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# THE IMPACT OF OWNER PRACTICES AND PROCEDURES ON CONSTRUCTION PROJECT SAFETY PERFORMANCE

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THE IMPACT OF OWNER PRACTICES AND PROCEDURES ON CONSTRUCTION  
PROJECT SAFETY PERFORMANCE

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DISSERTATION

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A dissertation submitted in partial fulfillment of the requirements for the degree of  
Doctor of Philosophy in the College of Engineering  
at the University of Kentucky

By

Huang Liu

Lexington, Kentucky

Co-Director: Gabriel B. Dadi, Assistant Professor of Civil Engineering  
and William F Maloney, Professor of Civil Engineering  
Lexington, Kentucky 2017

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## ABSTRACT OF DISSERTATION

### THE IMPACT OF OWNER PRACTICES AND PROCEDURES ON CONSTRUCTION PROJECT SAFETY PERFORMANCE

Construction sites are dangerous work environments. One traditional assumption prevails in the construction industry that construction safety should be the sole responsibility of the contractor. However, some safety researchers gradually begin to challenge this assumption. The elementary research in this field try to validate the existence of relationship of the owner's practices and safety performance, which indicates that the involvements of the owner have a positive impact on improvement of safety performance. Therefore, the owner can and should take a responsibility of the project safety. Some subsequent research focus on collecting and summarizing the best safety practices and procedures of the owner. Other research efforts are directed to laying out rules or principles for the owner to play a positive role in construction safety. However, relevant issues are still under-researched. Rare research is undertaken to quantify the impacts of the owner practices and procedures on safety performance.

To explore and improve the involvement of the owner in the safety issues, the research in this dissertation develops a systematic and effective model to rate the impacts of the owner practices and procedures on project safety. The model is entitled the Owner's Role Rating Model (ORRM), which can yield a score to evaluate the owner's safety performance. Operational Excellence (OE) will be embedded into the establishment to enhance the effectiveness, and also serves as the fundamental theory. OE is borrowed from the chemical processing industry. OE can be defined as doing the right thing, the right way, every time – even when no one is watching. The essence of OE is that culture drives behavior and behavior sustains culture. Good Operational Excellence results in effective reinforcement of appropriate safety systems, and significantly reduces the rate of unsafe behaviors (AIChE, 2011). ORRM will be structured as a Critical to Safety (CTS) Tree beginning with the owner's role in safety. The model will have four components: Safety Driver, CTS, Critical to Expectations (CTE) and Specification/Measurement (S/M). Through an extensive literature review, comprehensive lists of CTS and CTE elements are developed. CTE-specific S/Ms are also developed for measurement. Analytic Hierarchy Process (AHP) is utilized to obtain weights of CTS elements, which aims to quantify the relative

importance of CTS elements. An empirical validation of 20 projects is conducted by using ORRM to verify its effectiveness and efficiency. ORRM could be used to assess the degree of the owner's involvement in the safety process, and present a final score to evaluate owner's overall performance in safety management. Also, the result of evaluation can indicate the direction for owners to improve their performance. ORRM will also serve as a prototype that can be used for the similar studies in the future.

**KEYWORDS:** Operational Excellence, Owners, Construction Safety, Analytic Hierarchy Process

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*To everyone who has help me.*

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# 1 INTRODUCTION

## 1.1 Background and Motivation

Because of the nature of construction industry, construction sites are dangerous work environments, and construction workers are usually exposed to various hazards.

According to statistics by the U.S. Department of Labor, construction frequently appears on the list of “Ten Most Dangerous Jobs” (CURT, 2004). According to the Census of Fatal Occupational Injuries (CFOI, 2012), an average of 828 workers, during the period from 2009 to 2012, lost their lives annually on construction sites. Although massive efforts have already been made to reduce the safety accident rate of construction industry, there are still many areas for improvement. Previous researchers have placed their emphasis on how to enhance the roles of designers, contractors, and subcontractors in construction safety. However, as the finance provider and ultimate user of the construction project, there has been a lack of research efforts concerning the owner’s role in construction safety.

Construction projects usually involve participations of owners, designers, and contractors. Every party in the project, from the subcontractor directly managing craftsmen to the owner regularly visiting the jobsite, must realize that they have an important role to play in ensuring high levels of safety performance. Most especially, the owner plays a key role in the whole construction safety management. Most previous research on construction safety focused on contractors and designers, limited research

was conducted by looking at project participants higher in the supply chain (Votano et al, 2014).

The owner is the only participant getting involved in each stage of the execution of the whole project. Safety-related processes belong to different phases that can affect each other significantly. For example, design processes in the preconstruction phase can significantly affect the safety on the jobsite. At this point, the contractor can do little to make a difference (Weinstein et. al, 2005). The owner should offer designers with adequate information and other necessary assistance for addressing safety in preconstruction (Anderson, 2005). Nevertheless, the owner could make the designer focus on addressing safety in design. From this perspective, the owner is in the best position to take the safety performance to the next level.

The owner has the authority to administrate almost every activity through the whole project. The owner is always the provider of project finance, and is in most cases the ultimate user of the final facility. Therefore, the owner has the right to propose a comprehensive set of objectives for the contractor and the designer, including safety objectives. These objectives would be deciphered by the contractor to understand the owner's emphasis on safety. Based on this, the contractor would draft different safety plans to satisfy the owner's requirement. In the light of this causation, it can be said that the owner's requirement for safety is the root cause for all actions the contractor takes to handle safety issues.

In the past few decades, the owner's role in construction site safety has been increasingly recognized by governmental health & safety departments outside of the United States. In



the European Union, the Council Framework Directive 92/57/EEC clearly indicates that the client is responsible for the safety at sites. And it is specially stressed that appointing a safety representative does not exempt the client from the responsibility of safety (European Directives, 1992). Australian government also sights the owner's role as a driving force to improve safety performance in construction industry. The National Standard for Construction Work by the National Occupational Health and Safety Commission in 2005 establishes clearly OHS responsibilities for the owner.

A survey was conducted by Mudsonda (2009) to investigate the relationship between the owner's attitude towards health and safety on jobsite and the contractor's safety performance. The research concluded that the owner can impose a great impact on the construction safety performance, particularly in cases of small or medium-sized contractors. Promoting or addressing the owner's attitude would make a great contribution to improvement of construction safety (Musonda, 2009). In the context of Design/Build (DB) project, whether the owner explicitly evaluates safety as an important target in request for proposal or not can cause a significant difference in the safety performance (Lopez del Puerto et.al, 2013). The author recommended that incorporating safety performance into criteria of selecting a contractor may lower the possibility of having an accident on the construction site. A U.S.-based research by Huang (2006) has presented a comprehensive set of elements to measure the impact of owner's performance on safety on jobsite. The research concluded that the owner should lead and coordinate the activities related to safety in the preconstruction stage, provide necessary resources to the contractor for implementing safety programs, and participate in safety activities on daily basis. (Huang et. al, 2006) Another research in Australia claimed that owners

should initially focus on six roles: (1) participate in site-based safety program; (2) review and analyze safety data; (3) appoint a safety team; (4) select safe contractors; (5) specify how safety is to be addressed in tenders; and (6) perform regular checks on plant/equipment (Votano et al, 2014).

Although since the 1980s owners have begun to gradually play an active role in craftsmen safety on the jobsite, the traditional view is still prevalent that construction site safety has been the sole concern of the contractor. Other partners in a project team, particularly the owner, do not take responsibilities of safety to a high degree. That is because the contractor, as the most professional and experienced team member, has an entirely firm control over the whole jobsite (Gambatese, 2000). However, contrary to conventional thought, owners' inactivity to perform their safety parts is one of the root causes of many construction accidents (HSE, 2003). Owners' ignorance of their roles in safety extensively exists, and up to 84% of owners never or rarely participate in construction safety audits and inspections (Musonda, 2009). Owners tend to give a high priority to other objectives such as cost and time. Therefore, decisions related to safety issues may actually not be made to create a safer workplace, but to reduce cost or accelerate progress (Votano et al, 2014). These kinds of behaviors eventually result in overtime work, low concern for safety, and reductions in construction safety practices (Loosemore, 2007).

As aforementioned, surveys and research have demonstrated that the owner indeed plays a key role in the safety performance, but also indicated that most owners are ignorant or inactive to exert pro-active part in reducing accidents on the jobsite. There is an imperative need to thoroughly study how the owner affects the construction safety.

Nevertheless, previous research on the relationship between the owner's role and workplace safety were limited in recognizing roles that the owner can play and presenting the best practices for select. A driving force behind the owner's behaviors was largely neglected, which was the culture. The culture leads to behaviors, and behaviors reflect the culture. The effort of research should be made to improve the owner's role in both cultural and behavioral ways. Operational Excellence (OE) is an effective and practical approach to addressing safety issues, taken from the chemical processing industry. OE is defined as the performance of all tasks performed correctly every time (AIChE, 2011). OE integrates behavioral and cultural approaches to create a system whereby individuals do the right thing, the right way, every time. By creating values, beliefs, and assumptions that spawns a strong safety culture, the behaviors of individuals will improve. In the light of OE concept, improvement for the owner's role in construction safety also requires a reinforcement of behavioral and cultural executions. Therefore, the aims of this research are to investigate the owner's role in influencing safety performance, embed OE concept into the mechanism of how the owner plays a safety role, develop an effective systematic model to guide the owner to act more positively and actively in the issues of safety, and validate the effectiveness and efficiency of the model with an empirical study of cases.

## **1.2 Research Purpose**

The primary objective of this research is to develop a systematic and effective model for rating the owner's role in safety on the jobsite by using the concept of operational excellence. The model is called the Owner's Role Rating Model (ORRM). The model should be used to assess the degree of owner involvement with the safety process, and present a final score to evaluate owner's overall performance in safety management.

Also, the final result of evaluation can indicate the direction for owners to improve their performance. To enhance the effectiveness of the evaluation tool, OE will be embedded into the establishment and serve as the fundamental theory.

To accomplish the goal of developing ORRM based on OE, the list of secondary objectives below must be achieved:

1. Define OE in the context of construction industry, and use it to analyze the owner's role in construction safety;
2. Decompose the owner's role into multiple elements that are Critical to Safety (CTS), and further into Critical to Expectation (CTE);
3. Develop CTE-specific S/Ms for measurement;
4. Extensively consider the typical owner involvement in four types of construction projects: fossil fuel power plants, nuclear power plants, highway and heavy civil projects and commercial projects;
5. Obtain weights of CTS elements by using Analytic hierarchy process (AHP);
6. Integrate the weights to form a functional ORRM; and

Conduct an empirical study of cases to validate the effectiveness and efficiency of the ORRM.

### **1.3 Research Scope**

The primary purpose of this dissertation research is to develop an effective and practical model for the owner to make an assessment on their own performance of playing a role in the safety on the jobsite, and identify the potential areas for improvement. This research intends to develop a prototype model for construction owners, through which the owner

can easily identify where they need to focus their effort. The owner is mainly referred to as an organization constantly involved in construction of mega-projects, such as ExxonMobil, which has numerous oil projects to construct. For this kind of owners who have an immense amount of facilities or factories to construct, the demand for learning how to operate more actively in safety scope is urgent.

However, the owner's role is a complicated and broad concept. Various and numerous elements can be included, some of them may be mixed with functions that the contractor performs. It is hard to incorporate these elements into modelling from both the contractor's and the owner's perspectives. For this reason, this model is owner-centered and disregards other stakeholders in the project.

In the same way, construction safety is also a double-fold concept, which includes safety of the project team (particularly construction workers) and general public safety (Lopez del Puerto, 2013). Construction worker safety refers to keeping members of the project team safe from hazards and dangers due to construction activities when they are on the job site during the course of construction. For general public safety, it refers to protecting people outside of the project team, such as surrounding pedestrians and residents. Managing general public safety depends on factors, such as jobsite location, surrounding traffic situation and types of nearby structures. In this research, construction safety is limited to the construction worker safety. General public safety is excluded from the research scope.

The approach to researching the owner's role in construction safety is OE, which is a culture and behavior-based methodology for safety management. Therefore, the focus of

this research is to build a set of cultural and behavioral elements conducted by the owner throughout the entire project. The major part of this study includes identifying critical cultural and behavioral elements and qualifying their impacts on safety.

#### **1.4 Research Methodology**

A thorough and extensive literature review will be conducted to accomplish an inclusive list of CTS elements, which are cultural and behavioral elements critical to safety on the jobsite. All CTS elements represent both the culture that the owner holds and behaviors that the owner encourages. Then CTEs will be further developed to obtain specific and measurable elements. CTEs assist in translating the broad role of the owner in construction safety into specific, actionable, measurable behaviors. The model can then include these behaviors to assess the contribution that the owner makes to the construction safety.

However, every key element obviously has a different degree of impact on the safety performance. To reflect that, weight should be assigned to each of key. Analytic hierarchy process (AHP) is a widely-used approach to obtaining weights, which is suitable for this research. CTS elements are dimensions of the owner's role in safety, and also serve as the basis to derive CTE elements. That means CTS elements have a more far-reaching and fundamental influence on the accuracy of the evaluation result.

Therefore, AHP is only applied to CTS elements for the weights. All CTE element under each CTS element are considered as identically important. This arrangement assists weight raters in focusing their efforts on several critical elements, rather than wasting effort on numerous and trivial elements. This weighting approach has been proven to be

superior in some situations and not significantly worse in the other situations (Einhorn et al, 1975).

After the establishment of the ORRM, an empirical study of projects is conducted to validate the effectiveness and efficiency of this model. The method of validation is to explore the correlation between the ORRM scores and safety performance of these project through linear regression analysis. If the ORRM is effective, a positive correlation should exist. That means the higher score indicates better safety performance. Dozens of construction projects are invited to participate in this case study. These projects span across various sectors of construction industry. Personnel on these projects are required to use the ORRM to evaluate the performance of the owner, and then a final score is yielded. On top of that, detailed projects demographics are collected through questionnaire survey, which include prevalent safety indicators such as Total Recordable Incident Ratio (TRIR). The linear regression analysis is undertaken between the final scores of the ORRM and safety indicators such as TRIR.

## **1.5 Structure of Dissertation**

Six chapters make up this dissertation. The establishment of the ORRM and the empirical validation are both presented in a structured manner.

The first chapter introduces the background and overview of this research including research motivations, purposes, scope, and methodology.

The second chapter presents the preparing work for the in-depth exploration into the main research objective, which mainly includes the collection and summary of previous relevant studies through an extensive literature review.

The third chapter presents the research methodology of developing the ORRM. CTS tree, adapted from Critical to Quality tree, is introduced to be the framework of the ORRM.

The detailed development of CTS elements, CTE elements, and S/Ms are depicted.

Analytic Hierarchy Process(AHP) is also described as an approach to weighting CTS elements.

The fourth chapter deals with the computation of weights of the CTS elements. This chapter presents all processes to generate relative weights including questionnaire design, data process, and findings and analysis. The essential part of data process is exhibited in accordance with standard AHP steps.

The fifth chapter deals with empirical validation of the ORRM. This task is undertaken in the manner of case study. Multiple statistic methods are utilized to validate the correlation between the ORRM scores and TRIRs. Applicable zone of project size is identified and verified. Great effectiveness and efficiency of the ORRM when evaluating applicable projects is also validated.

The sixth chapter discusses the contributions of this research to the body of knowledge and limitations. Besides, future research opportunities are also presented.



## **2 LITERATURE REVIEW**

### **2.1 Introduction**

The owner's role in construction safety is increasingly recognized by researchers in the recent years (Gambatese, J., 2000; Huang et.al, 2006; Lopez del Puerto et.al, 2013; Votano et al, 2014). The purpose of this study is to identify the critical elements influencing the role the owner plays in construction safety, and to utilize these elements to form a comprehensive rating model. By using this model, owners can find the weak areas in their safety performance and figure out an effective improvement plan to achieve a better result.

In order to achieve the research goal, two tasks must be accomplished before formally establishing the rating model. The first one is to select a robust and scientific methodology to construct the safety model. The second one is to work out the critical elements related to how the owner takes a role in safety through an extensive literature review.

This chapter mainly addresses these two problems. As mentioned above, Operational Excellence (OE) is a safety management concept that comes from the chemical processing industry. The fundamental theory of OE is that good safety culture and behaviors result in good safety performance. Culture and behaviors are both the focus of OE. Therefore, OE is selected as the methodology to establish the safety model.

Previous research was conducted on construction safety from the perspective of the owner. The relationship between the owner's involvement in safety management and safety performance on the jobsite was also studied. Numerous versions of the elements

are concluded. These research results are a valuable resource for the construction of the element set.

## **2.2 Operational Excellence**

Operational Excellence (OE) is a professional term that is commonly mentioned by experts and managers across various industries. OE is a very useful tool to facilitate all kinds of organization to achieve the desired targets. The fundamental idea of OE is that perfect operations indeed lead to perfect results, so achieving an excellent target can rely on excellent operations.

### **2.2.1 Definition of Operational Excellence**

According to various sources, people who use the term of OE define it in many different ways, although there is something similar across them.

Operational Performance Systems (OPS), a management consulting company, defines OE as “the performance of tasks according to written expectations, policies and procedures in a safe and professional manner” (Uglow, 2013).

Exploration of the definition of OE was conducted in terms of both organization level and individual level. From the organization level, they defined OE as “the deeply rooted dedication and commitment by every member of an organization to carrying out each task the right way, each time”. From the individual view, OE is defined as “commitment to working safely by doing every task, the right way, every time” (Klein et al., 2011).

Afterburner is a company that provides health, safety and environmental services. They define Operational Excellence as “a mindset and commitment to strict adherence to

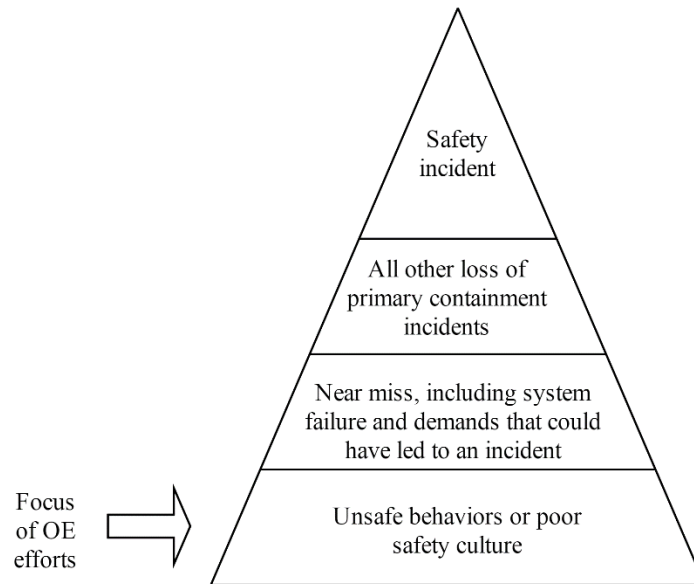
standards, processes and rules that govern operations in groups or individuals” (Horton, 2012).

Dennis Johnson (2005) thinks of OE as “the dedication and commitment by the organization to perform their work consistent with the requirements of the managing system and defined procedures.” Robert J. Walter (2002) presents a definition of OE that is “a consistent pattern of desirable behavioral choices that supports successful human activity.” American Institute of Chemical Engineers (2011) defines OE as “the performance of all tasks correctly every time”.

Through reviewing these definitions, several similar messages that they want to convey can be summarized. The final aim of OE is achieving excellent performance; the approach to reaching this aim is to ensure excellent operation which requires the engagement of all members in the organization. Therefore, OE can be defined as doing the right thing, the right way, every time – even when no one is watching.

### **2.2.2 Focus of Operational Excellence Efforts**

The concept of OE arises from safety management based on process. Process safety management (PSM) places a heavy focus on the improvement of process, which is regarded as the most fundamental method for reductions in major accident risks and for improved safety performance. According to PSM, safety incidents are the final result of multiple factors, which is a lagging indicator for safety. Before one safety incident occurs, multiple layers of protection intended to prevent an incident failed (AIChE, 2011).



**Figure 2.1 Typical Process Safety Pyramid**

*Modified from Conduct of Operations and Operational Excellence (p. xxxii), by AIChE, 2011, Hoboken, New Jersey: John Wiley & Sons, Inc. Copyright 2011 by American Institute of Chemical Engineers, Inc.*

Figure 2.1 shows a typical process safety pyramid showing the causation for safety incidents. Unsafe behaviors or poor safety culture are the root causes for safety issues ranging from minor, serious, and catastrophic injuries. Eliminating or reducing the issues at the base layer of the pyramid should result in a reduction in all kinds of safety incidents. OE efforts are typically focused on the bottom part of the pyramid to reduce the number of unsafe behaviors and to strengthen the safety culture, and finally reduce the number of safety issues at higher layers of the pyramid.

### **2.2.3 Characteristics of Operational Excellence**

Generally speaking, OE is considered as an engine to facilitate operation to achieve an excellent level of safety and then finally make the business successful. It is intangible, but

perceivable. It manifests itself in various forms, but there is a pattern to these forms. Prior researchers utilize characteristics to describe and embody the makeup of OE. Dennis Johnson (2005) compiled a set of 10 characteristics to represent OE. Brian D. Rains (2012) identified a set of 11 characteristics. James A. Klein and Bruce K. Vaughn (2008) set up an OE framework consisting of 11 characteristics. Some characteristics are included by more than one set; the others are unique. Robert J. Walter (2002) incorporates all these characteristics and proposes a more comprehensive version consisting of 15 characteristics. These 15 characteristics are classified into three categories: internal characteristics, interpersonal characteristics, and organizational characteristics. The list below will provide information in more detail.

- Internal Characteristics
  1. Hold a sense of personal responsibility for your actions;
  2. Honor commitments to yourself and others;
  3. Seek outcome-based results rather than activity-based results;
  4. See problems, setbacks, and mistakes as opportunities for improvement;
  5. Use time-management techniques to achieve goals effectively;
- Interpersonal Characteristics
  6. Respect and attempt to understand the idea and worldviews of others;
  7. Seek fairness in all exchange;
  8. Share recognition with others;
  9. Value your life and health and the lives and health of coworkers and the community;

10. Use active, two-way communication so information is understandable to all parties;

- Organizational Characteristics

11. Seek to perform the duties and tasks required by your position;

12. Desire to use informational, capital, and human resources efficiently;

13. Assume a leadership role when needed and, conversely, follow when appropriate;

14. Use existing systems to achieve goals and seek to improve the systems when needed; and

15. Trust that others have a high degree of Operational Excellence and treat them accordingly.

From the above, it can be concluded that the characteristics of OE are abstract and have a wide spectrum of application. However, for the owner's role in safety, the conceptual characteristics are too abstract to implement in the practice. New modifications should be made to adjust the traditional OE characteristics, and there is a need to design a new set of characteristics specific for this research. The new ones should be more tightly based on safety roles of the owner and, at the same time, consider the influence of safety culture.

