observations of employees' performance, appropriate training and courses can be developed for the employees.

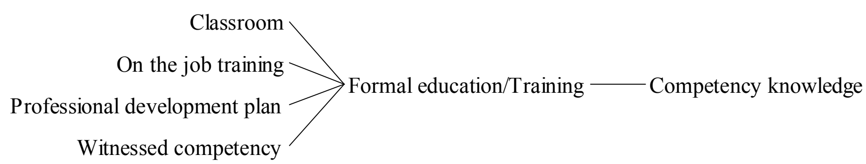

Figure 4. 9: Cause tree of competency knowledge.

Given the data available for modeling the relationships in the CLD, a stock and flow diagram (SFD) model can be developed for simulating the safety performance over time.

4.3. Case Study

A practical case study at a steel fabrication company is used to demonstrate the proposed SD approach and to examine the impact of implementing the competency management system on construction safety performance. The following subsections (i) define the scope of simulating the feedback process, (ii) develop the SD simulation model, and (iii) apply the sensitivity analysis to quantify the impact of competency management process on safety performance.

4.3.1. Scope of Simulation

Among the variables associated with the competency management process (Figure 4. 2), the measurable and manageable variables that continuously describe the state of the interactions between the process and those that the industry partners collected were chosen. Constrained by the availability of data provided by the steel fabrication company, the scope of the simulation was narrowed to simulate the significance of formal education/training in terms of increasing workers' competency knowledge and improving workers' competency level. The CLD, which consists of 10 variables, is shown in **Figure 4.10**.

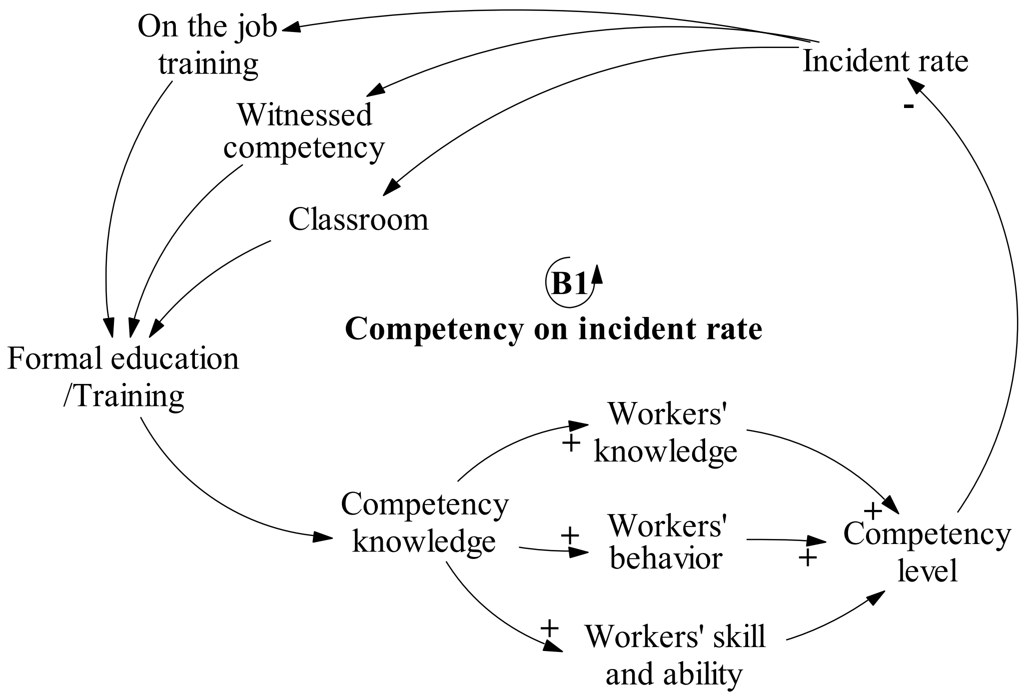

Figure 4.10: Causal loop diagram highlights the scope of simulation for practical case study.

4.3.2. Simulation Model

Given the CLD as shown in **Figure 4.10**, the corresponding SFD is presented in **Figure 4.11**. Notably, the SFD is built based on Vensim simulation platform (Ventana Systems 2017). The relationships between the variables are characterized using equations given by Yu et al. (2004). The equations are defined through the interview, literature, and database. **Table 4.2** lists the definition of the variables, sources, and formulas used to model the safety condition in the steel fabrication company. The initial condition for each variable (or stock) must be determined before running the SD model. The values and equations of the variables were defined through literature review (i.e., lost learning), actual data (i.e., classroom, on-the-job training, witness competency hours, being trained, and number of competent workers), and database (i.e., incident rate). For other variables, logical equations are used.