The safety roles would be further specified into concrete behaviors for accurate assessment. The next subsection mainly addresses this issue.

#### **2.2.4 Critical to Safety Tree Based on Operational Excellence**

To a great degree, OE is an abstract philosophy more than a set of concrete procedures. Applying OE to specific industry context needs a transition from pure concept to an embodied framework.

Prior researchers utilize characteristics to describe and embody the makeup of OE (Johnson, 2005; Rains, 2012; Klein et al., 2011; Walter, 2002). Thus, a framework that breaks down a complex concept into levels of subsequent details is needed. Critical to Quality (CTQ) trees provides a framework that matches that description. CTQ trees arise from the six-sigma methodology (Aartsengel et al., 2013), which is widely used to decompose broad research objective into more easily quantifiable elements. In this research, the CTQ tree framework is adopted as the structure of the ORRM.

The precondition for developing an effective and easy-to-use tool is the decomposition of the owner's role into specific, quantitative, and measurable requirements. These requirements are termed as Critical to Safety (CTS) characteristics. CTSs are considered as key elements to improve and sustain the owner's role in construction safety.

The ORRM is structured to be four-level: Safety Driver (SD), Critical to Safety (CTS), Critical to Expectations (CTE), and Specification/Measurement (S/M). Safety Driver (SD) indicates the factor that will be used to evaluate the performance of the safety program. CTSs indicate basic elements or policies of the owner's role in construction safety, which is the reflection of "the right thing" in the OE philosophy. CTEs indicate procedures and/or processes constituting the elements, which corresponds to "the right way" in the OE philosophy. S/M indicates a quantitative measurement or practice of the CTE, which embodies "every time" part of the OE philosophy. This four-level structure reflects the core concept of OE. Consequently, the CTS tree based on OE will serve as the framework for the ORRM.

## **2.3 Driving Forces behind the Involvement of the Owner in Construction Safety**

The conventional viewpoint has regarded construction safety on the jobsite as the sole responsibility of the contractor. It is reasonable, because the contractor is the primary manager and constructor of the entire project during the course of construction. Major entitlement comes with major responsibility. However, the trend has begun to change since 1980s. Owners began to expand their active roles in construction safety (Gambatese, 2000). There are two main driving forces behind the trend. The first one is the huge amount of cost associated with construction safety incidents and litigations. The second one is the effort of the government by stipulating the owner's liability in the legal documents (Huang, 2003).

### **2.3.1 Increasing Cost of Construction Accidents**

Cost, quality and schedule are the three basic objectives of project management. In contrast with them, safety has a lower priority. Decisions relative to safety management may actually not be based on construction worker safety at the jobsite, but construction cost (Votano et al, 2014). This consequently results in overtime work, low appreciation for safety, and unsafe behaviors in construction practices (Loosemore et al., 2007). However, ridiculously, the huge expense caused by safety accidents makes safety investment and management able to offer economic benefits for construction owners. A construction safety program aiming at eliminating or reducing accidents may generate almost 46% of return on investment (Zou et al. 2010).

The increasing costs of health care and workers' compensation are too expensive to be neglected by construction owners. As early as the 1990s, a study was conducted to



explore the cost due to safety accidents (Hinze et al., 1991). 103 construction organizations throughout the USA took part in the study, and 185 construction projects from 34 states were reviewed. Table 2.1 presents the outcome of the research.

**Table 2.1 Average cost of Construction Site Injuries**

Type of injury	Job Costs		Estimated Liability Costs	Total Cost to Employer
	Direct	Indirect		
<b>Medical Only</b>	\$520	\$440	\$240	\$1,200
<b>Lost Work Day</b>	\$6,900	\$1,600	\$16,500	\$25,000

The costs of health care are the major portion of the total cost. In the past two decades, the costs have grown dramatically. During the same course, litigation costs have also begun to contribute more to the total cost. Thanks to various types of litigations, an increasing number of owners have started to realize that lowering the number of construction safety accidents is the only effective way to reduce their potential economic loss (Levitt et al, 1993).

### **2.3.2 Safety Duties or Responsibilities of the Owner in the Legal Document**

In the last several decades, the role that the owner can take in construction safety improvement has been gradually recognized and confirmed by governments of several developed countries, such as the USA, Australia, and European Union countries. The trend toward the government putting focus on the owner's role in safety continues, and a

rising amount of evidence can be found in the national and international legal documents and publications of industry associations (Gambatese, 2000; Huang, 2003).

Over the last several decades, a few efforts have been made to propose formal requirements for the owners to play an active part in construction safety on the jobsite. Take America's effort for instance: a major effort to incorporate the owner into safety legislation resulted from a tragedy where 28 workers died in the collapse of the L' Ambiance Plaza Building in Bridgeport, Connecticut (Godfrey, 1988). This accident turned out to be the convincing reason for U.S. Senate Bill 2581 to amend the Occupational Safety and Health Act to "require all construction projects to be supervised by a professional engineer-architect designated by the owner and registered in the state where the construction is to be performed" (ASCE, 1988). A large segment of the construction industry has constituted a powerful opposition to this bill, which ultimately led to its failure. Although these legislation efforts failed, ASCE moved to the first line to promote the trend of owners involved in safety. ASCE released Policy Statement 350 on construction site safety in 1998, which stresses the basic idea that attention and commitment from all parties involved guarantees construction site safety improvement. The policy also typically indicated that the owner should "take an active role in project safety", and provided various ways for the owner to address safety issues. That is given in the following:

- Assigning overall project safety responsibility and authority to a specific organization or individual (or specifically retaining that responsibility) that is qualified in construction safety principles, rule, and practice appropriate for the particular project;

- Including prior safety performance as a criterion for contractor selection;
- Designating an individual or organization to monitor safety performance during construction; and
- Designation in contract documents responsibility for the final approval of shop drawings and details (ASCE, 1998).

In the European Union, the Council Framework Directive 92/57/EEC clearly indicates that the client is responsible for the safety at sites. And it is specially stressed that appointing a safety representative does not exempt the client from the responsibility of safety (European Directives, 1992). Under this framework, the Construction (Design and Management) Regulations 1994 (CDM) specified responsibilities of owners in Great Britain, in which the owner's main duties are contained in Regulations 6, 10, 11 and 12 (Holt, 2001). CDM defines the owner as "any person for whom a project is carried out, whether carried out by another person or in-house." CDM assigns criminal responsibility to the owner in the case that an accident occurs due to the owner's ignorance of construction safety. The keynote is that the owner has a project-specific responsibility for safety on the project. If there are multiple owners for one project, the owners can designate an organization or individual (including the owners) to fulfill the owner's duties, and then have to make a declaration to the enforcing authority (the Health and Safety Executive) to complete the transfer of duties. Under CDM, the detailed list of the owner's duties is in the following:

- Appoint a Planning Supervisor and a Principal Contractor for each project, being satisfied that these "duty holders" are competent and have the resources to perform their duties adequately;

- Not permit the construction work to start unless a health and safety plan, which complies with the safety regulations, is in place for that project;
- Provide the planning supervisor with information about the state or condition of the premises where the work is to be carried out. This is information which is relevant, and which the owner either has or could get after making reasonable inquiries;
- Verify that any designer or contractor that is appointed directly is competent for the task and has allocated sufficient resources to it; and
- Make the health and safety file available for inspection by anyone who may need information to comply with legal requirements. The owner will sell or pass on the file to a future owner or a person acquiring the interest in the property of the structure to which it refers (Joyce, 1995).

The Australian government also sights the owner's role as a driving force to improve safety performance in the construction industry. The National Standard for Construction Work by the National Occupational Health and Safety Commission in 2005 clearly establishes OHS responsibilities for the owner. These responsibilities include:

- A requirement to consult with the designer to ensure that construction work undertaken in connection with the design can be undertaken without risk to the health and safety of those undertaking the construction work;
- A requirement to consult with persons in control of construction projects to ensure that persons undertaking the construction work and others on or near the construction site are not exposed to health and safety risks; and

- Where information regarding OHS aspects of the project is provided by the designer, the person in charge of the construction work or another party, the client relays this information to any person who has control of the construction site or who obtains the structure for use, either by themselves or others (NOHSC, 2005).

## **2.4 Previous Research on the Owner's Role in Safety**

Owners can exert a positive and active impact on construction safety through various ways, such as selecting safe contractors, addressing safety issues in design, and participating in safety management during construction (Hinze, 1997). Hinze (2006) further found that the owner can also promote construction site safety by participating in a constructability review and incorporating safety requirements in contracts. To expand their role on safety issues, the owners or their safety representatives should go beyond the traditional tasks, such as new employee orientation, safety meetings, audits and accident investigations, training, incentive programs and other safety related programs (Gambatese, 2000). The owner should do more than that. The owner should effectively collaborate with the contractor on safety issues and actively participate in all project safety activities.

Gambatese (2000) developed a six-point safety program for the owner, which can be used as a guide to carry out safety duties. The principles are given in the following:

- Establish a clear position on safety;
- Ensure that safety is addressed in project planning and design;
- Consider safety performance when selecting a contractor;
- Address safety in the construction contract;

- Assign safety responsibility during construction; and
- Participate in project safety during construction.

Musonda (2009) stressed that the importance of the owner's attitude towards safety would significantly influence the contractor's performance on construction site safety. However, the other ways the owner can apply to safety performance has not been explored.

Mwanaumo (2013) argued that the owners should have an impact on construction health and safety (H&S) as they are the only stakeholder having contractual relationships with all other important project participants. Therefore, they will have an overall authority and responsibility to the construction site safety. The owners should take the responsibility of ensuring clear and proper safety arrangements. The specific H&S tasks for the owner are given in the following:

- Ensuring that designers have considered H&S during their design phase;
- Setting safety as a key criterion when selecting the contractor;
- Incorporating H&S provisions into the contract;
- Requiring bidders to submit the H&S method statements;
- Participating in and approving the contractor's H&S plans before the commencement of construction work;
- Appointing a qualified safety representative;
- Monitoring H&S performance of the contractor throughout the construction phase; and

- Conducting regular site walks, inspections, monthly audits and regular H&S meetings.

Votano and Sunindijo (2014) proposed a list of the owner’s key management actions relative to safety, which is based on the model client framework by the Australian government. Although the list is designed specifically for the Australian construction industry, it does have a universal applicability. The key elements in the list are given in the Table 2.2.

**Table 2.2 The Owner's Key Management Actions**

	<b>Design phase</b>	<b>Construction phase</b>
<b>Owner role and responsibility in safety</b>	Conduct design safety reviews Set project safety targets Participate in site-based safety program Review and analyze safety data Appoint safety team Undertake a safety feasibility study Establish project brief and design requirements Select safe designers Specify how safety is to be addressed in tenders	Include safety in contract documents Record risk information Conduct safety inspections/audits Evaluate project performance Select safe contractors Review safe work method statements Perform project completion review Perform regular checks on plant/equipment

Huang (2003) conducted extensive research on the owner’s role in construction site safety, which also indicates that for large projects, the contractor can reach better safety performance when owners are proactively involved in setting safety objectives, selecting safe contractors, and participating in safety management during construction. In the end of the article, the best ways that owners can address their concern for safety are found out, which can be summarized into four different categories. All of the best ways are given in the Table 2.3.

**Table 2.3 The Best Ways for Owners to Address Safety**

<b>Intensive involvement</b>	<b>Partnering with contractor</b>	<b>Carefully selecting contractors and set high safety expectations in contracts</b>	<b>Other safety practices</b>
<p>100% proactive participation in a project safety program, one that is not owned by the owner or contractor but by the project</p> <p>Be involved in the process by performing audits and assisting in training programs</p> <p>Support and be involved in the process</p> <p>By showing their willingness to stop a project in order to make it safe for</p>	<p>Discussing with the contractor on the project and addressing concerns in a team approach Set project safety targets</p> <p>Work with the contractor to identify and resolve potential hazards, forget cost and schedule issues</p> <p>By supporting the efforts of the contractors and requiring the same actions of their</p>	<p>Bid list open only to companies with good safety levels</p> <p>Set expectations in the contract and hold contractors accountable</p> <p>Draft contracts that focus on safety activities and actions, NOT numbers. Measure positive performance and compliance, allow time and monies for training and manage proactively</p>	<p>Walk the talk. No double standards.</p> <p>Have regular safety meetings, with all primes and subs involved</p> <p>Support the cost of training and safety professionals with resources</p> <p>Training seminars - focus on job hazard analysis</p> <p>Do not start field construction until the engineering is 80% complete and do not allow</p>



<p>construction employees</p> <p>Continuous involvement: can assist the contractor with regular assessments and audits</p> <p>VISIBLY lead by example - get involved at a personal level</p> <p>They need to help promote and drive the overall site safety program</p>	<p>employees, one program for all</p> <p>Make safety a priority and work with the contractor to perform to a high standard</p> <p>Demonstrate their commitment to the project team and the workers regularly by being part of the team. The owner's representative should be visible. Owners could support the constructor by understanding the effort being made to be injury free and not get focused on statistics only</p> <p>Show leadership and integrate their team with the contractor team</p>	<p>Work with the contractor to address concerns and be willing to award work on parameters other than just price</p> <p>Select the correct GC or CM and have a great contractor selection process for every contractor who performs work</p>	<p>contractors to start work until the complete construction package, including material, is available; also complete each phase of the project before starting the next phase</p> <p>Continue to place a priority on safety, insist on trained persons from contractors, do not place schedule above safety, always try and take a practical approach, do not have double standards, i.e., owner forces, direct hire forces, nonunion forces and other forces should not be treated differently</p> <p>Safety meetings</p> <p>Hold their employees to the same level as contractors</p>
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Lopez del Puerto et al. (2013) conducted research on the owner's role in construction safety in the context of the DB project. The result indicates that the way the owners get their concerns on safety across in the request for proposals (RFPs) has an impact on the

construction safety on the jobsite. The research recommended that safety requirements should be articulated as evaluation criterion. The five basic safety measures were summarized, which is presented in the following:

- Safety plan, including a description of safety certifications and project-specific scheme;
- Safety fences and barricades, including the location and construction plan;
- Experience Modification Rating (EMR), which allows the owners to form an opinion about a company's commitment to safety;
- Files relative to OSHA Recordable incident rate; and
- Safety professional onsite, which is relatively common practice for construction companies to hire safety professionals to make sure safety practices are followed.

Site Safe New Zealand (1999) published a guide about construction safety, which specified the roles the owner should play in the form of asking questions. The guide indicates that the owner has the duty and the authority to ensure that contractors who carry out the various phases of the whole project are safe while they are working on the jobsite. The guide divides the whole project construction lifecycle into four phases, and also suggests that the owner should participate in every one of the four stages. The first two stages are too closely mixed with each other to separate them clearly; the first two stages are called "the project begins/design and planning." The third stage is "tender/selection;" the fourth stage is "construction." For the purpose of clarity, all of the questions are presented in Table 2.4.

**Table 2.4 Health and Safety Questions for Owners to Consider**

<b>Stages</b>	<b>The Project Begins/Design and Planning</b>	<b>Tender/Selection</b>	<b>Construction</b>
<b>Health and Safety Questions for Owners to Consider</b>	<p>Have you made sure any designer/adviser or contractor engaged to do any work is professional and has made adequate provision for health and safety?</p> <p>Have you provided information needed for the health and safety management of the project, including pointing out any known hazards?</p> <p>Have you made sure of coordination between designers/contractors?</p> <p>Have you checked that designers consider health and safety in their design?</p> <p>Have you considered the timeframes required for the safety completion of the project?</p>	<p>Have you made sure that a pre-tender stage selection procedure that takes health and safety into account has been prepared (this may be prepared by the designer/adviser on your behalf)?</p> <p>Have you provided the designer/adviser and tenderers with relevant health and safety information (such as existing drawings, any existing site safety plan — including any known hazards, surveys of the site or premises or information on the location of services)?</p>	<p>Have you made sure the building program allows sufficient time to carry out the construction phase safely?</p> <p>Have you made sure construction work does not begin until the head contractor has prepared a suitable health and safety plan?</p> <p>Have you made sure you are satisfied that any contractors carrying out construction work are competent and have made proper provision for health and safety (such as by seeking advice from other advisers or organizations as to the ongoing competency of people contracted to do any of the work)?</p> <p>Have you provided ongoing advice and information, if</p>

			<p>requested, regarding the head contractor's health and safety plan (such as by advising them of any changes to planned activities)?</p> <p>Have you made sure the designers/advisers and other contractors continue to carry out their duties and co-ordinate with others on the project (such as by requesting regular written activity reports)?</p>
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Health and Safety Executive (HSE) elaborates an action plan on the health and safety management for the owner in one of its publications. A successful action plan should consist of five critical parts: policies, organizing, planning and doing, monitoring, and reviewing and learning (HSE, 1997). 24 elements are developed from the five parts, which are presented in Table 2.5.

**Table 2.5 Successful Health and Safety Management**

<b>Policies</b>	<b>Organizing</b>	<b>Planning and Doing</b>	<b>Monitoring</b>	<b>Reviewing and Learning</b>
<p>We have a clear statement of management’s commitment to health and safety.</p> <p>It says who is responsible for health and safety.</p> <p>It states or refers to our arrangements for managing contractors.</p> <p>It is regularly reviewed, based on its effectiveness in preventing injuries and reducing losses, and is updated if needed.</p>	<p>Staff know their responsibilities for managing contractors on site.</p> <p>Responsible staff have enough knowledge about the risks and preventative measures for all jobs involving contractors.</p> <p>Responsible staff know what to look for when checking that contractors are working safely and know what action to take if they find problems.</p> <p>Health and safety is a key criterion in the selection of contractors.</p> <p>We take steps to ensure our contractors are competent in health and safety.</p>	<p>We discuss and agree on the job with contractors. Our requirements and the contractors’ responsibilities for health and safety are in writing.</p> <p>We have safe working procedures and site rules. Contractors are made aware of them in advance.</p> <p>Responsible staff plan the contractor’s job with them. We ask for a safety method statement.</p> <p>Contractors sign in and out - we always know where they are.</p> <p>Contractors are given site information before starting the job.</p>	<p>Responsible staff check on progress with the job and that contractors are working safely.</p> <p>Responsible staff take correct action if contractors are not working safely.</p> <p>We check on contractors’ arrangements for supervision.</p> <p>We tell contractors to report all incidents/accidents (even minor ones).</p> <p>If the contractor sends different staff we will know.</p>	<p>When a job is finished, responsible staff review how it went, including the health and safety performance of the contractor.</p> <p>The review is recorded for future use.</p> <p>The company is good at learning from mistakes and improving contractor arrangements.</p>

	Staff are involved in discussing contractor arrangements for management and supervision.	We go through the job before allowing work to start.		
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Hartford (2002) claims that contractors have the main responsibility for keeping safety on the jobsite, but owners should play a supportive part to assist contractors in achieving better construction safety. It recommends that owners should:

1. Become familiar with the high cost of construction accident; this will reinforce their moral commitments to provide a safe work environment;
2. Be prepared to financially support contractors' efforts to ensure an effective safety program;
3. Realize that merely adopting a safety program will not yield the desired results without a serious and persistent management commitment;
4. Recognize that the principles of management control commonly applied to cost, schedule, quality, and productivity are equally applicable to safety, and that, when used, and they will improve safety performance;
5. Make safety improvement an important consideration in the selection of contractors for bidding on their construction projects, including evaluation of contractor's past safety performance, safety attitude, and present programs and practices;
6. Explain to the contractor prior to the bidding process what is expected safety performance;

7. Evaluate, in the bid analysis, the ability of the contractor to achieve expected safety performance and from this, determine the degree of owner involvement required to meet safety objectives;
8. Become more directly involved in the safety activities of their construction projects and take proper measures to achieve better safety performance, such as:
  - Providing safety and health guidelines that the contractor must follow.
  - Requiring a formal site safety program.
  - Requiring the use of permit systems for potentially hazardous activities.
  - Requiring the contractor to designate the responsible supervisor to coordinate safety on the site.
  - Discussing safety at owner-contractor meetings.
  - Conducting safety audits during construction.
  - Requiring prompt reporting and full investigation of accidents;
9. Function with the contractor as a cohesive safety team during the planning and execution of a construction project; and
10. Establish, with the contractor, lines of communication at all levels so that safe work practices are understood by both parties.

CURT (2004) has insisted that the safety performance on the jobsite is up to the owner. Effective safety leadership by the owner can lead to reduced injuries, disabilities, and deaths resulting from project accidents. Two principles for construction user's safety management are summarized: establishing construction safety culture and monitoring construction safety performance. A practical guideline to construct a project safety management program is also proposed, which includes fifteen tactical elements. For the

sake of implementation, each of the fifteen elements has a few of detailed sub-elements to help the owner develop more executable program. The fifteen elements stem from the two principles. The elements in relation to safety culture mainly focus on how to show the owner's positive and serious attitude towards safety, which can force the contractor to take safety management seriously and build a safe workplace. The rest of the elements primarily address the issues of monitoring the execution of safety management, which is related to responsibility arrangement, accident investigation, audits, review, and so on.

## **2.5 Critical to Safety Elements for the Owner to Improve Construction**

### **Safety**

In past studies, various researchers have proposed numerous safety roles that the construction owners should take or implement. They each have a different emphasis on how to improve and refine the construction safety management, but they all definitely believe that the owner's overall involvement in collaboration with the contractor can enhance the safety performance. One philosophy for the owner's safety management is that the owner must participate in all activities in relation to safety on the construction site throughout the whole project cycle. To achieve a breakthrough in the reduction of construction accidents, the owner must go beyond the traditional and limited domain for safety management, such as contractor employee orientation, regular safety meetings, and other safety related programs.

Critical to safety (CTS) elements for the owner's role are summarized and organized in accord with the project timeline. In the beginning of planning a new project, the owner must establish a strong safety attitude and get it across to designer and contractor candidates. Subsequently, the owner should select a qualified contractor to conduct



construction; the contractor should give a high priority to construction safety and be willing to create a safe environment on the jobsite. Construction contract is the legal basis for collaboration between the owner and the contractor, and also serves as the basis for the owner to require the contractor to fulfill the construction safety duties. Contract arrangement would designate the safety responsibilities to various stakeholders in the project, and provide the legal reason for the owner to participate in the contractor's safety management. Design has a significant influence on construction safety; the owner must take an active role in the coordination between designers and contractors to enhance the constructability of the project and reduce deaths and injuries in accidents. Another CTS for the owner is to monitor whether the contractor is in compliance with the safety requirements in contract. Measuring and analyzing the safety results are also within the responsible scope of the owner. Operational Excellence requires the safety effort to be directed towards the conduction of the right behaviors. Therefore, the owner should participate in behavior observation surveys, which can enhance the rate of the right behaviors and prevent the problem behaviors or near miss. The execution of the planned safety program has a need of sufficient resources such as funds, time, and human power. That requires the owner to guarantee the provision of necessary resources to the contractor. Additionally, the owner should focus on safety training for the whole staff on the jobsite and propose a minimum requirement for the training content. Ten CTS elements are identified and presented in the following.

1. Establishing and Communicating Attitudes towards Safety;
2. Selection of contractor;
3. Contractual safety arrangement;

4. Owner's involvement in safety pre-construction;
5. Monitoring Contractor Safety Compliance;
6. Measuring and Analyzing Safety Results;
7. Participation in Behavior Observation Surveys (BOS);
8. Participation in incident investigations;
9. Providing assistance to contractor for safety; and
10. Participation in Safety Training.

## **2.6 Summary**

This chapter introduces the model proposed for the research and identified the CTS elements of the owner's role in construction safety. Critical to safety tree can facilitate to develop the owner's safety function from vague concept into clear, specific, and quantitative requirements. Four levels of the model completely and perfectly correspond to all the key elements of OE definition. Besides, through extensive literature, ten CTS elements of the owner's role in construction safety are also identified. These elements include almost every safety activities throughout the entire construction process. The combination of the two will work as the basis for the follow-up research in the dissertation.

### **3 RESEARCH METHODOLOGY**

The previous chapters describe the background information of this research. The primary objective of this research is to develop a systematic and effective model for rating the owner's role in safety on the jobsite by using OE concept. The model is entitled the Owner's Role Rating Model (ORRM). The model should be used to assess the degree of the owner's involvement with the safety process, and present a final score to evaluate the owner's overall performance in safety management. Also, the final result of evaluation can indicate the direction for owners to improve their performance. To enhance the effectiveness of the evaluation tool, OE is embedded into the establishment and serve as the fundamental theory.

This chapter will elaborate on the procedures to build the ORRM, which mainly includes identifying the critical to safety (CTS) elements and weighting CTS elements. The first part is primarily based on the result of a thorough and extensive literature review. In addition to that, subject matter expert validation and discussions with industry experts are also applied to the determination of CTS elements, which substantiates them with expertise and experience of safety practitioners on the jobsite. The result does not only include the CTS elements, but also more specific and measurable components. These components are referred to as CTE elements, which are behaviors and/or processes used to provide the elements.

The second part mainly addresses the inequality of importance existing among these CTS elements. Obviously, these elements are not equally critical to the potential impact on the construction safety. Therefore, relative weight for each CTS is needed to achieve an

accurate rating score. For the aim of this research, the data inputs are obtained from three categories of industrial projects: fossil fuel or natural gas power plants, nuclear power plants, and other industrial projects. Industrial projects often feature a high level of complexity that entails a proactive and in-depth involvement of the owner in safety work.

### **3.1 Framework of the ORRM**

As mentioned above, this research aims at developing a model of Operational Excellence that can be used to quantitatively assess the degree of the owner's safety performance.

This model will integrate both behavioral and cultural theories. However, the traditional characteristics of OE have difficulties in meeting the requirements of the intended model.

The Critical to Quality (CTQ) tree can serve as the tool to develop measurable characteristics, which arise from the six-sigma methodology (Aartsengel et al., 2013).

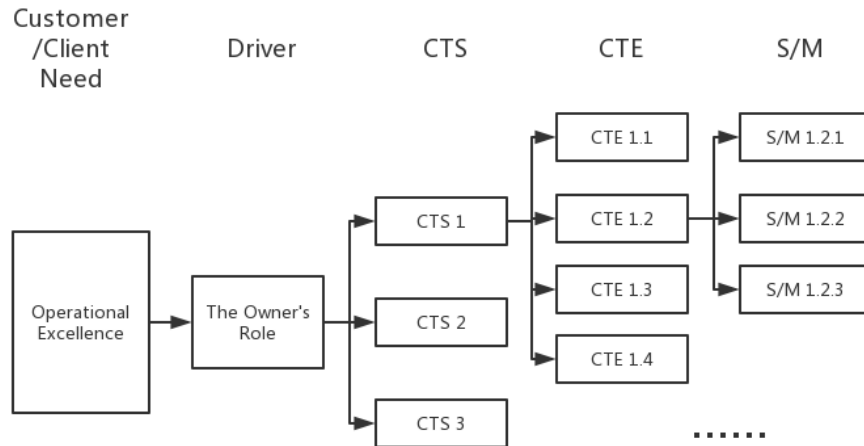
CTQ trees are used to decompose broad research objectives into more easily quantified elements. CTQ trees are often used as part of six sigma methodology to help prioritize such objectives (George, 2002).

The owner's role in safety must be developed into clear, specific, quantitative requirements to be helpful in the development of the "process to be improved" outcomes.

In the context of construction safety, these quantitative requirements are called Critical to Safety characteristics (CTSs). CTSs are the measurable safety characteristics that are considered important for the owner to play an active role.

The model will be structured as a Critical to Safety (CTS) Tree beginning with Operational Excellence for the owner's role in construction project safety. The model

will have four components: Safety Driver, CTS, Critical to Expectations (CTE), and Specification/Measurement (S/M). The structure of the model can be seen in Figure 3.1.



**Figure 3.1 Diagram for CTS Tree of the Owner's Role**

Safety Driver (SD) indicates the factor that will be used to evaluate the performance of the safety program. In this research, SD exclusively indicates the owner's role including the owner's decisions, behaviors, and involvements that impact on site safety performance.

Critical to Safety (CTS) indicates elements of the driver, which corresponds to "the right thing" in the definition of OE. For example, the selection of a contractor can be regarded as a CTS, because it is one thing within the domain of the owner's role and relevant to the safety.

Critical to Expectation (CTE) indicates behaviors and/or processes used to provide the elements, which corresponds to "the right way" in the definition of OE. For example,

giving a high priority to safety when selecting a contractor can be regarded as a CTE, because it is one behavior of the selection of a contractor.

Specification/Measurement (S/M) indicates a quantitative measurement of the CTE, which corresponds to “every time” in the definition of OE. For example, the question of “Does the owner set Zero-Injury as the objectives for the project?” is a CTE element, its S/M is binary, the answer of which is “Yes/No”.

The four-tiered model represents the essence of the OE: focus on doing the right thing, the right way, every time – even when no one is watching. However, the important piece of the “even when no one is watching” is missing in the model. The approach to this issue is to embed safety culture into the whole model. Culture drives behavior and behavior sustains culture (Maloney, 1989). Through the rigorous execution of OE, the number of unsafe behaviors will be reduced and the safety culture will be reinforced. Once the safety culture is embedded into every member’s mind, the goal of “even when no one is watching” will be achieved. Consequently, CTS trees based on OE will be selected as the skeleton of ORRM.

## **3.2 Determination of CTS elements**

### **3.2.1 Preliminary list of CTS elements**

The list of CTS elements was obtained from the previous research that put a strong focus on the principles or areas that the owner should follow or emphasize. Although they concluded various results, the common pattern they adopted was to identify key elements through tracking the construction project lifecycle. From project conception to final construction, each stage was one opportunity for the owner to play the active role. For

this reason, following the project timeline is the basic principle when developing the list of CTS elements. However, some duties that the owner should fulfill do not exist in any single stage. For example, establishing the safety culture does not exclusively belong to each of stages in project cycle, but it should work throughout the stakeholders on the jobsite. CTS elements of this kind are also included in the list.

In the preliminary stage of constructing the list of CTS elements, another issue needed to address was to summarize CTS elements from various studies. For safety principles developed by the previous studies were based on various viewpoints, it proved hard to incorporate the CTS elements in the same framework. The challenges mainly include different ways of dividing project stages and logics behind identification of the owner's roles. A large number of information stemming from various research products are categorized into groups, based on their natural relationships, for review and analysis. Finally, a CTS list of 10 elements was developed. The list is presented in the following:

1. Establishing and Communicating Attitudes towards Safety;
2. Selection of contractor;
3. Contractual safety arrangement;
4. Owner's involvement in safety pre-construction;
5. Monitoring Contractor Safety Compliance;
6. Measuring and Analyzing Safety Results;
7. Participation in Behavior Observation Surveys (BOS);
8. Participation in incident investigations;
9. Providing assistance to contractor for safety; and
10. Participation in Safety Training.

The ten CTS elements have covered the whole project construction cycle, from the conception of building a project to completion of the project. The first one, establishing and communicating attitudes towards safety, focuses on the cultural aspect of operational excellence, which deals with the creation of safety culture and environment. The rest of the nine CTS elements provide basic principles for the owner to play a safety role in different stages.

### **3.2.2 Subject matter expert validation**

However, the preliminary list of CTS elements is mainly based on academic research by safety scholars. The knowledge behind it have minimal inputs from the safety practitioners on the jobsites. Although the preliminary list of CTS elements is based on reasonable assumptions and conclusions, it is still difficult to guarantee that it can reflect the real situation of safety on the jobsite. Professional opinions from the construction industry should be collected to validate those CTS elements. To do that, a subject matter expert validation is conducted through a questionnaire survey.

Subject matter expert validation of the CTS elements mainly focused on determining the relative degree of significant contribution that each CTS elements makes to operational excellence in construction safety. Based on the results, the most important CTS elements will be selected to form the final list. Questionnaire survey is performed through the use of Select Survey's server-based software. Most of the participants are experienced practitioners. This online survey system is designed to provide credible data and facilitate research. A total of 92 surveys were initiated, but not all were completed. Finally, 60 responses were collected.



Respondents were asked to provide demographic information on their organizations.

Organization characteristics are shown in Table 3.1. Most companies have participated in national or even international projects and conducted construction-related work. Types of projects they participate in cover almost all construction sectors.

**Table 3.1 Organization Characteristics**

<b>Work Area</b>	<b>Percentage (%)</b>	<b>Respondent's Organization</b>	<b>Percentage (%)</b>	<b>Primary Construction Sectors</b>	<b>Percentage (%)</b>
Regionally	20.69	Owner	37.39	Industrial	57.03
Nationally	34.48	Designer	0.87	Commercial	23.44
Internationally	22.99	Constructor	56.52	Infrastructure/Heavy Civil	8.59
All	21.84	Other	5.22	Residential	1.56
				Others	9.38

Participants were also asked to evaluate the importance of each CTS to developing and understanding of the owner's role in construction safety. The average value will be computed as the final score for each CTS. Respondents were requested to rate importance on a 5-point scale where 1=No importance, 2=Little importance, 3=Some importance, 4=Moderate importance, and 5=Great importance. This measurement scale is adapted from conventional Likert scale to skew intentionally. A traditional Likert scale would not show variability in the responses, since many of the items are based on previous literature and unlikely to have high levels of nonimportance. Two criteria are developed to examine the subjective opinions from experts. The first criterion is a threshold value of 3.50 for all mean values. Three from the 5-point scale means "some importance", a mean value

higher than 3.50 indicates that experts agree with the importance of the CTS element to the owner's role in safety. The second criterion is comparing the percentage of responses higher than 3 with 90%. If the percentage is higher than 90%, it means more than 90% of experts agree that this CTS element is important to the owner's role in safety. Mean values are given in column 2, and the percentage of response higher than 3 is presented in column 3. The results of the survey can be seen in Tables 3.2 for each safety driver.

**Table 3.2 Survey Results for CTS elements**

<b>CTS Elements</b>	<b>Mean</b>	<b>Percentage of response higher than 3 (%)</b>
1	2	3
Establishing and Communicating Attitudes towards Safety	4.65	95.74
Selection of contractor	4.69	95.92
Contractual safety arrangement	4.47	93.88
Owner's involvement in safety pre-construction	4.49	91.84
Monitoring Contractor Safety Compliance	4.54	93.75
Measuring and Analyzing Safety Results	4.45	93.88
Participation in Behavior Observation Surveys (BOS)	4.17	74.47
Participation in incident investigations	4.28	81.63
Providing assistance to contractor for safety	4.44	85.71
Participation in Safety Training	4.33	87.76

### **3.2.3 Final list of CTS elements**

The means of all CTS element are higher than 3.50, which indicates that experts agree with the importance of the CTS element to the owner's role in safety. This result matches

up with the fact that the elements are based on previous literature. However, the result of percentages of response higher than 3 sends a slightly different view on importance. According to Table 3.2, it can be found that “Participation in BOS”, “Participation in incident investigations”, “Providing assistance to contractor for safety” , and “Participation in Safety Training” are not as important as the other CTS elements. The percentages of response higher than 3 of them are all lower than 90%, which indicates less than 90% of respondents agree with their importance to the owner’s role in safety. Therefore, those CTS elements should be excluded from the list. Discussion with construction safety experts was also initiated to examine the CTS remainders. Two decisions were made. The first one is to integrate “Monitoring Contractor Safety Compliance” and “Measuring and Analyzing Safety Results” into one CTS element, since the two CTS elements share a huge common portion of safety practices on the jobsite. The second one is to divide “Establishing and Communicating Attitudes towards Safety” into “Establishing Attitudes towards Safety” and “Communicating Attitudes towards Safety”, since establishing and communicating attitudes are two completely different practices. The final list of CTS elements is presented below:

1. Establishing Attitudes towards Safety;
2. Communicating Attitudes towards Safety;
3. Selection of contractor;
4. Contractual safety arrangement;
5. Owner's involvement in safety pre-construction; and
6. Monitoring Contractor Safety Compliance.

*Establishing Attitudes towards Safety*

The owner's attitude towards safety is a key part to the safety performance of the contractor. Once the owner establishes their attitude to safety, it will affect the safety performance in two ways. The attitude will determine the effort the owner willing to make to the safety work, and also impacts other stakeholders what is acceptable.

#### *Communicating Attitudes towards Safety*

The owner should communicate their concerns on safety issues to all stakeholders on the construction project through various channels. As the financier and end-user of buildings or facilities, the owner's attitude can significantly affect safety work of other participants.

#### *Selection of contractor*

The contractor is the actual constructor of the building or facility, and responsible for safety on the jobsite. Therefore, selecting contractors based on safety performance is a crucial process for final safety result. If the owner selects a contractor with a proven track record of safety, the safety performance should be improved.

#### *Contractual safety arrangement*

Contract stipulates the safety duties for all participants in the construction project. It also serves as the basis for the communication between them. Through contractual arrangement, the owner could propose safety requirements which could navigate the contractor to focus on the safety work.

#### *Owner's involvement in safety pre-construction*

Many activities before construction could affect safety performance. The owner's involvement could significantly prevent such problems and reduce the potential risk for

construction safety. For example, the constructability of the design can determine the risk taken by craftsmen with standard construction practices. If the owner can encourage the designer to consider safety issues during their work, the constructability will improve and the risk will be reduced.

### *Monitoring Contractor Safety Compliance*

To achieve an excellent safety result, the owner should monitor the contractor's compliance with safety. For example, the owner should audit the contractor's work on a regular basis and frequently communicate with the contractor on safety issues. By doing so, the owner and the contractor can take the safety performance to the next level.

## **3.3 Development of CTE elements and S/Ms**

### **3.3.1 Development of CTE list**

The purpose of the ORRM is to produce an accurate rating score for performance of the owner in construction safety. To do that, the CTE s should be categorized and identified. The categories for CTEs are the CTS elements, each of which represents a critical aspect of the owner's function in the construction safety management. CTEs should be developed from these CTS elements, which will be more specific and measurable. To construct a comprehensive and detailed list of CTEs, an extensive literature review is conducted amongst academic articles on the owner's role in construction safety and publications by government agencies and industry associations.

As mentioned above, the ORRM is structured as a four-level model. CTS elements comprise the second level of the model. However, it does not suffice to provide specific and measurable elements to obtain an accurate rating score. Therefore, a few of CTEs

were developed below each of CTS elements. The ideas and information also stemmed from the previous studies. Because the legal documents by government agencies and the guides by the industry associations are primarily directive principles, they do not contribute much to extracting and summarizing CTEs. By comparison, most research articles made a great effort to explore into the details on how the owner conducts safety practices on the jobsite. However, the same challenge emerged when designating the CTEs to relative CTS element. After several refining processes and improvements, a list of 38 CTEs were finally created.

### **3.3.2 Development of S/Ms**

Based on features of these CTE elements, thirty-eight specification and measurements (S/Ms) were also developed to measure the performance of CTE elements. S/Ms describe further detailed and specific practices for CTEs. To adapt to the nature of respective CTE elements, three types of S/Ms were developed: a frequency based Likert scale response, a metric driven response, and a binary (Yes/No) response.

CTE 6.4, CTE 6.6, CTE 6.7, and CTE 6.9 are practices and procedures that the owner may take on a reoccurring basis. Therefore, the frequency with which the owner conducts the behavior has become the key criteria to measure the owner's performance. For these four CTE elements, quantitative S/Ms are designed on the basis of frequency level. The measurement scale ranges across "Never", "Monthly", "Weekly", and "Daily", which respectively correspond to scores of "0", "1", "2", and "3". Subsequently, increased engagement in safety issues earns the owner more scoring points.

Another unique CTE element is CTE 3.5. The purpose of this CTE is to understand the owner's practices when vetting contractors' capability of safety management. Therefore, S/Ms designed for this CTE element are options including "Total Recordable Incidence Rate", "Experience Modification Rating", "Loss Ratios of Workers' Compensation", "Records of OSHA Citations and Fines", "Litigation Related to Injuries", and "Safety Performance Records of Key Personnel". Considering the possibility that the owner might use several methods at the same time, selection of multiple options is allowable. Each option could earn the owner a score of 0.5 points. Because these measures focus on different aspects of safety performance, it is a reasonable way to obtain overall score of this CTE by accumulating scores assigned to each option. Thus, the maximum score allowable are 3 points.

The remainder of the CTE elements have qualitative S/Ms that focus on whether the owner conducts the behavior or not. These CTE elements are often practices or procedures that the owner conducts one time. Therefore, it is not possible to measure the frequency with which the owner implements these CTE elements. Ensuring whether the owner fulfills these CTE elements or not is a practical and effective method. These S/Ms comprise two options of "Yes" and "No" with scores of "3" and "0" respectively corresponding to the two options.

ORRM is a rating model detachable to a main rating model based on operational excellence. Other ancillary and trivial information on development of S/Ms is reported in the research report entitled "Safety Performance through Operational Excellence" published by the Construction Industry Institute (Maloney et al., 2016).

The final version of the ORRM is presented in the Table 3.1, which consists of 38 CTE s grouped into 6 CTS elements. The list includes the CTE descriptions and Specification/Measurement (S/M).

**Table 3.3 CTS Elements, CTE s and Specification/Measurement**

<b>CTSs</b>	<b>CTEs</b>	<b>S/M</b>
CTS 1 - Establishing Attitudes towards Safety	CTE 1.1 - Does the owner understand that his involvement contributes to safety?	YES/NO
	CTE 1.2 - Does the owner set Zero-Injury as the objectives for the project?	YES/NO
	CTE 1.3 - Does the owner go beyond a regulatory compliance approach to prevent injuries?	YES/NO
CTS 2 - Communicating Attitudes towards Safety	CTE 2.1 - Does the owner communicate with all project stakeholders clearly about his safety position?	YES/NO
	CTE 2.2 - Does the owner communicate his commitment to safety to the contractors?	YES/NO
CTS 3 - Selection of contractor	CTE 3.1 - Does the owner prequalify contractors?	YES/NO
	CTE 3.2 - Does the owner consider safety in prequalifying contractors for bidding on projects?	YES/NO
	CTE 3.3 - Dose the owner provide specific contractual safety requirements to prospective contractors?	YES/NO
	CTE 3.4 – Does safety have a high priority when selecting a contractor?	YES/NO
	CTE 3.5 – Does the owner utilize the following safety measures in selecting a contractor?	Total Recordable Incidence Rate Experience Modification Rating Loss Ratios of Workers’ Compensation



		Records of OSHA Citations and Fines
		Litigation Related to Injuries
		Safety Performance Records of Key Personnel
CTS 4 - Contractual safety arrangement	CTE 4.1 - Does the owner assign at least one full-time safety representative on the project?	YES/NO
	CTE 4.2 - Does the owner provide the contractor with safety guidelines that must be followed?	YES/NO
	CTE 4.3 - Does the owner require contractors to submit the resumes of key safety personnel for the owner's approval?	YES/NO
	CTE 4.4 - Does the owner require contractors to provide specific minimum safety training for workers?	YES/NO
	CTE 4.5 - Does the owner require contractors to submit a site-specific safety plan?	YES/NO
	CTE 4.6 - Does the owner require contractor's employees at all levels to have specific safety responsibility integrated into work processes?	YES/NO
	CTE 4.7 - Does the owner require contractor to submit a safety policy statement signed by its CEO?	YES/NO
	CTE 4.8 - Does the owner require the contractor to submit an emergency plan?	YES/NO
	CTE 4.9 - Does the owner require the contractor to submit and utilize an immediate reporting procedure for accidents and near misses on this project?	YES/NO
	CTE 4.10 - Does the owner require the contractor to submit a mitigation plan for this project?	YES/NO

	CTE 4.11 - Does the owner require that subcontractors must be included in the safety program?	YES/NO
	CTE 4.12 - Does the owner make it clear that contractor is ultimately responsible for the safety of his employees?	YES/NO
	CTE 4.13 – Does the owner specify the actions that can be taken to contribute to safety performance on this project?	YES/NO
CTS 5 - Owner's involvement in safety pre- construction	CTE 5.1 - Does the owner address safety issues in the feasibility study and conceptual design phases?	YES/NO
	CTE 5.2 - Does the owner require designers to consider construction safety/constructability?	YES/NO
	CTE 5.3 - Does the owner require designers to conduct a review of the design for construction safety for this project?	YES/NO
	CTE 5.4 - Does the owner conduct a review of the design for safety?	YES/NO
	CTE 5.5 - Does the owner prefer to award the contract to a design and construction contract to promote safety performance?	YES/NO
	CTE 5.6 - Does the owner conduct the pre-construction meeting with contractor for safety issues?	YES/NO
CTS 6 - Monitoring Contractor Safety Compliance	CTE 6.1 - Does the owner assign a full-time site safety representative to this project?	YES/NO
	CTE 6.2 - Does the owner specify the responsibilities of the site safety representative?	YES/NO
	CTE 6.3 - Does the owner establish a construction safety unit to monitor contractor safety?	YES/NO
	CTE 6.4 – How frequently does the owner conduct safety meetings with contractor managerial and supervisory personnel?	“Never”, “Monthly”, “Weekly”, and “Daily”
	CTE 6.5 - Does the owner maintain statistics of contractor accidents and near misses?	YES/NO

	CTE 6.6 - How frequently does the owner communicate with contractor's employees about safety on this project?	"Never", "Monthly", "Weekly", and "Daily"
	CTE 6.7 - How frequently does the owner conduct safety audits on the contractor's processes?	"Never", "Monthly", "Weekly", and "Daily"
	CTE 6.8 - Does the owner initiate or implement a safety recognition/reward program on this project?	YES/NO
	CTE 6.9 - How frequently does the owner periodically discuss safety audits of the contractor operations with the contractor?	"Never", "Monthly", "Weekly", and "Daily"

### 3.4 Clarification of CTS and CTE elements

CTS elements are fundamental principles profoundly affecting the performance of owners to fulfill their roles. CTE elements are specific and measurable practices and procedures contributory to construction safety performance. All of them were summarized and refined from various relevant research. When developing these elements, many details on the roles and functions of the owner were deliberated on along the normal procedures applied in the project practices. To address potential confusion between the CTS and CTE elements, the following examples of CTS and CTE elements hope to highlight the differences.