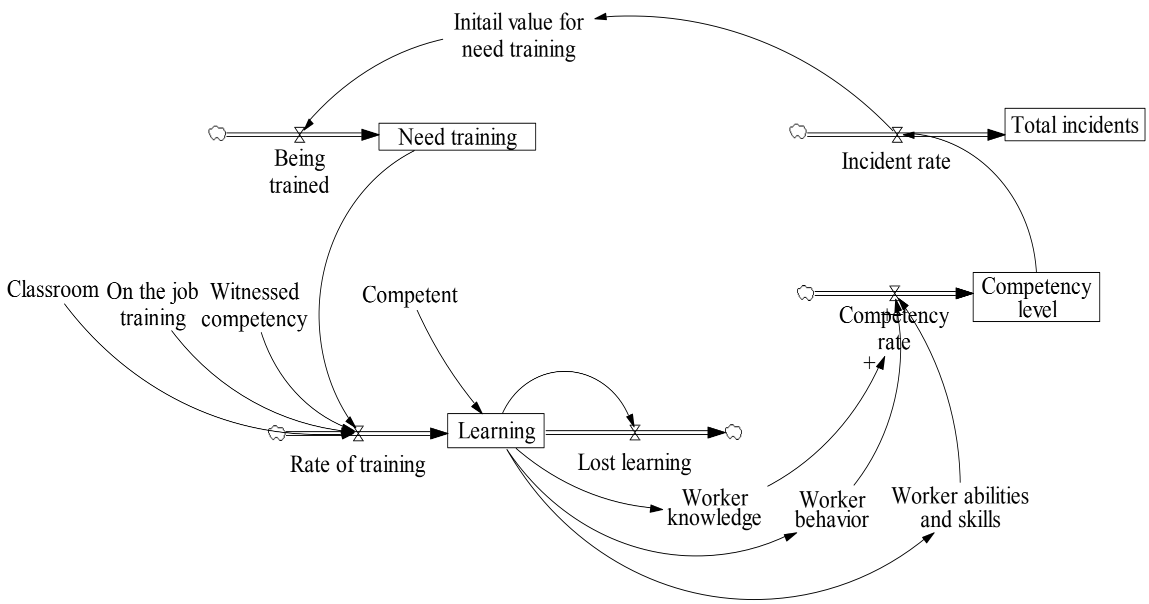

Figure 4. 11: Stock and flow diagram showing the safety condition through the application of competency management system.

Table 4. 2: Definition of all Variables used to Model the Impact of Competency Management Program on Safety Performance

Variable name	**Definition**	**Formula**	**Source**
Classroom	Classroom is a type of training influencing rate of training	Hours of monthly classroom training (3)	Actual data
On-the-job training	On-the-job is a type of training influencing rate of training	Hours of monthly on-the-job training (3)	Actual data
Witness competency	Witness competency is a type of training influencing rate of training	Hours of monthly witness competency (2)	Actual data
Rate of training	Rate of training is the training hours for workers need training	Need training × (classroom+on-the-job training+ witnessed competency)	Logical equation
Number of	Workers which were classified as	Number of workers being	Actual data

competent workers	competent in evaluations	competent	
Lost learning	Learning loss refers to any specific or general loss of knowledge and skills	Learning×0.4	(Ebbinghaus 2013)
Learning	Learning is done through training	((Competent×constant value)+ rate of training)-lost learning	Logical equation
Workers' behaviour	Learning influencing workers' behaviour is a source of competency	Learning/3	Logical equation
Workers' knowledge	Learning influencing workers' knowledge is a source of competency	Learning/3	Logical equation
Workers' ability and skill	Learning influencing workers' ability and skill is a source of competency	Learning/3	Logical equation
Competency rate	Flow	Workers' behaviour+workers' knowledge+workers' ability and skill	Logical equation
Competency level	Level of competency depending on the competency rate	Competency rate	Logical equation
Incident rate	Flow	"If statement"	Database
Total incident	Identifies the incident trend during the simulation period	Incident rate	Logical equation
Initial value for need training	Identifies workers who need training	Incident rate	Logical equation
Being trained	Flow	Minimum (Initial value for need training, 10)	Actual data
Need training	Identifies workers who had training	Being trained	Logical equation

4.3.3. Simulation Results

The purpose of simulation is to understand the feedback process in which competency program (i.e., job training) interactively affect safety performance (e.g., incident rate). Due to a deficiency of the data, the developed simulation model is limited to face-validation. The purpose of this model is only to show the relationships and interactions between the components of the competency management system and safety performance. The impact of behavioral aspects, such as emotions associated with individuals on safety performance, is not investigated in this model. The data collected over 12 months for 70 employees is used. Time boundary from January to December with the time step of each month is considered. The data of monthly training hours in current practice of the company are collected (3 hours of classroom training/month, 3 hours of on-the-job training/month, and 2 hours of witness competency/month).

The simulated results of competency level and safety performance over time are presented in **Figure 4.12** and **Figure 4.13** respectively. These figures conclude that there is a strong relationship between the competency level and incident rate. The safety performance improves as the competency level of worker increases through job trainings. However, it is not possible to remove all incidents in the job site with high competency level workers. From August to December, the incident rate is stabilized although the workers' competency level continuously increases.

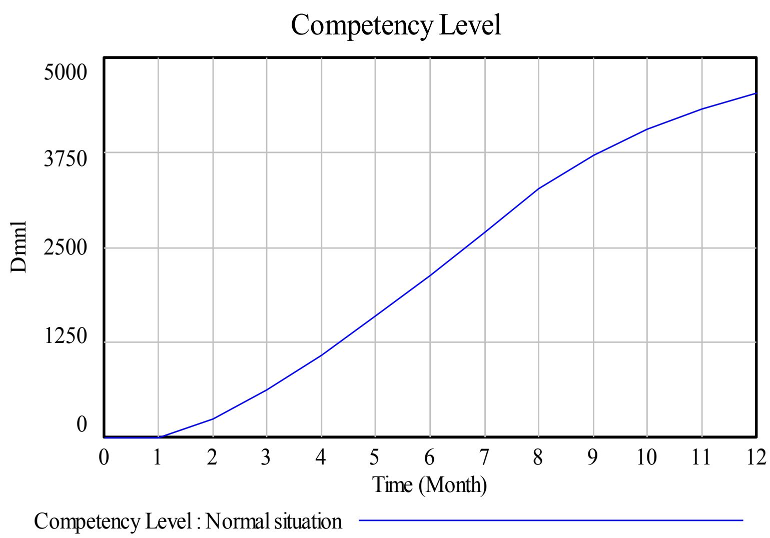

Figure 4.12: Simulation result for competency level over time (current situation).

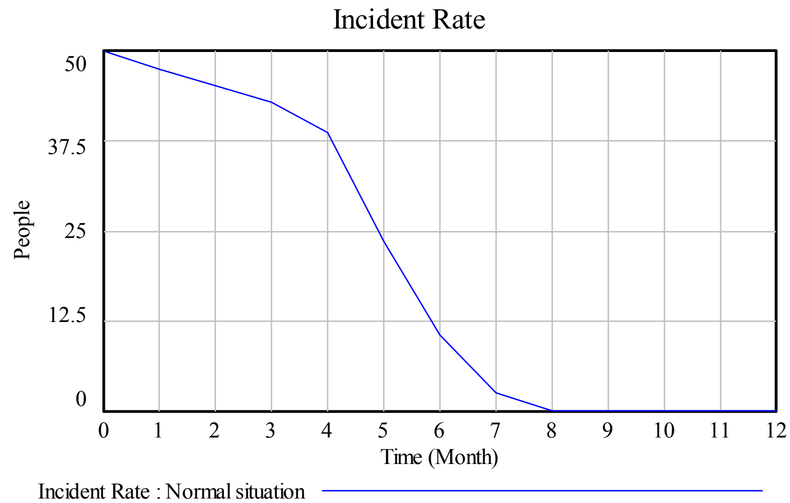

Figure 4.13: Simulation result for incident rate over time (current situation).

4.3.4. Sensitivity Analysis

Three case studies of sensitivity analysis were carried out to observe the effect of the source of job training (i.e., classroom training, on-the-job training, and witness competency) on incident rate. In each case study, the effects of two scenarios were simulated by a 20% increment and a 20% decrement of normal training hours (3 hours ± 20%). The variation of 20% is helpful for testing the sensitivity of the model variables. [Notably, the common variation range in engineering, biology, mathematics, and finance literatures is between 10% and 20% for conducting sensitivity analysis (Bouloiz et al. 2013)].