Among the 6 Critical to Safety factors, the difference between "establishing attitudes towards safety" and "communicating attitudes towards safety" appears to be minimal. However, they are two different aspects or stages of the implementation of safety culture. The two CTS elements deal with different parties on the jobsite. The CTS element of "establishing attitudes towards safety" addresses the attitude of the owner organization

towards safety. It helps the owner check its own dedication to achieve high safety performance. The CTS element of "communicating attitudes towards safety" addresses how to communicate the owner's attitude to other stakeholders on the jobsite. If other stakeholders perceive the owner's concern on safety, they would place a heavier emphasis on safety efforts. Therefore, making the owner's attitude known to others also has an importance comparable to establishing the attitude.

For CTE elements under the CTS of "Selection of Contractor", "CTE 3.2 – Does the owner consider safety in prequalifying contractors for bidding on projects" and "CTE 3.4 – Does safety have a high priority when selecting a contractor" seems to be similar. Actually, these two CTEs reference the two stages of bid solicitation: prequalifying contractors as to who is allowed to participate in the bidding and then selecting the winning contractor. CTE 3.2 deals with the first stage of prequalifying contractors, which could assist the owner in screening out contractors with poor safety history. However, CTE 3.2 by itself could not guarantee the selection of the contractor with excellent safety performance. The second stage of comparing tenders usually employs a comprehensive rating method considering various factors such as estimated cost, personnel competency, and similar factors. CTE 3.4 helps the owner ensure that safety is the most important consideration when deciding the winner. Overall, CTE 3.2 and CTE 3.4 respectively deal with safety issues at different stages. They are complementary CTE elements, but not interchangeable ones.

CTE 1.3 is "Does the owner go beyond a regulatory compliance approach to prevent injuries", it seems to be loosely defined because of lacking the specific statutes. However, the rough wording of "regulatory compliance" serves as a basis for universal application

of CTE 1.3. Whether in the US, the Australia, or the EU countries, government statutes or publications by industry associations all specify basic guidelines for the owner to engage in safety issues. An example being the Health and Safety Executive (HSE) of the United Kingdom's Construction Design and Management Regulations 2015 (HSE, 2015) outlines specific roles and responsibilities of clients to improve safety on construction projects. The audience for this effort spans outside the borders of the United States, therefore, the authors did not specify a particular piece of legislation or regulation as it may vary across countries. However, such obligations only serve as bottom line and are not sufficient for excellent safety work. Therefore, whether "the owner goes beyond regulatory compliance" is a key indicator to the owner's willingness to proactively improve construction safety.

### **3.5 Introducing the use of the ORRM**

ORRM is derived from the OE philosophy with the top-down approach. However, the use of the ORRM should adopt a bottom-up approach. The process to rate the owner's role starts from the S/Ms level. Based on the owner's performance of implementing CTE elements, corresponding options from each S/M were selected and checked.

Subsequently, scores of each CTE element were obtained, which serves as the basis for scoring CTS element. Scoring CTS element consists of two steps. The first step is accomplished by summing CTE scores belonging to this CTS element. The second step is to multiply the score sum of CTE elements by weight of this CTS element to gain the CTS score. The weight is a relative importance quantifying this CTS element's contribution to the owner's overall safety performance. The detailed process to produce the weights of CTS elements will be presented in the following sections. Once CTS

scores are obtained, the final rating result for the owner's role could be generated by accumulating all CTS scores.

To establish a quantitative rating model, quantified relative importance and measurement scale should be developed and embedded into the ORRM. The main objective of the following study is to present the process of obtaining weights of CTS elements.

Analytical Hierarchy Process (AHP) is utilized to obtain the weights.

### **3.6 Weight the CTS elements with Analytic Hierarchy Process (AHP)**

Analytic hierarchy process (AHP) was first proposed by Saaty (1980). As a management tool, AHP is designed to aid decision-making when addressing complex, unstructured and multi-attribute problems (Partovi, 1994). The primary approach of AHP is to decompose a "complex" objective into multiple "simple" elements and weight these "simple" elements through pairwise comparison to make a decision (Shapira et al, 2009). Although the focus of the current study is not placed on decision making, the methodology of AHP to weight various elements is considered to be applicable here. Five major steps are proposed with an emphasis on the current study, which are based on the ASTM AHP standard (ASTM E 1765-95) and adapted to the specific assets of the current study (ASTM, 1995).

#### ***Step 1: Construction of Hierarchic Structure***

The primary objective of the analysis, the owner's impacts on construction safety, should be broken down to a series of relevant elements, which are termed as CTSs and CTEs in the current research. Hierarchic structure can facilitate decision makers to formulate a well-informed and sound choice. In Table 1, the hierarchic structure is presented. The

column of CTS serves as the first level of criteria, and the column of CTE corresponds to the second level. Each CTS element, in turn, is directly affected by these CTE elements adjacently listed below this CTS element (e.g. the CTS of Establishing Attitudes towards Safety is affected by the CTEs of understanding the contribution of its engagement to safety, setting zero injury goals, and going beyond a regulatory compliance approach).

### ***Step 2: Pairwise Comparison***

One main goal of AHP is to obtain the relative weights of critical elements, to which pairwise comparison is the principal approach. Pairwise comparison only applies to elements on the same level. Conducting pairwise comparison requires the construction of a comparison matrix to record results of comparison sets. To quantify the relative importance, a measurement scale of 1 to 5 is developed. The detailed description of comparison process will be presented in the research methodology section.

### ***Step 3: Aggregation of Comparison Matrices***

Generally, AHP is built on multiple comparison matrices by a group of experts. In this study, nine experts present their judgements on the owner's impacts on safety issues. Aggregation of comparison matrices deals with translating judgements of multiple experts into a single judgement of the group, which serves as the basis for relative weight computation. One of the most popular solutions to this problem was the aggregation of individual judgments (AIJ) (Saaty, 1989). The basic way to practice AIJ is to use geometric mean of the values assigned by experts to the individual comparison matrix to form a group comparison matrix. It needs to be stressed that the group comparison matrix must be composed using the geometric mean rather than the

arithmetic mean (Forman et al, 1998). For example, if  $a_{ij}^1, a_{ij}^2, \dots, a_{ij}^n$  stand for comparison result of CTS  $i$  versus CTS  $j$  by the experts  $1, 2, \dots, n$  respectively, the entry of CTS  $i$  versus CTS  $j$  to the group comparison matrix can be calculated by the equation follow:

$$a_{ij}^g = \prod_{k=1}^n a_{ij}^k \quad (1)$$

Where  $a_{ij}^g$  is the value at row  $i$  and column  $j$  of the group comparison matrix, and  $a_{ij}^k$  is the raw value at row  $i$  and column  $j$  of the comparison matrix by the  $k$ th expert.

#### ***Step 4: Relative Weight Computation***

There are several methods to compute relative weights. The most widely used is the Eigenvector method proposed by Saaty (1980). The basic theory is that each entry  $a_{ij}$  of the comparison matrix  $A$  is exactly the ratio of weight  $w_i$  to  $w_j$ . For an  $n \times n$  comparison matrix, the calculation of  $w_i$ , the relative weight for the  $i$ th CTS element, can be obtained by the following equation:

$$w_i = \frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \quad (2)$$

Where  $a_{ij}$  is the raw value at row  $i$  and column  $j$  of the comparison matrix,  $w_i$  is the weight of the  $i$ th element, and  $\sum_{k=1}^n a_{kj}$  indicates the sum of all raw values in column  $j$  that is used to normalize column  $j$ .

#### ***Step 5: Consistency Ratio (CR)***

One advantage of AHP is the measure that it provides to check the consistency of the pairwise comparison. Consistency indicates the logic consistently existing within a series of pairwise comparison. For example, an expert thinks of CTS 1 more important than



CTS 2, and also considers CTS 2 more important than CTS 3. If the expert follows the same train of thought to judge CTS 1 more important than CTS 3, consistency exists. Otherwise, if the expert places more importance on CTS 3 than CTS 1, inconsistency occurs. Saaty (1980) developed a measure of deviation or degree of consistency named Consistency Index (CI), which can be calculated with the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

Where  $\lambda_{max}$  is the principal Eigenvalue, which is the summation of products between elements of Eigenvector and the column sums of the synthesized comparison matrix;  $n$  is the size of comparison matrix or the number of CTS elements.

CI reflects the consistency of the matrix on test. A benchmark is needed to compare with CI. Saaty (1980) developed a Random Index (RI) table to serve as the benchmark, which is presented in Table 3.4.

**Table 3.4 Random Index**

<b>n</b>	1	2	3	4	5	6	7	8	9
<b>RI</b>	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

CR is exactly the ratio of CI to RI, which can be obtained with the following equation:

$$CR = \frac{CI}{RI} \quad (4)$$

To guarantee the acceptability, CR should be kept under 0.1 regardless of the project nature (Saaty, 1980). However, this threshold does not guarantee the correctness of

weights. It is only designed to prevent intolerable conflicts in the comparisons, and ensure acceptable logic exists in weighting process.

## 4 DATA COLLECTION, PROCESS, AND ANALYSIS

A questionnaire survey was conducted to collect professional views on weights of CTS elements, which then serves as the basis of computing weights. This section will introduce the processes of collecting data and how to translate the raw data into weights with AHP.

### 4.1 Design and Conduction of Questionnaire Survey

Obtaining weights of CTS elements cannot merely capitalize on literature review and authors' "guesswork". Professional insights from qualified experts are the reliable source for weights of CTS elements. A questionnaire survey was conducted to investigate construction safety experts' opinions on relative importance of CTS elements. The questionnaire consists of three sections.

The first section comprises the explanation of the survey and the guideline for the participants to weight CTS elements. The explanation stresses the primary research objective and definitions of CTS elements, which can assist participants to understand the purpose of this survey. Measurement scale of comparison can be seen in Table 4.1.

**Table 4.1 Measurement Scale of Comparison**

<b>Degree of Comparison</b>	<b>Equally</b>	<b>Moderately</b>	<b>Strongly</b>	<b>Very Strongly</b>	<b>Extremely</b>
<b>If A is more important than B</b>	1	2	3	4	5
<b>If A is less important than B</b>	1	1/2	1/3	1/4	1/5

The guideline deals with the practical techniques of pairwise comparison, which is introduced with elaborate examples. In the case of CTS A versus CTS B, two possible situations are proposed and respective measurement scale specific for each situation is also developed. Situation 1 is that CTS A is more important than CTS B. In this case, the measurement scale of 1 to 5 applies to weighting, where 1 means “Equally Important”, 3 “Strongly Important”, and 5 “Extremely Important”. Situation 2 is that CTS B is more important than CTS A. Reciprocals of values in the other scale form the scale for situation 2, where 1/1 means “Equally Important”, 1/3 “Strongly Important”, and 1/5 “Extremely Important”.

The second section includes all sets of pairwise comparisons between 6 CTS elements. AHP only applies to weighting CTS elements. As for CTE elements, they are considered to have the equal relative importance. The reason is that weighting many attributes at the same time could constitute a significant cognitive burden for decision makers (Hwang et al, 1995). This arrangement assists participants to focus their efforts on several critical elements, rather than waste effort on numerous and trivial elements. This weighting approach has been proven to be superior in some situations and not significantly worse in the other situations (Einhorn et al, 1975). Totally, 15 questions are asked to collect experts’ professional insights into CTS relative importance. Take CTS 1 and CTS 2 for example, question of “How much more valuable is Communicating Attitudes towards Safety than Establishing Attitudes towards Safety?” is asked. Respondents can answer this question against the measurement scales.

The third section requires participants to provide their demographic information and experience in construction industry. Besides demographic information, experience on

construction safety was also asked, which included total years of undertaking construction safety work, type of project they primarily work on, and type of organization they primarily work for.

## **4.2 Data Process**

The questionnaire was developed through Qualtrics©, a professional online survey software. Survey links were sent to senior managers of member organizations of the research team. These organizations were members of the CII and/or the CURT. Nine completed questionnaires were collected. To verify the validity of the response rate, the authors conducted a search through literature databases including Google Scholar and ASCE journals for publications that applied the AHP methodology. From this search, the majority of publications do not report a sample size. A few publications reported a sample size of slightly more than 10. Therefore, sample size of 9 should suffice and is verified by the consistency ratio test.

### **4.2.1 Demographics of Respondents**

Among the respondents, the most experienced expert has undertaken work related to construction safety for 38 years. The relatively most inexperienced one has spent 15 years on construction safety work. For all respondents, the average years are 24.5 years, which proves that they all have rich experiences on and deep insights to the owner's impacts on construction safety. Another feature of their experience is that they are evenly distributed across four different construction project types: fossil fuel or natural gas power plants, nuclear power plants, and other industrial projects. It can be concluded that experts got their experience mainly from industrial sector. Compared to residential and/or commercial constructions, industrial projects have greatly higher complexity and require

a much higher level of the owner’s engagement. Experts on industrial projects have more and greater opportunities to interact with owners on safety issues than those on other projects, and therefore, more insightful information could be provided. Three respondents came from contractor organizations; the rest were working for owner organizations. Experts working for owner organizations could fully engage in the influence of the owner on the contractor; on the other hand, they also have access to requests on safety issues from the contractor. Therefore, they could compare CTS elements from the perspective of the owner. Experts of contractor organization are more close to the safety works on the construction site, which means they could summarize the needs of the owner’s involvement from construction practices on jobsite basis. The summary of respondent demographics is presented in the Table 4.2.

**Table 4.2 Respondent Demographics**

<b>Average years of construction safety work</b>	<b>Organization Type</b>	<b>Percentage</b>	<b>Construction Sector</b>	<b>Percentage</b>
24.5 years	Owner	66.67%	Fossil fuel or natural gas power plants	22.22%
	Contractor	33.33%	Nuclear power plants	11.11%
			Other industrial projects	66.67%

**4.2.2 Aggregation of Comparison Matrices**

Nine completed comparison matrices constituted a solid basis for the relative weight computation. As mentioned above, AIJ was adopted to synthesize the judgements of experts. Geometric means of corresponding values in comparison matrices by nine experts comprise the synthesized matrix, which is presented in Figure 4.1.

	CTS 1	CTS 2	CTS 3	CTS 4	CTS 5	CTS 6
CTS 1	1.00	0.91	0.63	1.16	0.82	0.59
CTS 2	1.09	1.00	0.42	0.86	0.61	0.60
CTS 3	1.60	2.38	1.00	1.05	0.96	0.83
CTS 4	0.86	1.17	0.95	1.00	0.66	0.51
CTS 5	1.22	1.63	1.05	1.51	1.00	0.76
CTS 6	1.68	1.66	1.20	1.96	1.31	1.00

**Figure 4.1 Synthesized comparison matrix of group**

The values with light blue fill are the geometric means of their counterparts in nine individual matrices by the experts. Besides values on diagonal line, values in the upper-triangle are the reciprocals of values in their symmetric cells of the sub-triangle.

### 4.2.3 Relative Weight Computation

Figure 4.2 presents the process of relative weights computation. The computation of relative weights stems from the synthesized comparison matrix. The sum of each column in the synthesized comparison matrix is calculated. These sums are critical to the attainment of a normalized matrix. Normalization is implemented with the process of dividing raw values in each column by the sum of this column. Once the normalization matrix is developed, values of each row in this matrix are summed. The results of dividing individually row sums by the CTS number of six are the relative weights.

### Relative Weights Computation Process

- CTS 1: Establish Attitudes towards Safety
- CTS 2: Communicate Attitudes towards Safety
- CTS 3: Selection of contractor
- CTS 4: Contractual safety arrangement
- CTS 5: Owner's involvement in safety pre-construction
- CTS 6: Monitoring Contractor Safety Compliance

### Synthesized Comparison Matrix

	CTS 1	CTS 2	CTS 3	CTS 4	CTS 5	CTS 6	
CTS 1	1.00	0.91	0.63	1.16	0.82	0.59	<b>Number of CTS</b> 6 ↓ <b>Relative Weights</b> 0.13 0.12 0.20 0.13 0.19 0.23 <b>1.00</b>
CTS 2	1.09	1.00	0.42	0.86	0.61	0.60	
CTS 3	1.60	2.38	1.00	1.05	0.96	0.83	
CTS 4	0.86	1.17	0.95	1.00	0.66	0.51	
CTS 5	1.22	1.63	1.05	1.51	1.00	0.76	
CTS 6	1.68	1.66	1.20	1.96	1.31	1.00	
Column Sum	7.46	8.75	5.25	7.54	5.36	4.30	



### Normalized Comparison Matrix with Column Sum

CTS 1	0.13	0.10	0.12	0.15	0.15	0.14	<b>Row Sum</b> 0.80 0.71 1.19 0.80 1.11 1.38
CTS 2	0.15	0.11	0.08	0.11	0.11	0.14	
CTS 3	0.21	0.27	0.19	0.14	0.18	0.19	
CTS 4	0.12	0.13	0.18	0.13	0.12	0.12	
CTS 5	0.16	0.19	0.20	0.20	0.19	0.18	
CTS 6	0.23	0.19	0.23	0.26	0.24	0.23	
Column Sum	1.00	1.00	1.00	1.00	1.00	1.00	



Figure 4.2 Relative weights computation process

#### 4.2.4 Consistency Test

Figure 4.3 presents the process of the Consistency Ratio (CR) computation. CR is the quotient of Consistency Index (CI) and Random Index (RI). CI was calculated with Equation 3, which is 0.013. As for RI, its value was determined by both matrix size and Table 2. The size of the synthesized comparison matrix is 6×6. For that size matrix, the RI is 1.24 per Table 2. By Equation 4, CR of 0.011 is much less than the acceptable threshold of 0.1. That means the synthesized judgement of the nine experts have excellent consistency, and conflicts are controlled under an acceptable level.



### Consistency Ratio Computation

	CTS 1	CTS 2	CTS 3	CTS 4	CTS 5	CTS 6
CTS 1	1.00	0.91	0.63	1.16	0.82	0.59
CTS 2	1.09	1.00	0.42	0.86	0.61	0.60
CTS 3	1.60	2.38	1.00	1.05	0.96	0.83
CTS 4	0.86	1.17	0.95	1.00	0.66	0.51
CTS 5	1.22	1.63	1.05	1.51	1.00	0.76
CTS 6	1.68	1.66	1.20	1.96	1.31	1.00
Column Sum	<b>7.46</b>	<b>8.75</b>	<b>5.25</b>	<b>7.54</b>	<b>5.36</b>	<b>4.30</b>
Relative Weights	<b>0.13</b>	<b>0.12</b>	<b>0.20</b>	<b>0.13</b>	<b>0.19</b>	<b>0.23</b>
	1.00	1.03	1.04	1.01	0.99	0.99
	$\lambda_{\max}$ :	6.067				
	CI:	0.013				
	RI:	1.240				
	CR:	0.011	<0.1			

Figure 4.3 Consistency ratio computation

### 4.3 Findings and Analysis

The essential part of this model is the relative weights of the CTS elements. They serve as the fundamental basis for quantifying contribution of each CTS to the owner's impacts on safety performance, and also guides practitioners to effectively allocate their efforts on improving safety through the owner's role. The data process with AHP generates the relative weights of CTS elements. They are presented in Table 4.3.

**Table 4.3 CTS Elements with Weights**

<b>CTS elements</b>	<b>Weight</b>
CTS 1 - Establishing Attitudes towards Safety	0.13
CTS 2 - Communicating Attitudes towards Safety	0.12
CTS 3 - Selection of contractor	0.20
CTS 4 - Contractual safety arrangement	0.13
CTS 5 - Owner's involvement in safety pre-construction	0.19
CTS 6 - Monitoring Contractor Safety Compliance	0.23

From Table 4.3, the CTS of “Monitoring contractor safety compliance” has the highest weight of 0.23. The relative weights of “Selection of contractors” and “Owner’s involvement in safety pre-construction” are 0.20 and 0.19 respectively. They have approximately same weights, both of them are considered to have secondary importance. The relative weight of “Establishing attitudes towards safety” is 0.13, “Communicating attitudes towards safety” 0.12, and “Contractual safety arrangement” 0.13. These CTS elements have similar relative importance around 0.12, all of them are considered to have lowest importance.

Evidently, experts place the heaviest emphasis on the CTS of “Monitoring contractor safety compliance”. Part of the reason may be the derivative of conventional wisdom of the sole responsibility of the contractor on safety. The contractor, the actual builder of the project, is still in the best position to directly manage safety issues. Another part is the fact that the owner cannot conduct safety work directly. The contractor must be incorporated into the implementation of the owner’s impacts on safety. Another point is also noteworthy. Compared with other CTS elements, “Monitoring contractor safety

compliance” is the only one with a sustainable engagement through the whole construction phase. Most safety incidents occur during construction. Therefore, continuously monitoring safety compliance indeed plays a key part in reducing safety risks.

“Selection of contractors” and “Owner’s involvement in safety pre-construction” are placed at the level of second importance. Experts attributed relative weights of around 0.2 to them. It is easy to understand why “Selection of contractors” is assigned a high weight. As mentioned above, the prevailing assumption is that the contractor’s sole responsibility for safety. It makes the contractor’s ability to manage safety determinant to eventual safety performance. Therefore, selecting a contractor competent for safety would lay out a sound foundation for the follow-up work. For the other CTS element, magnitude of pre-construction activities for construction safety are significantly appreciated by stakeholders on the jobsite. In traditional the Design-Bid-Build project delivery system, design work is done before the commencement of construction. It is very likely to have safety problems due to design faults or inappropriateness. Because of the separation between design and construction, it is very difficult, if not impossible, for the contractor to directly negotiate with the designer on these issues. The most practical and effective way to prevent such dilemma is to introduce the owner’s involvement in pre-construction tasks. The owner can put these tasks under perspective of project lifecycle and address potential safety issues before construction.

“Establishing attitudes towards safety” and “Communicating attitudes towards safety” are placed at the lowest level of importance, which is a surprising result for authors. Safety attitude is always sighted as a critical factor to the establishment of safety culture,

and safety culture is also considered to be determinant to safety behaviors. However, experts assigned relatively low weights to the two CTS elements related to safety attitude. Based on their jobsite experience, experts may have thought of the way that the owner's safety attitude works too subtle and indirect to be sufficiently effective. In construction practices, tangible and direct approaches to safety are easier to implement and generate effects. Although this result deviates from authors' original assumption, it still reflects the truth of how effectively safety attitude works on the construction site.

The other surprising finding for authors is the low weight of "Contractual safety arrangement". Construction contracts are the ruling authority on jobsites, which stipulates fundamental principles of all procedures and behaviors of the owner and the contractor. It also serves as the basis for safety activities. However, when it comes to the comparison between stipulation and compliance of safety, practical experiences of experts may decide on the latter to be more crucial. For the safety clauses in the contract, more efforts should be placed on how to rigorously comply to clauses rather than merely how to stipulate right requirements. This result fully represents the practical perspective of experts working in the industry.

Weights of CTS elements are important components of the ORRM. The rating process should incorporate weights to generate an accurate score. Per the calculation process introduced in section 3.5, the weighted ORRM score spans from 0 to 19.59. 0 is the minimum possible score, which means the owner is not involved in safety work at all. 19.59 is the maximum possible score, which means the owner performs all safety functions.

## **5 EMPIRICAL VALIDATION**

Previous chapters provide a detailed introduction to the development of the ORRM. Both academic research and safety practitioner's expertise constitute a solid foundation for this rating model. However, although these insightful inputs are either scientifically validated or refined with long-term professional experience, they alone cannot guarantee the effectiveness of the ORRM. Therefore, an empirical validation is initiated to test the its performance when applying it to the actual construction projects, which is conducted with a questionnaire survey. The principal testing design is to collect data on safety performance from multiple projects; calculate scores by applying the ORRM to the same group of projects; and then run a linear regression analysis between them to obtain  $R^2$ . The chapter explains the questionnaire to collect safety performance and the ORRM score, provides a summary and analysis of project demographics, provides the statistical analysis on safety performance and the ORRM score, and reaches a conclusion based the result of statistical analysis.

### **5.1 Selection of Testing Projects**

The aim of the ORRM is to evaluate the level of owner's involvement in the construction safety management. One fact widely accepted is that the need for necessary involvement of the owner in construction safety is heavily dependent on the type of project. The evident reason is that the type of project decides on the complexity of its construction, and the complexity decides on the need for the owner's involvement. Herein the definition of construction complexity is that the interaction, interdependencies, and interrelationships between parts of a project and that the greatest deal of complexity lies within the organizational aspects of a project (Wood, 2008). In comparison to a

sophisticated nuclear power plant, a residential house has much less interaction, interdependencies, and interrelationships between the owner and the contractors. In other words, it has a lower complexity. To validate the ORRM effectively, projects with high complexity needs to be selected. Therefore, five types of projects are selected as testing subjects, which are commercial project, fossil power plant, light industrial project, nuclear power plant, and heavy industrial project. All of them have a relatively higher complexity, which can translate into a higher safety incident rate if the owner involvement is absent. Although it is a potential risk for construction safety, it is a positive factor for this validation study.

The other important factor should be considered when selecting projects is the project size. It is easily understandable that projects with smaller size are relatively less risky than ones with bigger size. The causes behind it include shorter construction period, less employees on jobsite, lower construction complexity, and better constructability. If projects have a size under a certain level, the owner's involvement in safety issues maybe have a very minimal effect on safety performance. It could become a confusing factor into the statistical analysis of data. However, it is not very clear on the relationship between project size and safety incident rate, especially for specific project type. In this validation, projects spanning a wide range of sizes are all considered, the purposes of which are to test the hypothesis and to ascertain the cut-off value of project size. The cut-off value will serve as an important guideline for the users to determine whether the project is suitable for the ORRM or not. Multiple indicators are adopted to form a holistic view on project size, which include Total Expected Man-hours, Total Cost, and Expected Maximum Number of Employees on Site.

## **5.2 Determination of Construction Safety Indicator**

The central part of the proposed empirical validation is to run a linear regression between safety performances and ORRM scores of the same group of projects. The precondition for this design is to ensure the indicator of safety performance. Various construction safety indicators were developed and utilized on actual projects, which included the Experience Modification Rate (EMR), the Total Recordable Incident Rate (TRIR), the Lost Time Incident Rate (LTIR), and the Workers' Compensation Claims Frequency Indicator (WCCFI). A study of comparative analysis was conducted on those safety indicators (Garza, 1998), the conclusion of which read that "what gets measured, get improved."

The criterion for determining the most suitable safety indicator should be derived from the ultimate objective of this dissertation, which is to improve the safety performance with the better practices of the owner. Therefore, the selected indicator should show its focus on safety issues. Per the argument of "what gets measured, get improved", the safety incident must be measured for the improvement. TRIR is the most suitable indicator in this research, because it only measures the relative rate of injury on the jobsite and does not incorporate any other factors. Other indicators are not pure safety indicators. For LTIR, schedule delay has the priority to be measured. For EMR and WCCFI, cost saving is most concerned. Compared to TRIR, they are merely means to the end. Another advantage of TRIR is the high utilization rate in construction industry. Construction Industry Institute (CII) uses it to reflect the safety situation and predict the future trend in construction industry. High utilization rate can reduce the risk of missing

data, which is critical to data collection. Considering the two advantages of TRIR, TRIR is selected to be the safety indicator in this research.

### **5.3 Design and Conduction of Questionnaire Survey**

The purpose of this questionnaire survey is to collect demographics of projects including TRIR and score these projects with the ORRM. Both of them are preparation for follow-up statistical analysis. The survey is compiled and conducted with Qualtrics®, a professional online survey software. The questionnaire consists of three sections.

The first section includes the explanation of the survey and qualifying question. The explanation focuses on the background of this research and definitions of the owner's role, which can assist participants to understand the purpose of this survey. Qualifying question requires the participants to decide to continue or not based on the role the owner played in safety. If the owner has a very active role, respondents continue with the survey by pressing the "continue" button. If the owner assumes a very minimal role and leaves safety to the contractor or construction manager, respondents press the "end" button.

The second section requires participants to provide demographic information of project. Details of stakeholders on project include name of project, organization of contractor, location, and organization of owner. Details of project size include project cost, total expected man-hours, and expected maximum number of employees on site. Construction safety indicator is total recordable incident rate. Other additional items include project type, project labor status, and delivery system.

The third section includes all questions of CTE elements. Because all CTE elements are displayed in the form of complete question, it is easy for participants to understand. The



necessity of instructions is not seen. Answer options for each question is developed based on its S/Ms, for details of which Table 3.1 can be referenced. However, answer options are not totally copied from S/Ms. For S/M of metric driven response, option of “none” is added for the participant who do not use any safety indicators. For S/M of binary (Yes/No) response, option of “I don’t know” is added for the participant having no knowledge of the existence of some CTE elements. For S/M of frequency based Likert scale response, no change is made. The reason is that option of “Never” is already listed. When translating answer options to scores, options of “none” and “I don’t know” are both assigned with the value of “0”. The method to calculate the ORRM score for each project is a bottom-up approach, which is already introduced above. Section 3.5 in this dissertation can be referenced for details on it.

#### **5.4 Preliminary Data Process**

The questionnaire was developed through Qualtrics©, a professional online survey software. Survey links were sent to project managers or superintendents working for the contractor. In this survey, the contractor employees, instead of the owner’s representatives, were targeted as the input sources. The contractor can directly manage safety issues, and the owner’s impacts have to take effect via the contractor. Therefore, the influence of the owner perceived by the contractor is the most accurate measure for the owner’s involvement in safety. Twenty-two responses were collected. When checking these data, three responses were found to share the same information of almost all demographics. Only their ORRM scores, although very similar, are different. After communicating with managers of this project, it is ensured that they are three responses

from the same project. Therefore, they are combined to be one project with an averaged ORRM score. Finally, twenty projects were collected.

#### **5.4.1 Demographics of Projects**

Per the plan to conduct the survey, projects with relatively higher complexity are preferred. Eight light industrial projects, four commercial buildings, four fossil/nuclear power plants and one heavy industrial project are collected. These projects take up 85% of all sample units. The common feature of these projects is to require the frequent and strong interaction, interdependencies, and interrelationships between the owner and the contractors. To substantiate the sample size, one library, one infrastructure project, and one university dormitory are also included. Despite the lower complexity, they are still considered to be suitable for measurement. Projects covered by this survey are worth 817.85 million dollars, consume 4,692 thousand man-hours, and have a maximum number of 3,080 employees on the jobsite. Estimated cost, total expected man-hours, and maximum number of employees on jobsite are collected as indicators of project size. Labor status and delivery system can provide other perspectives on the analysis of the owner's role in safety. One of the primary purposes of this survey is to collect TRIR, which will serve as the construction safety indicator. ORRM scores are also calculated with responses, which range from 4.42 to 18.90. All variables are summarized in the Table 5.1.

**Table 5.1 Demographics of Projects**

<b>Project number</b>	<b>Type of project</b>	<b>Estimated cost (million \$)</b>	<b>Total expected man-hours (thousand man-hours)</b>	<b>Maximum number of employees on jobsite (person)</b>	<b>Labor status</b>	<b>Delivery system</b>	<b>Total Recordable Incident Rate(TR IR)</b>	<b>ORRM score</b>
1	Light industrial	12.00	75.00	110	Union	GC* (self-performing)	0.00	17.83
2	Light industrial	12.00	75.00	110	Union	GC (self-performing)	0.00	18.77
3	Light industrial	11.00	75.00	100	Union	CM** Agency	0.00	18.90
4	Heavy industrial	59.00	150.00	50	Mixed	GC (not self-performing)	1.00	17.94
5	Library	1.65	8.00	15	Nonunion	GC (not self-performing)	0.00	7.58
6	Commercial	10.00	40.00	40	Union	CM at Risk	0.00	13.78
7	Nuclear power plant	7.00	2.00	30	Union	CM at Risk	0.00	12.66
8	Fossil power plant	10.00	110.00	175	Union	GC (self-performing)	0.00	17.72
9	Nuclear	24.00	460.00	700	Union	IPD***	0.43	16.49

	power plant							
10	Light industrial	55.00	250.00	250	Nonunion	Design-Build	0.00	16.70
11	Commercial	15.00	150.00	75	Mixed	CM at Risk	0.00	10.80
12	Light industrial	90.00	1,000.00	500	Union	GC (self-performing)	0.62	17.35
13	Light industrial	32.00	65.00	80	Mixed	CM Agency	0.00	17.31
14	Commercial	160.00	600.00	225	Mixed	CM at Risk	6.69	10.24
15	Dormitory	30.50	44.00	150	Mixed	CM at Risk	10.36	7.76
16	Light industrial	20.00	220.00	100	Union	CM Agency	0.62	17.02
17	Infrastructure	1.70	9.00	25	Nonunion	GC (self-performing)	0.00	11.59
18	Fossil power plant	42.00	500.00	50	Union	CM Agency	1.13	15.46
19	Light industrial	65.00	258.00	185	Mixed	IPD	8.80	18.40
20	Commercial	160.00	600.00	110	Mixed	GC (not self-performing)	6.69	4.42
	Tota	817.8	4,692.00	3,080				

	1	5						
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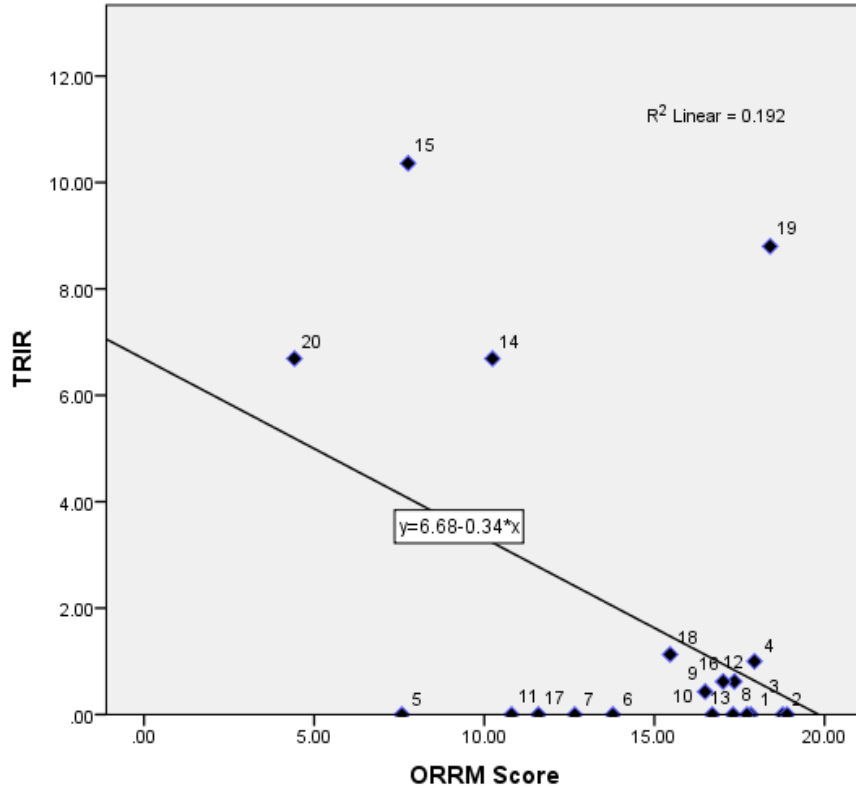
\* *GC stands for General Contracting;*

\*\* *CM stands for Construction Management; and*

\*\*\* *IPD stands for Integrated Project Delivery.*

#### **5.4.2 Linear Regression with All Responses**

The method to test the ORRM model is to run a linear regression between the TRIRs and ORRM scores of sample projects. Dataset of the TRIR and ORRM scores are listed in the Table 5.1. The linear regression between them is performed with IBM SPSS Statistics 24, a professional statistical software. The scatter plot with trend line can be seen in the Figure 5.1. To detect project-associated point, number of project is labelled on each point.



**Figure 5.1 Correlation between TRIR and ORRM Scores for All Sample Projects**

Two outputs of the regression analysis would be used to validate the effectiveness of the ORRM. The first output is the slope, which can decide on the direction of trend line. The fundamental theory behind the rating model would be considered as correct if the TRIR declined as ORRM score rose (i.e., a negative slope). Per Figure 5.1, the slope is -0.34. It can be interpreted that if owners engaged themselves in safety work more proactively, the project safety performance would get improved. This result could corroborate the assumed direction of relationship between the owner’s involvement and safety performance.

The second output is the correlation factor of  $R^2$ , which can measure the accuracy of the rating model. The  $R^2$  can be defined as the percentage of the dependent variable variation

that is explained by a linear regression model. The  $R^2$  ranges from 0 to 1. The closer to 1 the value of  $R^2$  is, the more accurately the rating model predicts safety performance. Per Figure 5.1, the  $R^2$  is 0.192, which is very low and indicates a weak linear correlation. This result means the ORRM score cannot accurately predict the TRIR values for the projects.

### **5.4.3 Cause Analysis**

The low value of  $R^2$  indicates the poor ability of the ORRM scores to predict TRIR values for the projects. After a close examination of Figure 5.1, it is found that outlier and projects with TRIR of 0 cause the low correlation.

The point numbered 19 represents a project with ORRM score of 18.40 and TRIR of 8.80. ORRM score of 18.40 is very close to the maximum possible score of 19.59. Based on this score, it can be concluded that the owner excellently performed the safety function. However, the TRIR value was as high as 8.80, which indicates a poor safety performance on the jobsite. The two measurements contradict with each other. From the distribution of points on the scatterplot, this project deviates largely from the normal group of points. The point numbered 19 is an evident outlier. The reason could be the uniqueness of its project type. It is a pharmacracy factory and prone to safety incident with severe consequence. This project is still under construction, the completion percentage of which is 55%. As the calculation of TRIR did not incorporate all workers on the jobsite, TRIR may be skewed with an underestimated number of workers on the jobsite. Therefore, it is well-justified to exclude project No. 19 from the regression analysis.

After further investigation into projects with TRIR of 0, project size is ascertained to be one plausible reason. As mentioned above, projects with smaller size are relatively less risky than ones with bigger size. For projects of the same type, the size determines the difficulty of safety management. In general terms, smaller project size suggests better constructability, easier safety communication, and less employees on the jobsite. All factors are positive to reduce the incident rate. It is very probable for the contractor to handle alone the safety issues well. In this case, the owner's involvement in safety would have a very minimal and much less detectable effect on safety improvement.

#### **5.4.4 Comparative Analysis on Project Size**

Cause analysis suggests that sample projects with smaller size are responsible for the part reason for the low  $R^2$  of 0.192. One hypothesis is proposed that if the project size is under certain level, smaller projects could become confusing factors due to minimal effect of the owner's involvement. To test this hypothesis, a comparative analysis on the project size is conducted between projects with TRIR of 0 and ones with TRIR higher than 0. If the difference in project size is significant, the hypothesis would be considered as true. Otherwise, it would be false.

To conduct this analysis, the indicators of project size should be ready to measure.

Estimated cost, total expected man-hours, and maximum number of employees on the jobsite are selected to measure project size. They are respectively measured in the units of million US dollars, thousand man-hours, and person. Estimated cost and total expected man-hours can serve as the indicators of project size, since they are the measurement of inputs to build the project. Construction is only the process to translate inputs into the outputs of completed project. Therefore, the measurement of inputs is an accurate way to



estimate the project size. However, maximum number of employees on the jobsite cannot provide an overall assessment on the workload of construction. It merely measures a project characteristic of a short period, which can provide a special perspective on project size but not accurately reflect the whole picture. Finally, it is selected as an ancillary indicator.

Independent samples t test is applied to sample projects listed in Table 5.1. TRIR is the grouping variable, indicators of project size are the test variables. The test will be performed to each indicator individually. Boxplots are also built to provide a graphic view on difference in project size.

#### 5.4.4.1 Estimated Cost

The first comparative analysis is performed with test variable of estimated cost. TRIR is the grouping variable, sample projects are divided into two groups: projects with TRIR of 0 and projects with TRIR above 0. Boxplot is also provided to illustrate difference in project size graphically. The statistical results can be seen below.

**Table 5.2 Group Statistics of Estimated Cost**

	<b>TRIR</b>	<b>N</b>	<b>Mean</b>	<b>Std. Deviation</b>	<b>Std. Error Mean</b>
<b>Estimated cost</b>	>.00	9	72.2778	54.38239	18.12746
	.00	11	15.2136	15.46483	4.66282

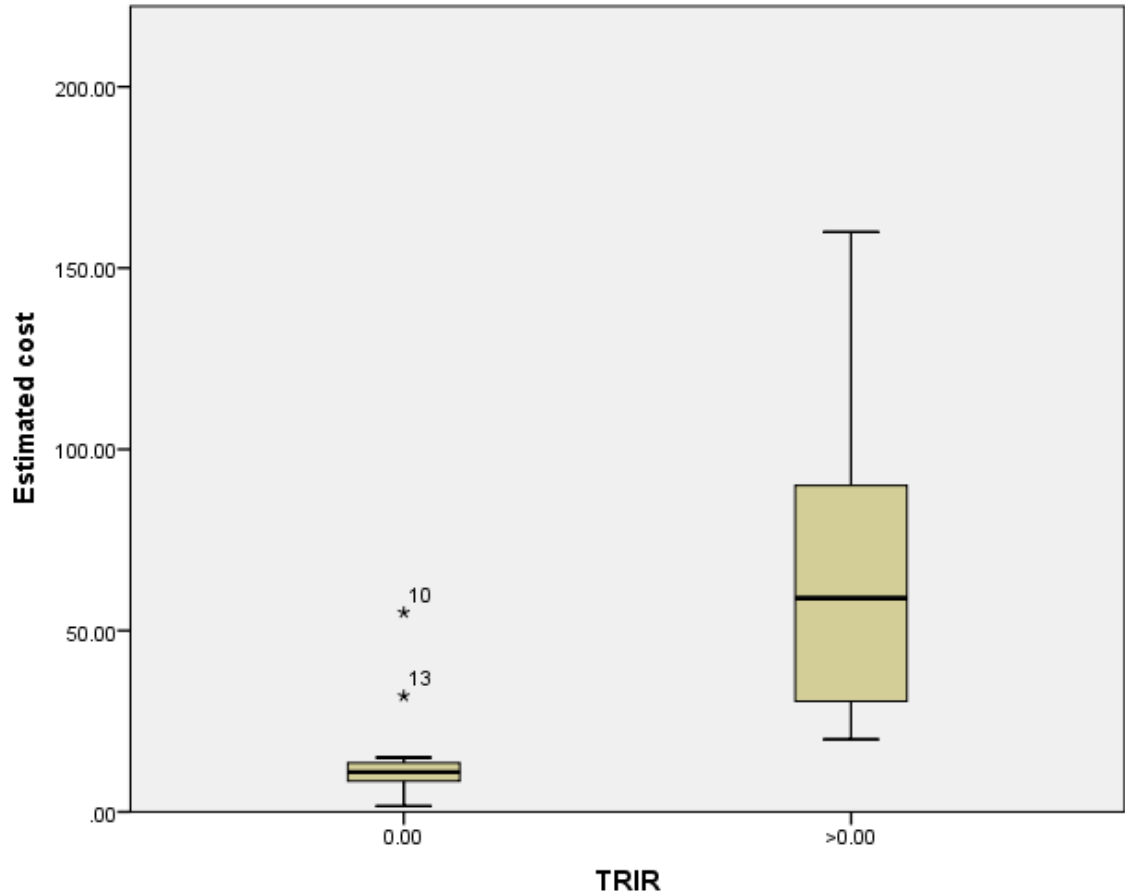
From Table 5.2, the most important outputs for the comparison are in the column of mean. The average of estimated cost of projects with TRIR above 0 is 72.28 million

dollars, and projects with TRIR of 0 only have an average cost of 15.21 million dollars. The former is 4.75 times of latter, which indicates the difference in size is considerable.