Figure 4. 14 simulates the sensitivity of classroom training hours on incident rate. It shows that a high degree of classroom training does not ensure a high degree of safety performance as the lines related to normal situation and 20% increment of classroom training hours being overlapped. However, a low level of classroom training hours can increase incident rate by a significant amount. This reveals that managers should not decrease the level of classroom training hours although increasing in-classroom training hours have no significant effect.

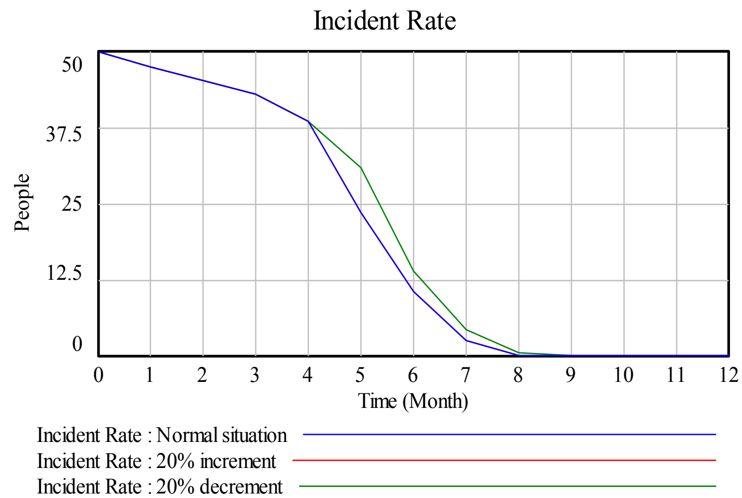

Figure 4. 14: Sensitivity of classroom training hours on safety performance.

Figure 4.15 simulates the sensitivity of on-the-job training hours on incident rate. It demonstrates that the safety performance is little affected when the degree of on-the-job training is increased (blue line). On the other hand, the impact of decreasing the job training hours (red line) on safety performance is significant compared to the normal situation (green line). The results highlight the importance of on-the-job training to improve the safety performance.

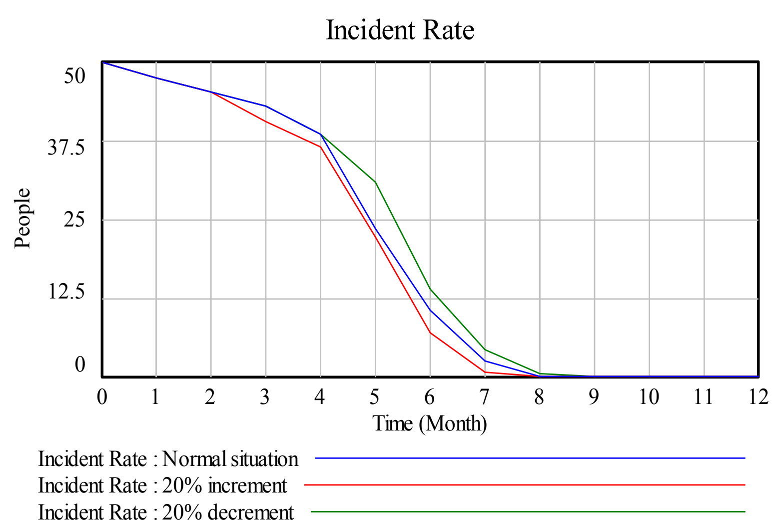

Figure 4. 15: Sensitivity of on-the-job training hours on safety performance.

Figure 4.16 shows the sensitivity of witness competency hours on incident rate. It shows that the impact of witness competency is not as significant as the other types of training; however, it can be considered as a tool for identifying if a worker is performing as prescribed in procedure. If the worker is not performing as witnesses, it enables the leader to coach during the witnessed session to increase awareness and performance, identifying that a longer-term mentor is required for performance coaching, and identifying that a more rigorous training program is required.