**Table 5.3 Independent Samples Test of Estimated Cost**

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Estimated cost	Equal variances assumed	11.432	.003	3.337	18	.004	57.06414	17.09916	21.14014	92.98814
	Equal variances not assumed			3.049	9.062	.014	57.06414	18.71755	14.76615	99.36213

From Table 5.3, the p-value (Sig. (2-tailed)) of 0.004 is less than 0.05, which indicates, in statistical terms, the difference in project size between the two groups of projects are significant.



**Figure 5.2 Boxplot of Estimated Cost**

From Figure 5.2, it is very evident that majority of projects with TRIR above 0 have a bigger project size than ones with TRIR of 0. Therefore, results of comparative analysis all prove the hypothesis to be true.

#### **5.4.4.2 Total Expected Man-hours**

The second comparative analysis is performed with test variable of total expected man-hours. TRIR is the grouping variable, sample projects are divided into two groups: projects with TRIR of 0 and projects with TRIR above 0. Boxplot is also provided to illustrate difference in project size graphically. The statistical results can be seen below.

**Table 5.4 Group Statistics of Total Expected Man-hours**

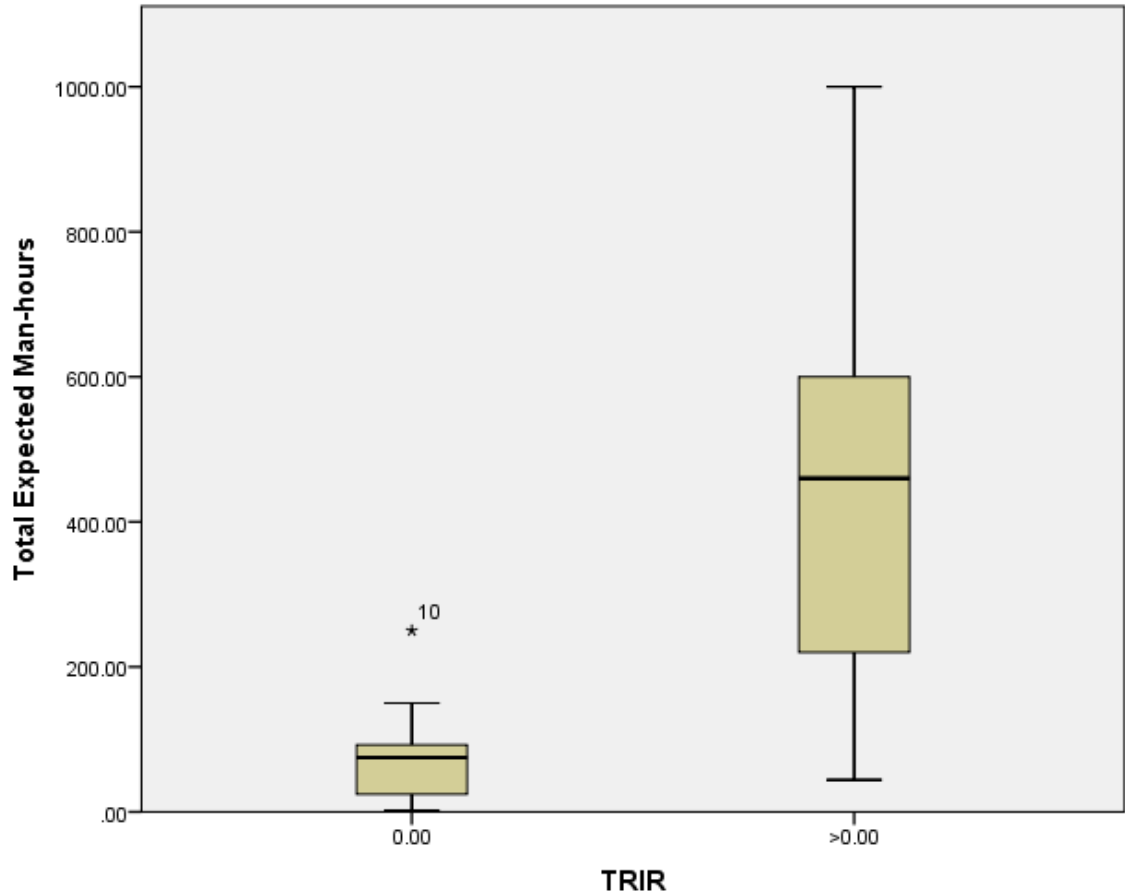
	<b>TRIR</b>	<b>N</b>	<b>Mean</b>	<b>Std. Deviation</b>	<b>Std. Error Mean</b>
<b>Total Expected Man-hours</b>	>.00	9	425.7778	293.55995	97.85332
	.00	11	78.0909	72.71101	21.92319

From Table 5.4, the most important outputs for the comparison are in the column of mean. The average of total expected man-hours of projects with TRIR above 0 is 425.78 thousand man-hours, and projects with TRIR of 0 only have an average of 78.09 thousand man-hours. The former is 5.45 times of latter, which indicates the difference in size is considerable.

**Table 5.5 Independent Samples Test of Total Expected Man-hours**

		<b>Levene's Test for Equality of Variances</b>		<b>t-test for Equality of Means</b>						
		<b>F</b>	<b>Sig.</b>	<b>t</b>	<b>df</b>	<b>Sig. (2-tailed)</b>	<b>Mean Difference</b>	<b>Std. Error Difference</b>	<b>95% Confidence Interval of the Difference</b>	
									<b>Lower</b>	<b>Upper</b>
<b>Total Expected Man-hours</b>	<b>Equal variances assumed</b>	11.792	.003	3.809	18	.001	347.68687	91.27409	155.92712	539.44661
	<b>Equal variances not assumed</b>			3.467	8.806	.007	347.68687	100.27910	120.07375	575.29998

From Table 5.5, the p-value (Sig. (2-tailed)) of 0.001 is less than 0.05, which indicates, in statistical terms, the difference in project size between the two groups of projects are significant.



**Figure 5.3 Boxplot of Total Expected Man-hours**

From Figure 5.3, it is very evident that majority of projects with TRIR above 0 have a bigger project size than ones with TRIR of 0. Therefore, results of comparative analysis all prove the hypothesis to be true.

#### **5.4.4.3 Maximum Number of Employees on Jobsite**

The second comparative analysis is performed with test variable of maximum number of employees on the jobsite. TRIR is the grouping variable, sample projects are divided into two groups: projects with TRIR of 0 and projects with TRIR above 0. Boxplot is also provided to illustrate difference in project size graphically. The statistical results can be seen below.

**Table 5.6 Group Statistics of Maximum Number of Employees on Jobsite**

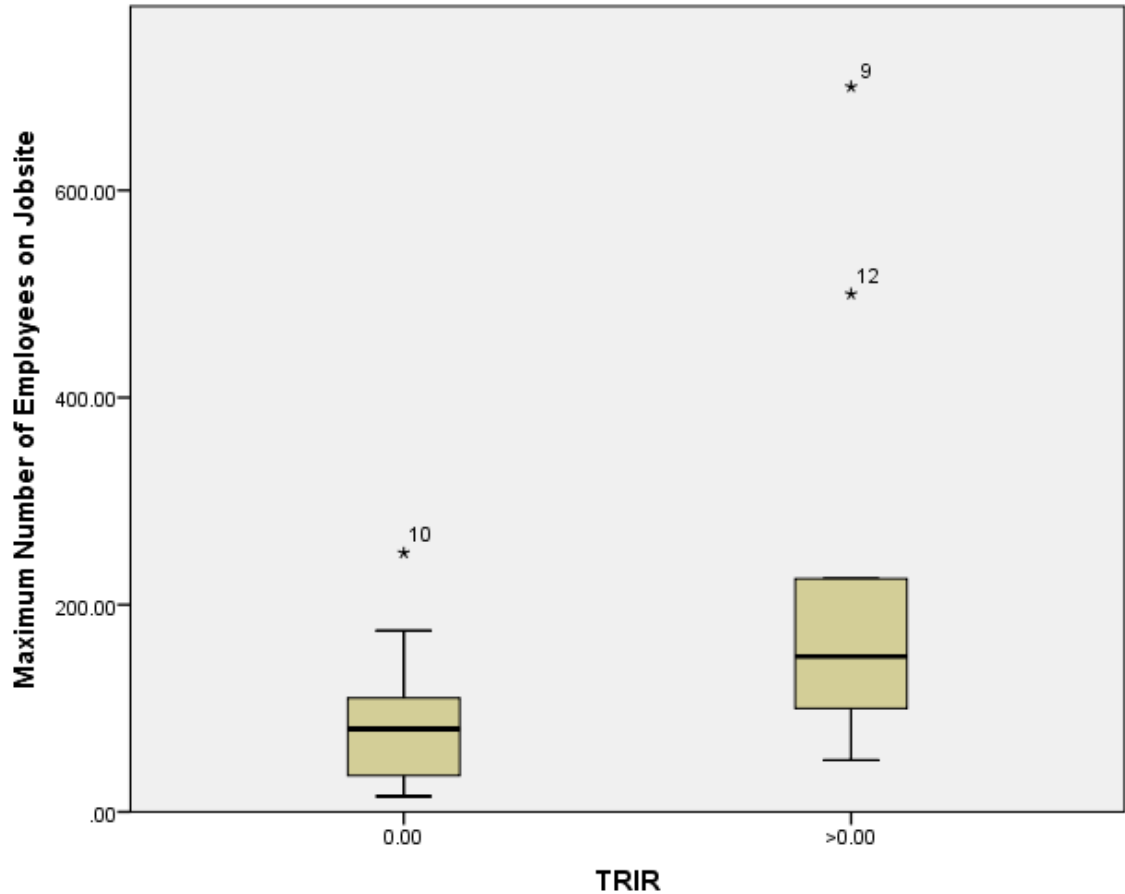
	<b>TRIR</b>	<b>N</b>	<b>Mean</b>	<b>Std. Deviation</b>	<b>Std. Error Mean</b>
<b>Maximum Number of Employees on Jobsite</b>	>.00	9	230.0000	223.14513	74.38171
	.00	11	91.8182	70.68496	21.31232

From Table 5.6, the most important outputs for the comparison are in the column of mean. The average of maximum number of employees on jobsite of projects with TRIR above 0 is 230 persons, and projects with TRIR of 0 only have an average of almost 92 persons. The former is 2.5 times of latter, which indicates the difference in size is considerable.

**Table 5.7 Independent Samples Test of Maximum Number of Employees on Jobsite**

		<b>Levene's Test for Equality of Variances</b>		<b>t-test for Equality of Means</b>						
		<b>F</b>	<b>Sig.</b>	<b>t</b>	<b>df</b>	<b>Sig. (2-tailed)</b>	<b>Mean Difference</b>	<b>Std. Error Difference</b>	<b>95% Confidence Interval of the Difference</b>	
									<b>Lower</b>	<b>Upper</b>
<b>Maximum Number of Employees on Jobsite</b>	<b>Equal variances assumed</b>	6.432	.021	1.948	18	.067	138.18182	70.93362	-10.84419	287.20782
	<b>Equal variances not assumed</b>			1.786	9.317	.107	138.18182	77.37476	-35.94779	312.31143

From Table 5.7, the p-value (Sig. (2-tailed)) of 0.067 is higher than 0.05, which indicates, in statistical terms, the difference in project size between the two groups of projects are insignificant.



**Figure 5.4 Boxplot of Maximum Number of Employees on Jobsite**

From Figure 5.4, it is very evident that majority of projects with TRIR above 0 have a bigger project size than ones with TRIR of 0. All results prove the hypothesis to be true, except the p-value of t-test.

#### **5.4.4.4 Results of Comparative Analysis**

Results of comparative analysis on estimated cost and total expected man-hours all prove the hypothesis to be true. That means project size constitutes a confusing factor into the correlation analysis. However, the analysis result of maximum number of employees on the jobsite does not fully support this argument, because the p-value of its t-test higher

than 0.05 indicates the difference is insignificant. Given the accuracy of these 3 indicators to measure project size, the maximum number of employees on the jobsite only reflects a safety situation of a short period and hardly provides the whole picture. Therefore, its result is only regarded as a compromised reference. The conclusion can be reached that if the project size is under certain level, smaller projects could become confusing factors due to minimal effect of the owner's involvement. Based on this conclusion, projects with TRIR of 0 should be removed from the regression analysis.

#### **5.4.5 Cut-off Value for Project Size**

Comparative analysis proves the fact that the project size indeed affects the measurement of the owner's role in safety. If the project size is under certain level, smaller projects could become confusing factors due to minimal effect of the owner's involvement. Therefore, the ORRM is not applicable for small projects. Per results of comparative analysis, the vague wording of "under certain level" can be refined to be an explicit cut-off value. Users of the ORRM can reference this cut-off value to judge the suitability of project for rating.

The method to ascertain the cut-off value is based on the project size means of different project groups. As groups are divided in terms of the TRIR, the mean of one group can provide a reliable value of project size to predict that of the TRIR. For group of projects with TRIR of 0, its mean can serve as a reference for the down-limit for cut-off value zone. It is because projects under this size are very likely to have a TRIR of 0. In the same manner, the mean of group of projects with TRIR higher than 0 can serve as a reference for the up-limit for cut-off value zone. The cut-off value is obtained by averaging these two means. One noteworthy point is that the indicators of project size



include estimated cost, total expected man-hours, and maximum number of employees on the jobsite. Therefore, there will be three cut-off values available for model users' judgements. As these three indicators respectively measure different aspects of project size, they can assist the ORRM users in a synergistic way. All cut-off values can be seen the Table 5.8. Values in the column of means are from Table 5.2, Table 5.4, and Table 5.6.

**Table 5.8 Cut-off Values for Project Size**

Indicators of Project Size	Means		Cut-off Values
	TRIR=0	TRIR>0	
Estimated cost (million dollars)	15.21	72.28	43.75
Total expected man-hours (thousand man-hours)	78.09	425.78	251.94
Maximum number of employees on the jobsite (person)	91.82	230.00	160.91

Given the accuracy of indicators, users should place a heavier emphasis on cut-off values of estimated cost and total expected man-hours. Maximum number of employees on the jobsite can be regarded as a reference with secondary importance. The ORRM users can directly compare the size of project for rating with cut-off values. If the project is higher than cut-off value, it is suitable for the ORRM. If the project is lower than cut-off value, it means the determinant factor for the project safety should be the contractor's safety expertise and experience.

One inevitable case for the comparison method is the contradicting results of different indicators. For example, in terms of estimated cost, the project is big enough for the

ORRM. However, in terms of another indicator, it is not sizable for rating. Per boxplots of Figure 5.2 and 5.3, estimated cost and total expected man-hours have a very high level of consistency. The likelihood for them to contradict each other is minimal. If maximum number of employees on the jobsite contradicts the other two, it should be excluded from the decision-making process due to its secondary importance. Therefore, the comparison is an effective and easy-to-use method to decide on suitability of projects to rate.

## **5.5 Data Analysis**

The main purpose of this empirical validation is to test the effectiveness of the ORRM through linear regression analysis. Though the original regression with all sample projects yields a negative slope of -0.34 that supports assumption of the model, the very low  $R^2$  of 0.192 still cannot corroborate the presumed association of ORRM score and the TRIR. After a close study on causes, two confusing factors of outlier and projects with TRIR of 0 are identified and verified. To reduce or eliminate the confusing effect, linear regression analysis will be applied to multiple different samples to test the model's effectiveness. The difference in sample depends on which confusing factors are excluded from the regression analysis.

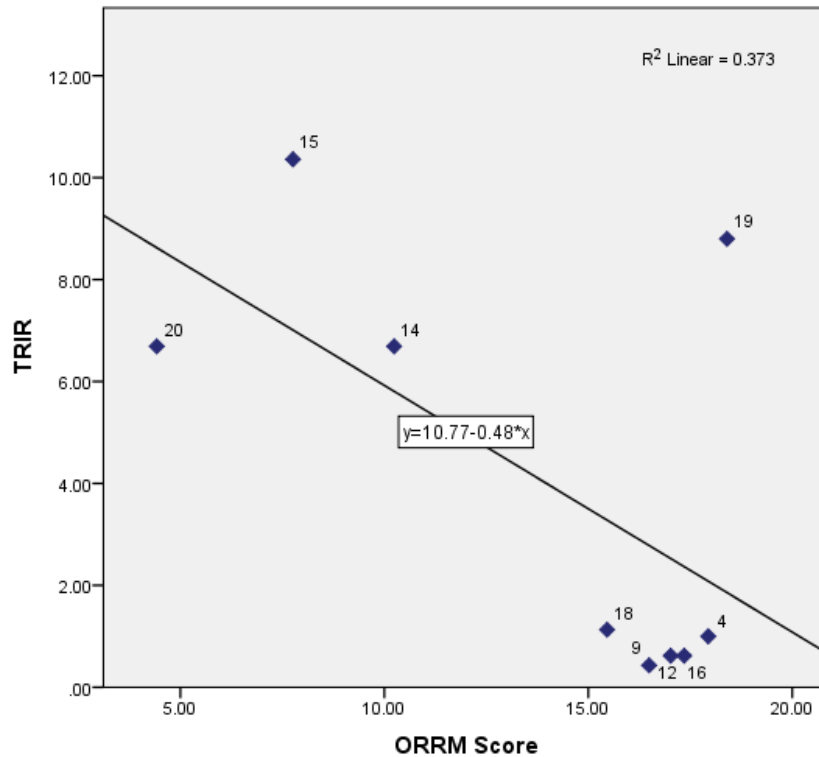
### **5.5.1 Analysis on Sample of Projects with TRIR above 0**

Based on Table 5.1, demographics of projects with TRIR higher than 0 are developed and listed in Table 5.9.

**Table 5.9 Demographics of Projects with TRIR above 0**

Project number	Total Recordable Incident Rate(TRIR)	ORRM score
4	1.00	17.94
9	0.43	16.49
12	0.62	17.35
14	6.69	10.24
15	10.36	7.76
16	0.62	17.02
18	1.13	15.46
19	8.80	18.40
20	6.69	4.42

Total 9 projects are selected for the linear regression analysis. The result of regression analysis is presented in Figure 5.5.



**Figure 5.5 Correlation between TRIR and ORRM Scores for Projects with TRIR above 0**

Two outputs of the regression analysis would be used to validate the effectiveness of the ORRM. The first output is the slope, which can decide on the direction of trend line. The fundamental theory behind the rating model would be considered as correct if the TRIR declined as ORRM score rose (i.e., a negative slope). Per Figure 5.5, the slope is -0.48. It can be interpreted that if owners engaged themselves in safety work more proactively, the project safety performance would get improved. This result could corroborate the assumed direction of relationship between the owner's involvement and safety performance.

The second output is the correlation factor of  $R^2$ , which can measure the accuracy of the rating model. The  $R^2$  can be defined as the percentage of the dependent variable variation that is explained by a linear regression model. The  $R^2$  ranges from 0 to 1. The closer to 1 the value of  $R^2$  is, the more accurately the rating model predicts safety performance. Per Figure 5.5, the  $R^2$  is 0.373, which is still low, but not bad for a model based on behaviors and culture. Although projects with TRIR of 0 are excluded, the presence of outlier of project No.19 still cause a considerable confusing effect. However, the  $R^2$  of 0.373 can already be considered as a support for the effectiveness of the model.

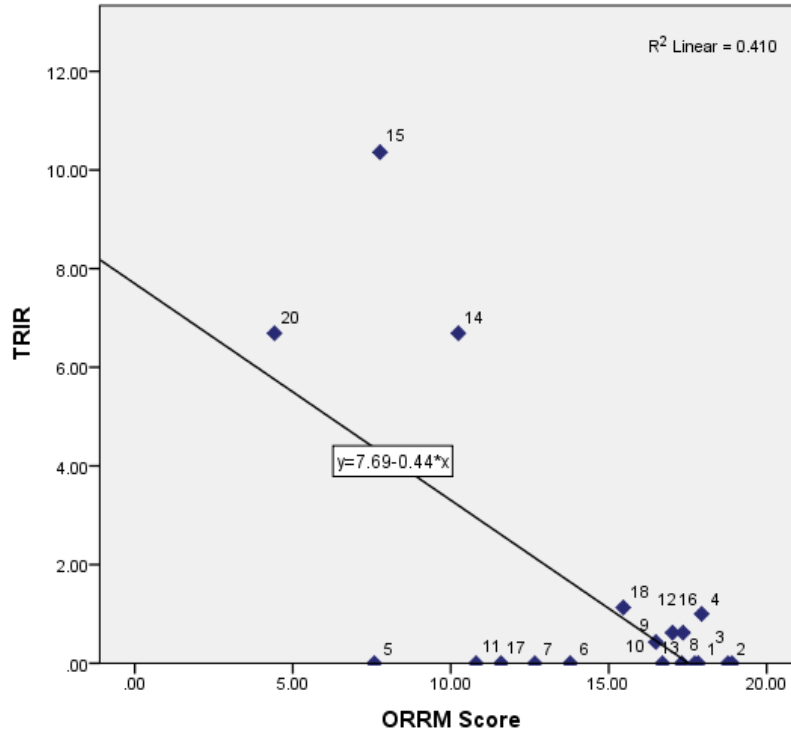
### **5.5.2 Analysis on Sample without Project of Outlier**

Based on Table 5.1, demographics of sample projects without outlier are developed and listed in Table 5.10.

**Table 5.10 Demographics of Projects without Outlier**

<b>Project number</b>	<b>Total Recordable Incident Rate(TRIR)</b>	<b>ORRM score</b>
1	0.00	17.83
2	0.00	18.77
3	0.00	18.90
4	1.00	17.94
5	0.00	7.58
6	0.00	13.78
7	0.00	12.66
8	0.00	17.72
9	0.43	16.49
10	0.00	16.70
11	0.00	10.80
12	0.62	17.35
13	0.00	17.31
14	6.69	10.24
15	10.36	7.76
16	0.62	17.02
17	0.00	11.59
18	1.13	15.46
20	6.69	4.42

Total 19 projects are selected for the linear regression analysis. The result of regression analysis is presented in Figure 5.6.



**Figure 5.6 Correlation between TRIR and ORRM Scores for Sample without Outlier**

Two outputs of the regression analysis would be used to validate the effectiveness of the ORRM. The first output is the slope, which can decide on the direction of trend line. The fundamental theory behind the rating model would be considered as correct if the TRIR declined as ORRM score rose (i.e., a negative slope). Per Figure 5.6, the slope is -0.44. It can be interpreted that if owners engaged themselves in safety work more proactively, the project safety performance would get improved. This result could corroborate the assumed direction of relationship between the owner’s involvement and safety performance.

The second output is the correlation factor of  $R^2$ , which can measure the accuracy of the rating model. The  $R^2$  can be defined as the percentage of the dependent variable variation that is explained by a linear regression model. The  $R^2$  ranges from 0 to 1. The closer to 1

the value of  $R^2$  is, the more accurately the rating model predicts safety performance. Per Figure 5.6, the  $R^2$  is 0.410, which indicates a quite strong correlation. It is even higher than that of projects with TRIR above 0. It can provide a perspective on levels of confusing effect of outlier and projects with TRIR of 0. The former can obscure the true result more strongly than latter. However, the  $R^2$  of 0.410 can already be considered as a support for the effectiveness of the model.

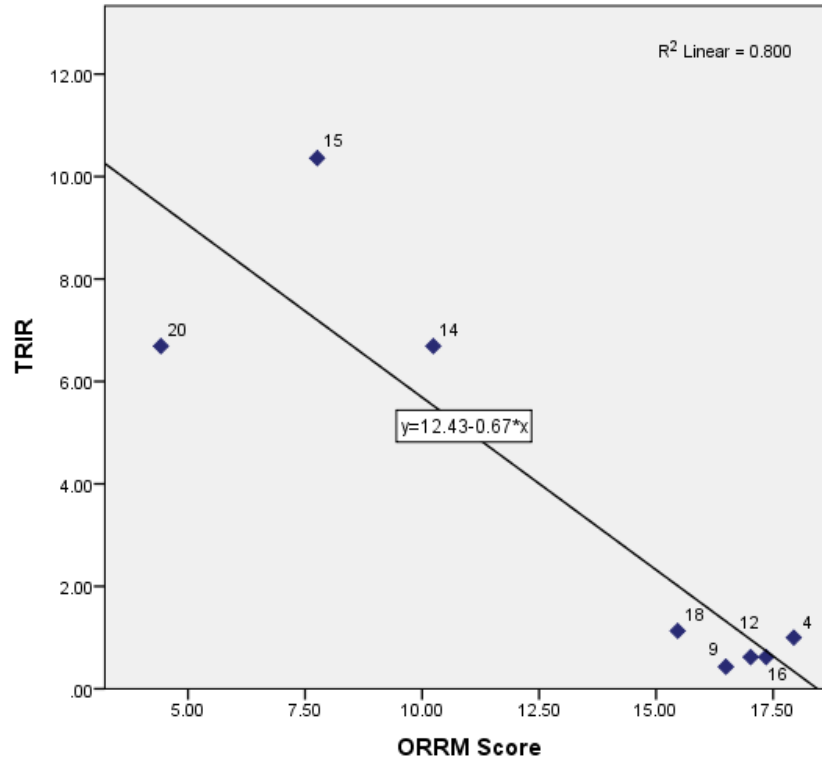
### 5.5.3 Analysis on Sample without Outlier and Projects with TRIR of 0

Based on Table 5.1, demographics of sample projects without outlier and projects with TRIR of 0 are developed and listed in Table 5.11.

**Table 5.11 Demographics of Projects without Outlier and Projects with TRIR of 0**

<b>Project number</b>	<b>Total Recordable Incident Rate(TRIR)</b>	<b>ORRM score</b>
4	1.00	17.94
9	0.43	16.49
12	0.62	17.35
14	6.69	10.24
15	10.36	7.76
16	0.62	17.02
18	1.13	15.46
20	6.69	4.42

Total 8 projects are selected for the linear regression analysis. The result of regression analysis is presented in Figure 5.7.



**Figure 5.7 Correlation between TRIR and ORRM Scores for Sample without Outlier and Projects with TRIR of 0**

Two outputs of the regression analysis would be used to validate the effectiveness of the ORRM. The first output is the slope, which can decide on the direction of trend line. The fundamental theory behind the rating model would be considered as correct if the TRIR declined as ORRM score rose (i.e., a negative slope). Per Figure 5.7, the slope is -0.67. It can be interpreted that if owners engaged themselves in safety work more proactively, the project safety performance would get improved. This result could corroborate the assumed direction of relationship between the owner's involvement and safety performance.

The second output is the correlation factor of  $R^2$ , which can measure the accuracy of the rating model. The  $R^2$  can be defined as the percentage of the dependent variable variation



that is explained by a linear regression model. The  $R^2$  ranges from 0 to 1. The closer to 1 the value of  $R^2$  is, the more accurately the rating model predicts safety performance. Per Figure 5.7, the  $R^2$  is 0.800, which indicates a very strong correlation. The  $R^2$  of 0.800 can be considered as an excellent support for the effectiveness of the model. Given the fact that the  $R^2$  of 0.800 is much higher than that of the two previous correlations, the confusing effects of project size and outlier are so significant that applicability of the ORRM must be closely studied in advance. Cut-off values for project size will play a key role in the execution of the ORRM.

## **5.6 Additional Data Analysis**

Project demographics includes additional information of labor status and project delivery system. Labor status categorizes the construction workers into three types: union workers, nonunion workers, and mixed workers. Project delivery system includes General Contracting(GC), Construction Management(CM), Integrated Project Delivery(IPD), and Design-Build(DB). GC is specified as self-performing GC and not self-performing one. CM is also detailed on whether it is at-risk type or agency type. Labor status and project delivery system are both assumed as potential factors for the level of the owner's involvement in safety worker, but major part of how it works is still a puzzle. Research effort is conducted to investigate the causation through data collected. ORRM is already proven to be a reliable assessment tool for the owner's influence on safety. Therefore, ORRM score of each project is utilized to reflect the level of the owner's involvement in safety.

### **5.6.1 Effects of Labor Status on the Owner's Role in Safety**

Project information on labor status and ORRM score are summarized in Table 5.12.

**Table 5.12 Labor Status and ORRM Score**

<b>Project number</b>	<b>Labor status</b>	<b>ORRM score</b>	<b>Average score</b>
4	Mixed	17.94	12.41
11	Mixed	10.80	
13	Mixed	17.31	
14	Mixed	10.24	
15	Mixed	7.76	
19	Mixed	18.4	
20	Mixed	4.42	
5	Nonunion	7.58	11.96
10	Nonunion	16.70	
17	Nonunion	11.59	
1	Union	17.83	16.60
2	Union	18.77	
3	Union	18.90	
6	Union	13.78	
7	Union	12.66	
8	Union	17.72	
9	Union	16.49	
12	Union	17.35	
16	Union	17.02	
18	Union	15.46	

Union is the organization to represent the employees to deal with employer. Its main purpose is to defend the interests of the employees. Recently, many criticisms of union’s role in protecting workers are building up. However, per Table 5.12, unions indeed encourage owners to do more about the safety improvement. For projects with union labors, the average ORRM score is 16.60. It is quite high score when weighing against maximum possible score of 19.59. Even so, it alone cannot explain anything about the impact of labor status. The level of the owner’s involvement on projects with nonunion labors should also be considered for comparison. The average ORRM score is 11.96, which is much lower than that of union labor projects. It can be interpreted that union

could increase the involvement of the owner in safety issues, which in turn improves the safety performance. To analyze it further, independent samples t test is applied to compare the ORRM score means of two project groups. Grouping variable is labor status, test variable is the ORRM score. Statistical results can be seen below.

**Table 5.13 Independent Samples Test of ORRM Score (Grouping with Labor Status)**

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
ORRM Score	Equal variances assumed	2.530	.140	-2.613	11	.024	-4.64133	1.77616	-8.55063	-.73204
	Equal variances not assumed			-1.707	2.250	.216	-4.64133	2.71851	-15.17703	5.89436

From Table 5.13, the p-value (Sig. (2-tailed)) of 0.024 is less than 0.05, which indicates, in statistical terms, the difference in average ORRM score between the two groups of projects is significant.

The data on mixed labor status might also support this conclusion in another manner. The average ORRM score is 12.41, which is close to that of projects with nonunion labor.

However, the deviation of them is significant. The lowest is 4.42, the highest is 18.4. The polarization among these ORRM scores may be explained with various percentages of union labor. For projects with higher ORRM score, they may have a higher percentage of

union labor; and vice versa. Because details on composition of mixed labor are not collected, it can only serve as a plausible explanation rather than a conclusion.

### 5.6.2 Effects of Delivery System on the Owner’s Role in Safety

Project information on delivery system and ORRM score are summarized in Table 5.14.

**Table 5.14 Delivery System and ORRM Score**

<b>Project number</b>	<b>Delivery system</b>	<b>ORRM score</b>	<b>Average score</b>
6	CM at Risk	13.78	11.05
7	CM at Risk	12.66	
11	CM at Risk	10.80	
14	CM at Risk	10.24	
15	CM at Risk	7.76	
3	CM Agency	18.90	17.17
13	CM Agency	17.31	
16	CM Agency	17.02	
18	CM Agency	15.46	
10	Design-Build	16.70	16.70
4	GC (not self-performing)	17.94	9.98
5	GC (not self-performing)	7.58	
20	GC (not self-performing)	4.42	
1	GC (self-performing)	17.83	16.65
2	GC (self-performing)	18.77	
8	GC (self-performing)	17.72	
12	GC (self-performing)	17.35	
17	GC (self-performing)	11.59	
9	IPD	16.49	17.45
19	IPD	18.40	

Delivery system has a significant impact on the owner’s involvement in safety, because it is defined with construction contract. One widely-accepted fact is that construction contract is the ruling authority on the jobsite, which determines the obligations and rights

of stakeholder on the project. Of course, the obligation and right for safety work are also included. In other words, the delivery system has already specified the zone of safety work where the owner can maneuver. The owner has the initiative to decide the contract type. In other way around, the selection of construction contract, to some extent, also reflects the degree of the owner's willingness to participate the safety work.

Per table 5.14, projects with CM Agency, Design Build, GC (self-perform), and IPD all have ORRM score of about 17. Compared to the top value of 19.59, it indicates a high level of the owner's involvement in safety. GC (no self-perform) and CM at Risk both have much lower scores. The analysis focus is placed on the CM and GC, because they both have two sub-types. The sub-types share many similarities, but also exhibit conspicuously different features. The comparative analysis between sub-types can reveal more elements of causation of the owner's involvement. Design-Build and IPD are combined for analysis. That is because they have many similar features, and sample sizes are too small to be representative. Despite the combination, the analysis result of them still should be considered as constructive exploration rather than conclusion due to the small sample size.

#### **5.6.2.1 CM at risk and CM agency**

CM at risk and CM agency have a significant difference in the contracting scope of the CM (Evans et al, 2016). Under the CM at risk model, the owner has a single prime contract with the CM, and the CM holds all of subcontractors. CM can directly deal with the subcontractors on cost, schedule, and safety. However, under the CM agency model, CM only has a contract with the owner. Its work is very similar to that of an owner's representative with professional expertise. CM cannot conduct any construction work and

enforce any work with subcontractor. All obligations and rights stipulated in the construction contract must be undertaken by the owner. One noteworthy point is that the contracting restriction is mainly imposed on the CM rather than the owner. Owners can decide when and how they could participate in the project activities. Per Table 5.14, average ORRM score of projects with CM at risk is 11.05, and that of projects with CM agency is 17.17. Latter is much higher than the former, which indicates owners selecting CM agency engage themselves in safety work more actively. For further analysis, independent samples t-test is applied to the ORRM scores of projects of CM at risk and ones of CM agency. Statistical results can be seen below.

**Table 5.15 Independent Samples Test of ORRM Score (Grouping with CMs)**

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
ORRM Score	Equal variances assumed	1.124	.324	-4.602	7	.002	-6.12450	1.33074	-9.27119	-2.97781
	Equal variances not assumed			-4.879	6.650	.002	-6.12450	1.25538	-9.12493	-3.12407

From Table 5.15, the p-value (Sig. (2-tailed)) of 0.002 is less than 0.05, which indicates, in statistical terms, the difference in average ORRM score between the two groups of projects are significant. The involvement of the owner under the CM agency model in

safety is significantly deeper than that under CM at risk model. The reason is the difference in contractual arrangement. CM agency model makes the CM become a professional consultant instead of construction manager. Contractual relationship with subcontractors allows the owner's proactive and deep involvement in safety issues. On the contrary, CM at risk model makes the CM become the actual manager of the whole project. Contracting with all subcontractors allows the CM to directly manage all safety-related issues, major part of which should be undertaken by the owner under CM agency model.

Although the purpose of this analysis is to explore the impact of delivery system on the owner's involvement in safety, causation between them should be viewed in the opposite direction. Owners take the initiative to decide on the delivery system, and, of course, have the initiative to decide on the level of their involvement in safety work. The discretion underpinning the decision includes their trust on the contractor's safety capability and willingness to participate. If they recognize the contractor's competency, the willingness to participate in safety work would be reduced; and vice versa. From the statistical result, the conclusion can be drawn that the owner's behavior is consistent with delivery system. Because there is no restriction on the owner's involvement in safety under both CMs, the owner has the freedom to participate in. Therefore, the consistency maybe indicates that the selected delivery system is appropriate for the owner's assumption.

#### **5.6.2.2 GC (not self-performing) and GC (self-performing)**

The criterion to differentiate the two sub-types of GC is whether the general contractor undertakes the construction work or not. One professional opinion is that general

contractors self-performing can bring more risks to owners than ones not self-performing (Schoenecker, 2014). The status as a builder is of the essence for general contractor self-performing. Constructing the project is the top important task, and also is the main source of profits. It is hard for them to shift the focus from construction to subcontractor management. Unless the delay of subcontractors negatively affects its own construction work. Therefore, compared to general contractors self-performing, not self-performing ones only play a role as the owner's representative and professional consultant. General contractors not self-performing can concentrate the focus on the management of subcontractors, majority of which would be the work of the owner if general contractor is not hired. Per Table 5.14, average ORRM score of projects with GC (self-performing) is 16.65, and that of projects with GC (not self-performing) is 9.98. Former is much higher than the latter, which indicates owners selecting GC (self-performing) engage themselves in safety work more actively. It supports the conclusion drawn from the professional opinion. For further analysis, independent samples t-test is applied to the ORRM scores of projects of GC (self-performing) and ones of GC (not self-performing). Statistical results can be seen below.



**Table 5.16 Independent Samples Test of ORRM Score (Grouping with GCs)**

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
ORRM Score	Equal variances assumed	4.300	.083	-1.939	6	.101	-6.67200	3.44042	-15.09040	1.74640
	Equal variances not assumed			-1.558	2.405	.239	-6.67200	4.28121	-22.41602	9.07202

From Table 5.16, the p-value (Sig. (2-tailed)) of 0.101 is higher than 0.05, which indicates, in statistical terms, the difference in average ORRM score between the two groups of projects are insignificant. Although this result contradicts with the conclusion, it can hardly change the conclusion. Firstly, considering the relatively small sample size, statistical result is very susceptible to outliers. Secondly, average ORRM score of projects with GC (self-performing) is much higher than that of projects with GC (not self-performing). Project No.4 is awarded to a general contractor not self-performing, but has a high ORRM score. The other two not self-performing projects have very low ORRM score. This deviation is the cause for the big p-value. For not self-performing general contractors work like a professional consultant and representative, the owner has a large

freedom to decide the level of the involvement in safety work. The case of Project No.4 could be explained with an owner keen to safety work. For five self-performing general contractors, their ORRM scores are consistently high. The conclusion can be drawn that the owner selecting GC (not self-performing) could lower the involvement in safety, as general contractor places focus on subcontractor management; the owner selecting GC (self-performing) could increase the involvement in safety, as general contractor places focus on construction.

### **5.6.2.3 Design-Build and IPD**

Design-Build and IPD have numerous commonalities (CMAA, 2012). That is why these two delivery systems can be combined for analysis. Under the Design-Build model, the owner only needs to contract with one party responsible for design and building, and the design-builder is also responsible for managing the details of safety-related work.

However, Design-Build model does not exclude the owner from the safety issues. The owner still retains multiple options of participating in safety work, which range from fully participatory to a purely representative approach. Under the IPD model, the owner, the designer, and the contractor collaboratively form a management team that is responsible for all project activities. All parties of the team should share the risks collectively. Such a structure forces the owner to deeply engage itself in safety management. In other words, the owner does not have such freedom as it has under Design-Build model. In this study, one Design-Build project and two IPD projects respectively have ORRM scores of 16.70, 16.49, and 18.40. All of them are quite high scores. High level of the owner's participation in IPD projects can be explained with collective risk sharing. Because the owner has choices of how to participate in safety

work on the Design-Build project, the high ORRM score can be explained with the owner's significant concern on safety.

## **5.7 Findings**

This chapter mainly introduces the process of validating the ORRM on actual projects and also includes additional relevant research.

During linear regression analysis, confusing factor of project size is identified and verified. Comparative analysis on project size demonstrates a hypothesis that if the project size is under certain level, smaller projects could become confusing factors due to minimal effect of the owner's involvement. Cut-off values on project size are also developed, which can serve as a guidance for the ORRM users to assess suitability of project for the ORRM.

After removing confusing factors, the  $R^2$  of linear regression analysis is as high as 0.800, which demonstrates the strong association between the ORRM score and safety performance. Pursuant to this result, the conclusion can be reached that the ORRM is an effective assessment tool for rating the owner's performance on safety work.

Additionally, analysis is also made on effects of labor status and delivery system on the owner's involvement in safety. Owners on projects with union labors engage themselves more intensely in safety than owners on projects with nonunion labors. Owners on project with CM agency engage themselves more intensely in safety than owners on projects with CM at risk. Owners on projects with GC (self-performing) engage themselves more intensely in safety than owners on projects with GC (not self-performing). Owners on

projects with Design-Build and IPD all have a high level of involvement in safety, but owners on projects with Design-Build have choices of involvement level.

## **6 CONCLUSIONS**

Various contributions to the body of knowledge are made in this dissertation. They are summarized and presented briefly for readers to conveniently comprehend the essence of this research. Additionally, recommendations of potential research opportunities are also presented.

### **6.1 Review of Accomplishments**

This study presented a weighted rating model for the impacts of the owner on construction safety. The scope of work for this effort includes any owner of capital construction projects. The model language produced is general enough to be applied to a wide range of projects regardless of its sector in the construction industry, as input from industrial, building, and infrastructure owners and contractors was solicited. The implications of this result involved two aspects: the weights of CTS elements and the ORRM model itself.

The weights can be used to assess the owner's impacts on construction safety on any individual jobsite. Further, highly weighted owner practices indicate an area of importance based on the feedback from the panel of experts. For practitioner clients that wish to devote more effort to project safety, those highly weighted practices desirable starting points. For other practitioner clients that may be strong in those areas, some of the lower weighted practices may help improve safety further. Certainly, for owners with little involvement in the construction of their facilities, they also could be taken for reference to identify the critical point for better performance while the owner develops its safety program/plan.

The other important finding is the ORRM model itself. The model is structured in form of CTS tree. The framework of four levels gives the users a comprehensive view on mechanism of owner's safety-related practices and procedures. Critical elements on each level present specific and executable practices. Given the common limited availability of resources, the owner practitioners on the jobsite need an easy-to-use, practical, and effective tool to quickly find out the improvement opportunities. The model meets this need by providing a systematic approach to addressing this issue.

The effectiveness of the model is validated with an empirical study of 20 projects. The linear regression analysis of all projects generates the  $R^2$  of 0.192, which indicates a low correlation between the ORRM score and safety performance. However, it is proven to be not a counterevidence to the effectiveness of the model, but an opportunity to reveal the confusing effect of project size. Comparative analysis on project size does not demonstrate the existence of confusing effect, but also develops cut-off values of project size. The linear regression analysis of cleansed project sample generates the  $R^2$  of 0.800, which strongly demonstrates the high effectiveness of the ORRM.

Additional findings are the effects of labor status and delivery system on the owner's involvement in safety. Owners on projects with union labors engage themselves more intensely in safety than owners on projects with nonunion labors. Owners on project with CM agency engage themselves more intensely in safety than owners on projects with CM at risk. Owners on projects with GC (self-performing) engage themselves more intensely in safety than owners on projects with GC (not self-performing). Owners on projects with Design-Build and IPD all have a high level of involvement in safety, but owners on projects with Design-Build have choices of involvement level.

## 6.2 Recommendations

One limitation of this work is the relatively small sample size for weighting with AHP. Although the results of the analysis show great consistency and have similar sample size to other AHP publications, limited sample size still compromises the justification of the model to represent the general situation in construction industry. But it also provides a great opportunity for further research on this subject. Expanding the sample size of weighting responses could synthesize more professional views into the final weights and generate more accurate score. The comparative analysis between the weights by this work and new ones could provide enlightening insights into the mechanism of the ORRM.

The other limitation of this work is also its advantage. As mentioned in the beginning of this dissertation, the ORRM is designed to be an assessment tool with a wide spectrum of application. The drawback of such design is the neglect of special assets of different construction projects. All projects handle site safety differently. Sacrificing the assets of certain type of projects maybe cause an inaccurate or even false evaluation result.

However, putting a long-term view on the ORRM, it could serve as a great prototype of assessment model for typical projects. The project type-specific ones could be easily developed with reasonable and necessary adaptations. The first necessary adaptation is to re-weight CTS elements, as the same CTS element must not have the same importance to projects of different types. The CTE elements could also be removed or added accordingly. Comparative analysis between different project types must generate constructive and insightful results.