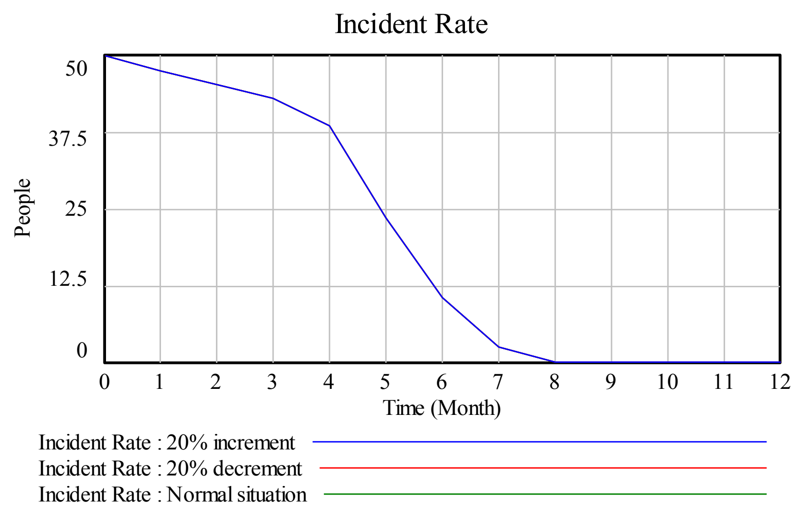

Figure 4.16: Sensitivity of witness competency hours on safety performance.

4.4. Conclusions

This research examines the relationships between competency management (i.e., different types of training and level of competency) and safety performance (i.e., incident rate) using proposed system dynamic (SD) approach in order to provide insight of improving safety performance in construction. The causal loop diagram (CLD) and stock and flow diagram (SFD) are developed to simulate the behaviour of competent management process and incident rate over time.

The CLD is used to identify and understand the causal relationships between competency management process and incident rate, in association with general-competency reinforcing loop, health, safety and environmental competency reinforcing loop, quality-competency reinforcing loop, clinical-competency reinforcing loop, and competency on incident rate balancing loop. Furthermore, the SFD is used to examine the impact of the job training hours, including classroom training hours, on-the-job training hours, and witness competency hours on the incident rate. The sensitivity of the job training hours is examined by applying 20% range variation.

The results show that the safety performance can be improved by increasing competency level through job trainings. This indicates that major management attention must be given to trainings as one critical factor in improving competency level and safety performance. In addition, the findings reveal that having training is essential to keep workers safe. Workers' safety performance increases with job training programs. Among all types of job trainings, on-the-job training is the most crucial one. These insightful findings can be applied to review the construction safety performance in terms of competency management.

Chapter 5: Conclusions

5.1. Research Summary

In recent years, competency management systems have become more applicable in construction industries as learning management system in improving workers' performance resulting in having a safer workplace. Due to the importance of safety issues in construction industries, a comprehensive conceptual method is required to examine the impact of competency management knowledge on safety performance. This study was conducted to develop a formalized framework and methodology for effectively investigating the impact of the workers' involvement in the existing competency management system in an industrial construction company, which contributes to the successful safety performance and a safe work place.

In this thesis, two new frameworks and approaches for demonstrating the application of competency management system in safety improvements were developed and proposed. Each of these frameworks ensures that safety rates are minimized and reduced while competency management programs were applied in construction industries. In the proposed statistical analysis, a strong correlation coefficient ($r = -0.91$ to -0.94) was found between the penetration rate of the competency program and safety indicators. In addition, the incident rates for workers who have participated in competency evaluations are much lower compared to the those who did not participate, which led to safety cost benefits.

In the proposed cause and effect approach, the search for the solution is based on a simulation model developed using Vensim software. This approach was conducted to understand the impact of competency assessments and process on improving safety performance. The results show that job training can be considered as a critical factor in increasing the level of competency leading to decreasing the incident rate in construction industries. Moreover, the on-the-job training was identified as the most important type of training in reducing incident occurrences. These results were achieved by the following: (i) quantifying the safety rates in a steel fabrication company, (ii) quantifying the workers' involvement in competency management system, (iii) proposing a correlation analysis to quantify the dependency between competency management programs and safety performance, (iv) developing a cause and effect diagram to understand the competency variables that impact the safety performance, and (v) developing a statistical simulation model to investigate the relationship between safety performance and competency management system. These developments achieved the objectives set out in chapter 1.

In chapter 2, an overview of previous work and research in the application of competency management system in improving performance in construction industries, competency definition and works conducted in the competency subject, the importance of safety issues, different safety techniques to eliminate workplace injuries, and cause and effect approach to analyze the competency impact on safety performance was provided.

In chapter 3, a comprehensive overview of the features of the existing competency management system, competency and safety sample characteristics were presented. A methodology was established to identify the relationship between safety performance indicators and penetration rate of the workers in competency evaluations. A comparison analysis was presented to demonstrate the differences in safety indicators for workers participated and not participated in the competency evaluations. A safety cost analysis was conducted to measure the cost benefit of applying a competency management program. A real case example in a steel fabrication company was used to demonstrate the features of the developed methodology. The results of the case study suggest that implementation of a competency management program can reduce safety incident rates and its associated costs.

In chapter 4, a methodology was presented to explain the interactions of the competency types and factors with safety performance. In this chapter, a hierarchy of the required competency for performing tasks was proposed. A cause and effect diagram was developed to visualize the impact of competency management approach and incident rate. Next, a system dynamic simulation model was presented to simulate the safety performance over time as a result of the competency management system's application. A real case example in a same steel fabrication company was used to apply the proposed mythology. The results of the simulation model show that by improving competency level of the workers through training, safety performance can be improved.

5.2. Research Contributions

The main contributions of this thesis are listed below:

1. The methodology adopted in this research study developed a novel method for quantifying the importance of competency management from a safety perspective, which cannot be found in the previous investigations in competency studies.

2. A comprehensive method was proposed to investigate the relationship between safety performance indicators (namely injury frequency rate, lost time frequency rate, and total frequency rate) and workers' participation in the competency evaluation program. In addition, the proposed method was used to shed light on the safety-associated cost-benefits resulted from the application of competency knowledge management. This method was applied to an industrial construction company established the competency management system.

3. A correlation analysis was generated to quantify the impact of competency approaches on safety improvements. This statistical approach can be used as decision support tools to examine the significance of human resource management systems.

4. A system dynamic approach was developed based on causal relationships between competency management process and safety performance to simulate the behaviour of competency management system and incident rate over time. This approach was applied to an industrial construction company established the competency management system.

5. A statistical simulation model was generated to assist managers in improving workers' competency level through training. The inputs of this simulation model include the job training hours associated with each type of training, the incident rate (people per month) for workers in the workplace, and the lost learning. Using these inputs, the model can estimate the impact of training as an essential factor in improving worker' competency level and to keep workers safe. This simulation model is beneficial for estimating the safety performance of the company in the future because of the competency management systems implementation.

5.3. Limitations and Recommendations for Future Work

The research presented in this thesis can be extended in the following areas:

1. The scope of this research is limited to the fabrication industries. A similar study is required to investigate the application of the competency management system in safety improvements in the other area of the construction industries such as manufacturing.

2. This study is conducted according to the existing competency management system in a steel fabrication company. To develop more accurate results and verify the proposed method, the study must be expanded to other companies that have implemented competency management approaches.

3. A comparison analysis between the impact of different competency types such as general-competency, safety and environmental competency, quality-competency, and clinical-competency on improving safety performance was not conducted but should be done in the future

4. In this study, only the impact of training on improving competency level was conducted. However, the simulation model developed in this study can be improved to consider the impact of other factors such as motivation, stress, experience, and work

environment on improving competency level of the workers, to perform a comprehensive cause and effect study at the conceptual level.

5. By enhancing the company databases it would be possible to conduct the analysis based on the quantitative relations between variables. This together with the expert judgements would lead to having more concrete results.

6. Due to the data deficiency, the scope of this research is limited to the safety performance of the ironworkers. The proposed methodology can be applied to the other tradesman.

7. The impact of psychological learning (i.e., the impact of incident occurrence on enhancing employees' subsequent care) is not discussed in the developed model.

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Appendix A: An Example of the Construction's Incidents

"A piece of cladding was removed from the side of a vessel by a worker. As the piece came loose, the top of the workers hand moved towards the cladding that was still attached to the vessel. The worker's hand contacted with the sharp edge of the cladding and caused laceration onto the top of the worker's hand."

Above is the example of an incident that took place in a construction company. The person who was performing the task is supposed to be responsible for this incident. However due to the application of competency management system there is a specific type of competency related to this incident, "Ability to identify requirements and inspect devices for rigging", which worker must be evaluated based on that before he/she starts working. In that case, the supervisor failed to evaluate the worker's competency in this specific task. To solve the supervisor's mistake, a front line leader profiling has been rolled up to evaluate the competency of the supervisors/leaders as well as workers.

Appendix B: Feedback Loop in the Causal Loop Diagram

Table A1: Feedback Loop in The Causal Loop Diagram

Loop Number 1 of length 1	**Loop Number 2 of length 2**
Formal education/Training ➢ Professional development plan	Formal education/Training ➢ Professional development plan ➢ Identification of skill competency
Loop Number 3 of length 2	**Loop Number 4 of length 3**
Formal education/Training ➢ Performance evaluation and examinations ➢ Professional development plan	Formal education/Training ➢ Performance evaluation and examinations ➢ Professional development plan ➢ Identification of skill competency
Loop Number 5 of length 3	**Loop Number 6 of length 4**
Formal education/Training ➢ Self-assessment and certificate evaluation ➢ Performance evaluation and examinations ➢ Professional development plan	Formal education/Training ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE Competency ➢ Professional development plan
Loop Number 7 of length 4	**Loop Number 8 of length 4**
Formal education/Training ➢ Self-assessment and certificate evaluation ➢ Performance evaluation and examinations ➢ Professional development plan ➢ Identification of skill competency	Formal education/Training ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan
Loop Number 9 of length 5	**Loop Number 10 of length 5**
Formal education/Training ➢ Self-assessment and certificate evaluation ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan	Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency ➢ Incident rate ➢ Classroom
Loop Number 11 of length 5	**Loop Number 12 of length 5**
Formal education/Training ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE competency ➢ Professional development plan ➢ Identification of skill competency	Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency ➢ Incident rate ➢ Witnessed competency
Loop Number 13 of length 5	**Loop Number 14 of length 5**
Formal education/Training ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan ➢ Identification of skill competency	Formal education/Training ➢ Self-assessment and certificate evaluation ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE competency ➢ Professional development plan
Loop Number 15 of length 5	**Loop Number 16 of length 5**

Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ On the job training	Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ Classroom
Loop Number 17 of length 5	**Loop Number 18 of length 5**
Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency ➢ Incident rate ➢ On the job training	Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ Witnessed competency
Loop Number 19 of length 5	**Loop Number 20 of length 5**
Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ Witnessed competency	Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ Classroom
Loop Number 21 of length 5	**Loop Number 22 of length 6**
Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ On the job training	Formal education/Training ➢ Self-assessment and certificate evaluation ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan ➢ Identification of skill competency
Loop Number 23 of length 6	**Loop Number 24 of length 7**
Formal education/Training ➢ Self-assessment and certificate evaluation ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE competency ➢ Professional development plan ➢ Identification of skill competency	Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Professional development plan
Loop Number 25 of length 7	**Loop Number 26 of length 7**
Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Professional development plan	Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Professional development plan
Loop Number 27 of length 8	**Loop Number 28 of length 8**

Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Professional development plan ➢ Identification of skill competency	Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Professional development plan ➢ Identification of skill competency
Loop Number 29 of length 8	**Loop Number 30 of length 9**
Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Professional development plan ➢ Identification of skill competency	Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE competency ➢ Professional development plan
Loop Number 31 of length 9	**Loop Number 32 of length 9**
Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE competency ➢ Professional development plan	➢ Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE competency ➢ Professional development plan
Loop Number 33 of length 9	**Loop Number 34 of length 9**
Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan	Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development
Loop Number 35 of length 9	**Loop Number 36 of length 10**
Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency	Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency

➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan	➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE competency ➢ Professional development plan ➢ Identification of skill competency
Loop Number 37 of length 10	**Loop Number 38 of length 10**
Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE Competency ➢ Professional development plan ➢ Identification of skill competency	Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan ➢ Identification of skill competency
Loop Number 39 of length 10	**Loop Number 40 of length 10**
Formal education/Training ➢ Competency knowledge ➢ Workers knowledge ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan ➢ Identification of skill competency	Formal education/Training ➢ Competency knowledge ➢ Workers skill and ability ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Inspection test plans developed ➢ Identification of quality competency ➢ Professional development plan ➢ Identification of skill competency
Loop Number 41 of length 10	
Formal education/Training ➢ Competency knowledge ➢ Workers behaviour ➢ Level of competency ➢ Incident rate ➢ On the job training ➢ Performance evaluation and examinations ➢ Job hazard analysis development and hazard identification ➢ Identification of HSE competency ➢ Professional development plan ➢ Identification of skill competency	