## **APPENDICES**

### **Appendix A: Questionnaire of Subject Matter Expert Survey**

#### **Project Safety Performance through Operational Excellence**

##### **CII Standard Survey**

The purpose of centralizing data collection through use of CII server-based software is to establish a centralized database to support CII research, benchmarking, and other CII committees working to support CII's mission. The centralized database should provide for more secure data collection and storage, and facilitates the sharing of data among authorized teams and committees while reducing the data collection burden on CII member companies. The primary purposes of the RT317 are developing a comprehensive model of operational excellence and determining the relationship between operational excellence and safety performance. Operational Excellence is defined as “Doing the right thing, the right way, every time – even when no one is watching.” The research team has developed a draft model for operational excellence and believes strong adherence to the model can lead to improvements in safety performance. All data provided for any CII survey in support of benchmarking and research activities by participating organizations are considered " company confidential". The data have been provided by participating companies with the assurance that individual company data will not be communicated in any form to any party other than CII authorized academic researchers and designated CII staff members. Any data or analysis based on these data that are shared with others or published will represent summaries of data from multiple organizations participating in the survey which have been aggregated in a way that will preclude identification of propriety data and the specific performance of individual organizations.

##### **Instruction and Contact Information**



Operational Excellence is defined as “Doing the right thing, the right way, every time – even when no one is watching.” The attainment and maintenance of operational excellence requires an organization to develop and sustain a culture that communicates its values, beliefs, and assumptions to its members; creates an understanding of why certain behaviors are appropriate and desirable and others are not; and provides appropriate incentives and disincentives to encourage the desirable behaviors and eliminate the undesirable ones.

The safety drivers listed in next pages are necessary for the attainment of operational excellence. For each driver, a series of elements termed “Critical to Safety” (CTS) were identified. You are being asked to evaluate the drivers and the CTSs.

To enable you to do that, we have provided a rationale for the selection of some of the drivers and the CTSs. Others are basically standard terminology and processes in safety management and need no explanation.

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### **Section 1: Organization Characteristic**

1. Which organization(s) is your company a member of?

- Construction Industry Institute
- Construction Users Roundtable

- both
- neither

2. Determine the work area of your company:

- Regionally
- Nationally
- Internationally
- All

3. Which of the following best describes your organization?

- Private Owner
- Public Owner
- Architect/Engineering Firm
- Construction Management Firm
- Constructor/Contractor
- Engineer/Procure/Construct Firm
- Design-Build Firm
- Consultant
- Other, please specify

4. What is the primary construction sector(s) that your organization serves?

- Heavy Industrial
- Light Industrial
- Commercial

- Infrastructure/Heavy Civil
- Residential
- Other, please specify

## **Section 2: Rating Importance of CTS Elements of Owner's Role**

Owner organizations play a critical role in safety on construction projects. An engaged owner that sets expectations for all parties, establishes a safety culture, and monitors and demands achievement of safety objectives is the model. The tone of the project is set by the owner, and this opportunity should be used to reinforce the importance of safety.

The Critical to Safety elements for worksite organization are:

1. Establish and communicate attitudes towards safety
2. Selection of contractor
3. Contractual safety management
4. Owner's involvement in safety pre-construction
5. Monitoring contractor safety compliance
6. Measuring and analyzing safety results
7. Participation in behavior observation surveys (BOS)
8. Participation in incident investigations
9. Providing assistance to contractor for safety
10. Participation in safety training

1. Establishing and communicating attitudes toward safety contribute to an understanding of the “Owner’s Role” driver.

(Establishing and communicating attitudes toward safety include understanding of owner about its involvement which contributes to safety, it also includes going beyond

regulatory compliance by owner to prevent injuries.)

- Yes
- No

2. How Important are Establishing and communicating attitudes toward safety to developing and understanding of the “Owner’s Role” driver.

- No importance, should be dropped
- Little importance
- Some importance
- Moderate importance
- Great importance

3. Selection of contractor contributes to an understanding of the “Owner’s role” driver. (Selection of contractor includes considering safety in pre-qualifying the contractor by owner, it also includes providing contractual safety requirement by owner to prospective contractors as part of the bid package.)

- Yes
- No

4. How Important is Selection of contractor to developing and understanding of the “Owner’s Role” driver.

- No importance, should be dropped
- Little importance
- Some importance

- Moderate importance
- Great importance

5. Contractual safety management contributes to an understanding of the “Owner’s Role” driver.

(Contractual safety management includes placing at least one full time safety representative by owner on the project and it can also include requiring contractor to submit a safety policy signed by its CEO.)

- Yes
- No

6. How Important is Contractual safety management to developing and understanding of the “Owner’s Role” driver.

- No importance, should be dropped
- Little importance
- Some importance
- Moderate importance
- Great importance

7. Owner's involvement in safety pre-construction contributes to an understanding of the “Owner’s Role” driver.

(Owner's involvement in safety pre-construction may include addressing safety issues as early as the feasibility study and conceptual design phase on the project and also it may include conducting a review of the design for safety on the project.)

- Yes

- No

8. How Important is Owner's involvement in safety pre-construction to developing and understanding of the “Owner’s Role” driver.

- No importance, should be dropped
- Little importance
- Some importance
- Moderate importance
- Great importance

9. Monitoring contractor safety compliance contributes to an understanding of the “Owner’s Role” driver.

(Monitoring contractor safety compliance may include assigning an owner's site safety representative to the project and it also may include conducting regular safety meetings with contractor supervisory personnel.)

- Yes
- No

10. How Important is Monitoring contractor safety compliance to developing and understanding of the “Owner’s Role” driver.

- No importance, should be dropped
- Little importance
- Some importance
- Moderate importance
- Great importance

11. Measuring and analyzing safety results contribute to an understanding of the “Owner’s Role” driver.

- Yes
- No

12. How Important are Measuring and analyzing safety results to developing and understanding of the “Owner’s Role” driver.

- No importance, should be dropped
- Little importance
- Some importance
- Moderate importance
- Great importance

13. Participation in behavior observation surveys (BOS) contributes to an understanding of the “Owner’s Role” driver.

(Participation in behavior observation may include evaluating the effectiveness of behavioral improvement strategies and it may also include helping the contractor gather information to determine root causes of problem behaviors on the project.)

- Yes
- No

14. How Important is Participation in behavior observation surveys (BOS) to developing and understanding of the “Owner’s Role” driver.

- No importance, should be dropped
- Little importance

- Some importance
- Moderate importance
- Great importance

15. Participation in incident investigations contributes to an understanding of the “Owner’s Role” driver.

(Participation in incident investigation may include participating owner's safety representative in incident investigation as a member of the accident investigation team and it may also include requiring accurate and complete documentation of the results of incident investigation, including findings and recommendations on the project.)

- Yes
- No

16. How Important is Participation in incident investigations to developing and understanding of the “Owner’s Role” driver.

- No importance, should be dropped
- Little importance
- Some importance
- Moderate importance
- Great importance

17. Providing assistance contributes to an understanding of the “Owner’s Role” driver.

(Providing assistance to contractor for safety can include coordinating safety issues between designer and contractor on the project, it may also include supporting project safety by providing funds to promote safety.)



Yes

No

18. How Important is Providing assistance to contractor for safety to developing and understanding of the “Owner’s Role” driver.

No importance, should be dropped

Little importance

Some importance

Moderate importance

Great importance

19. Participation in safety training contributes to an understanding of the “Owner’s Role” driver.

(Participation in safety training can include participating of owner's safety representative in safety orientation and safety training on the project, it may also include allocating sufficient funds for safety training on this project.)

Yes

No

20. How Important is Participation in safety training to developing and understanding of the “Owner’s Role” driver.

No importance, should be dropped

Little importance

Some importance

Moderate importance

- Great importance

Is there any addition, deletion, or modification that would improve the validity of the driver and its elements?

## **Appendix B: Questionnaire of Weighting the Owner's Role Rating**

### **Model(ORRM)**

#### **Weighting the Owner's Role Rating Model (ORRM)**

##### **Section 1: Explanation of the ORRM**

Huang Liu, a Ph.D. student at the University of Kentucky, is working on his Ph.D. dissertation to understand the impact that owner involvement has on construction project safety. Mr. Liu will be completing this work under the supervision of Dr. Gabe Dadi, Assistant Professor of Civil Engineering at the University of Kentucky.

Research has shown that the practices and procedures of the owner can significantly affect construction safety performance. To quantify the involvement of the owner in safety issues, this research aims to develop a systematic and effective model for rating the owner's role in project safety. The model is entitled the Owner's Role Rating Model (ORRM). The ORRM is structured similar to a Critical to Quality (CTQ) seen in Six Sigma. The ORRM would quantify the owner's role in construction safety management and finally yield a score that can be used to evaluate the owner's performance and develop improvement plan.

The ORRM contains 6 Critical to Safety (CTS) elements, however, not all are equally critical to safety. We are requesting that experienced construction owners take part in this questionnaire survey to determine the weights of each element. It is believed that your knowledge and experience can help us to work out weights assigned to each element.

Questionnaire survey mainly consists of the following documents:

- Guidelines for Weighting the CTSS
- Brief Introduction to the Definitions of the CTSS

- The ORRM Weighting Table
- Background Information Form
- Suggestions for CTSs Improvement
- Acknowledgement

We appreciate every effort you make to establish the ORRM. It will be a simple and effective rating model for owners to assess and enhance their role in construction safety management. Thank you for your participation and contribution!

All data provided by participating individuals and organizations is to be considered confidential. The data provided will not be communicated in any form to any party other than researchers identified within this survey. Any data or analyses that are shared with others or published will represent aggregate results of all the organizations participating in the survey in a way that will preclude identification of specific performance of individual organizations.

## **Section 2: Guidelines for Weighting the CTSs**

### **How to weight the CTSs**

In this survey, pairwise comparison is used to weight the CTSs. Please place a number in the cell corresponding to the relative weight of the first CTS in the question to the second CTS in the question. However, in each comparison, there are two possible situations.

**Situation 1** is that the first CTS is **equal to or more important than** the second CTS.

**Situation 2** is that the first CTS is **equal to or less important than** the second CTS. In each situation, please weight on different scale.

### **Situation 1:**

Please place a number as a degree of comparison in the cell from the table below:

Degree of comparison	Equally Important	Moderately Important	Strongly Important	Very Strongly Important	Extremely Important
	1	2	3	4	5

Example:

How much more valuable is **Communicating Attitudes towards Safety** than **Establishing Attitudes towards Safety**?

If you believe that **Communicating Attitudes towards Safety** is very strongly important compared to **Establishing Attitudes towards Safety**, you can put 4 in the cell.

**Situation 2:**

Please place a number as a degree of comparison in the cell from the table below:

Degree of comparison	Equally Important	Moderately Important	Strongly Important	Very Strongly Important	Extremely Important
	1	1/2	1/3	1/4	1/5

Example:

How much more valuable is **Communicating Attitudes towards Safety** than **Establishing Attitudes towards Safety**?

If you believe that **Establishing Attitudes towards Safety** is very strongly important compared to **Communicating Attitudes towards Safety**, you can put 1/4 in the cell.

### **Section 3: Brief Introduction to the Definitions of the CTSs**

#### **Establishing Attitudes towards Safety**

The owner's attitudes towards safety is key part to the safety performance of the

contractor. Once owners establish their attitude to safety, it will affect the safety performance in two ways. The attitude will determine the effort the owner willing to make to the safety work. It also affects emphasis of other stakeholders on safety management.

### **Communicating Attitudes towards Safety**

The owner should communicate their concerns on safety issues to all stakeholders on the project through various channels. As the fund provider and end-user of building or facility, the owner's attitude can significantly affect safety work of other participants.

### **Selection of Contractor**

The contractor is the actual constructor of the building or facility, and responsible for entire safety on the jobsite. Therefore, selecting contractor based on safety performance is a crucial process for final safety result. If the owner could select a contractor able at safety, the safety performance will tremendously improve.

### **Contractual Safety Arrangement**

Contract stipulates the safety duties for all participants in the construction project. It also serves as the basis for the communication between them. Through contractual arrangement, the owner could propose safety requirements which could navigate the contractor to focus on the safety work.

### **Owner's Involvement in Safety pre-construction**

Many activities before construction could affect safety performance. The owner's involvement could significantly prevent such problems and reduce the potential risk for construction safety. For example, the constructability of the design can determine the risk taken by craftsmen to a extent. If the owner can encourage the designer to consider safety

issues during their work, the constructability will improve and the risk will be reduced.

### **Monitoring the Contractor's Compliance with Safety**

To achieve an excellent safety result, the owner should monitor the contractor's compliance with safety. For example, the owner should audit the contractor's work on a regular basis and frequently communicate with the contractor on safety issues. By doing so, the owner and the contractor can take the safety performance to the next level.

### **Section 4: Owner's Role Rating Model (ORRM) Weighting Table**

1. How much more valuable is Communicating Attitudes towards Safety than Establishing Attitudes towards Safety?

2. How much more valuable is Selection of Contractor than Establishing Attitudes towards Safety?

3. How much more valuable is Selection of Contractor than Communicating Attitudes towards Safety?

4. How much more valuable is Contractual Safety Arrangement than Establishing Attitudes towards Safety?

5. How much more valuable is Contractual Safety Arrangement than Communicating Attitudes towards Safety?

6. How much more valuable is Contractual Safety Arrangement than Selection of Contractor?

7. How much more valuable is Owner's Involvement in Safety pre-construction than Establishing Attitudes towards Safety?

8. How much more valuable is Owner's Involvement in Safety pre-construction than Communicating Attitudes towards Safety?

9. How much more valuable is Owner's Involvement in Safety pre-construction than Selection of Contractor?

10. How much more valuable is Owner's Involvement in Safety pre-construction than Contractual Safety Arrangement?



11. How much more valuable is Monitoring the Contractor's Compliance with Safety than Establishing Attitudes towards Safety?

12. How much more valuable is Monitoring the Contractor's Compliance with Safety than Communicating Attitudes towards Safety?

13. How much more valuable is Monitoring the Contractor's Compliance with Safety than Selection of Contractor?

14. How much more valuable is Monitoring the Contractor's Compliance with Safety than Contractual Safety Arrangement?

15. How much more valuable is Monitoring the Contractor's Compliance with Safety than Owner's Involvement in Safety pre-construction?

**Section 5: Background Information**

Name:

Date:

Company:

Job Title:

Department:

Preferred contact method (if necessary):

Phone:

Email:

Total years of construction safety-related work:

Type of project you primarily work on:

- Fossil fuel or natural gas power plants
- Nuclear power plants
- Other industrial projects
- Commercial projects
- Highway and heavy civil projects
- Other

Type of organization you primarily work for:

- Owner's organization
- Contractor
- Other

### **Section 6: Suggestions for CTSs Improvement**

Is the list of 11 CTS elements sufficient to represent the owner's role? If not, please list

all others that should be added.

Are any of the CTS elements redundant? If so, please list the elements that should be deleted.

Should any of the CTS elements be changed? If so, please list the elements and any recommended changes.

Do you have other suggestions for CTS list improvement?

### **Section 7: Acknowledgement**

Thank you very much for your participation and contribution! If you have any questions, please contact:

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## **Appendix C: Questionnaire of Validating the Owner’s Role Rating Model(ORRM)**

Welcome to the Construction Industry Institute/University of Kentucky survey on operational excellence in construction project safety. For this study, we have defined operational excellence as “Doing the right thing, the right way, every time - even when no one is watching.” Questions will be asked about your organization’s policies, procedures, and practices at the corporate, project, and field levels. The answers you provide will enable us to further develop and refine our model as well as provide you with a picture of where your project stands relative to the model.

Federal government research regulations require us to have an approved consent form from an individual before that individual may participate in a research study.

- Continue
- Decline

### **Background of this Research**

Study Title: Improved Safety Performance through Operational Excellence

Researchers:

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***What is this study about?***

The Construction Industry Institute is sponsoring a research effort through the University of Kentucky on measuring operational discipline (or operational excellence) in organizations involved in the delivery of capital projects. Operational Excellence (OE) is defined as “Doing the right thing, the right way, every time – even when no one is watching.” Attaining and sustaining operational excellence requires an organization to develop and sustain a culture that communicates its values, beliefs, and assumptions to its members; creates an understanding of why certain behaviors are appropriate and desirable and others are not; and provides appropriate incentives and disincentives to encourage the desirable behaviors and eliminate the undesirable ones. The research team has developed a model for operational excellence internally and believes strong adherence to the model can lead to improvements in project safety performance. The next step is to collect data on individual projects in relation to this OE model. A self-assessment model will be provided to you with general instructions in how to complete it.

We need your help to complete the rigorous self-assessment tool for your project.

***What will I be asked to do if I agree to participate in this study?***

You will be one of the primary project contacts for the researchers named above. They will provide you with the assessment tool and instructions on how to complete the tool.

The assessment tool is multi-faceted and may require input from multiple individuals. As a primary contact point for the project, you are being asked to manage the workflow, be a champion of the assessment, and provide the final completion of the assessment to the researchers.

***Are there any benefits to me for participating in this study?***

Completing the survey gives you the opportunity to self-assess the level of operational excellence for safety on your project. We also hope the findings from the study will help you understand the relationship between operational excellence and safety performance.

Thus, the self-assessment tool and score can become powerful benchmarks for a project's dedication to improving safety.

***Are there any risks to me if I participate in this study?***

There are no known risks for you taking part in this study.

***Will my information be kept private?***

All data provided for any CII survey in support of benchmarking and research activities by participating organizations are considered "company confidential." The data have been provided by participating companies with the assurance that individual company data will not be communicated in any form to any party other than CII authorized academic researchers and designated CII staff members. Any data or analyses based on these data that are shared with others or published will represent summaries of data from

multiple organizations participating in the survey which have been aggregated in a way that will preclude identification of proprietary data and the specific performance of individual organizations.

***Are there any costs or payments for being in this study?***

There are no costs to you nor will you receive money or any other form of compensation for taking part in this study.

***Who can I talk to if I have questions?***

Any questions or concerns about your participation in this study can be addressed to [william.maloney@uky.edu](mailto:william.maloney@uky.edu) or [gabe.dadi@uky.edu](mailto:gabe.dadi@uky.edu).

***What are my rights as a research study volunteer?***

Your participation in this study is completely voluntary. You may choose not to be a part of this study. There will be no penalty to you if you choose not to take part. You may choose not to answer specific questions or to stop participating at any time.

***By selecting the YES button below, you acknowledge that:***

- You understand the information given to you in this form.
- You have been able to ask the researcher questions and state any concerns. The researchers have responded to your questions and concerns.
- You believe you understand the research study and the potential benefits and risks that are involved

***If, after reading the consent form, you agree to participate in the study, please select the Continue button.***

***If you do not wish to participate, select the Decline button.***

- Yes
- Decline

**Demographics of Projects**

I have signed the Informed Consent Form agreeing to participate in this study, “Safety Performance through Operational Excellence”, conducted by the University of Kentucky through the Construction Industry Institute. I understand that my responses to this questionnaire are voluntary and that I can choose not to answer certain questions. Furthermore, I understand that I will not be identified by name in any research or publications resulting from this study.

***Project Demographic Information***

Name of project:

Contractor:

Owner:

Size (in \$):

Location (City, State) :

Total Expected Man-hours:

Expected maximum number of employees on site:

Total Recordable Incident Rate:

Total Lost Time:

Expected Length of Project:

Percent completed:

Type:



- Nuclear power
- Fossil power
- Other heavy industrial
- Light industrial
- Commercial
- Infrastructure/heavy civil
- Other

Project Labor Status:

- Union
- Nonunion
- Mixed

Delivery System:

- CM at risk
- CM agency
- GC (self-perform)
- GC (not self-perform)
- DB
- IPD
- P3

Does the GC/CM require their subcontractors to adhere to their safety management systems?

- Yes
- No

### **Owner's Role Acceptance**

#### Owner's Role

For many projects, such as power plants, refineries, and petrochemical facilities, the owner takes a very active role in the project in terms of safety. This can range from talking about safety to develop a constant emphasis on safety to prescribed activities that must be undertaken for owner participation in safety talks and accident investigations. If, on this project, the owner has a very active role, continue with the survey by pressing the following Continue button.

If, on the other hand, the owner assumes a very minimal role and leaves safety to the contractor or construction manager, press the following End button.

- Continue
- End

### **Owner's Role Rating Table**

1. Does the Owner understand that his involvement contributes to improved project safety?

- Yes
- No
- I do not know

2. Does the owner set Zero Injuries as the objective for the project?

- Yes
- No
- I do not know

3. Did the owner communicate with all project stakeholders clearly about his safety position?

- Yes
- No
- I do not know

4. Does the owner go beyond a regulatory compliance approach to prevent injuries?

- Yes
- No
- I do not know

5. Does the Owner communicate his commitment to safety to the contractors?

- Yes
- No
- I do not know

6. Did the Owner prequalify contractors?

- Yes
- No
- I do not know

7. Was the contractors' safety performance considered in the prequalification?

- Yes
- No
- I do not know

8. Did the Owner provide specific contractual safety requirements?

- Yes
- No
- I do not know

9. Did safety have a high priority in selecting a contractor?

- Yes
- No
- I do not know

10. Did the Owner utilize the following safety measures in selecting a contractor? Check all that apply.

- Total Recordable Incidence Rate
- Litigation Related to Injuries
- Loss Ratios of Workers' Compensation
- Safety Performance Records of Key Personnel
- Experience Modification Rating
- Records of OSHA Citations & Fines
- None

11. Did the Owner assign at least one full-time safety representative to this project?

- Yes
- No
- I do not know

12. Did the Owner provide the contractor with safety guidelines that must be followed?

- Yes
- No
- I do not know

13. Did the Owner require the contractor to submit the resumes of key safety personnel?

- Yes
- No
- I do not know

14. Did the Owner require the contractor to provide specific minimum safety training for workers?

- Yes
- No
- I do not know

15. Did the Owner require the contractor to submit a site-specific safety plan for this project?

- Yes
- No

- I do not know

16. Did the Owner require contractor employees at all levels to have specific safety responsibilities integrated into work processes?

- Yes
- No
- I do not know

17. Did the Owner require the contractor to submit a safety policy statement signed by the CEO?

- Yes
- No
- I do not know

18. Did the Owner require the contractor to submit an emergency plan for this project?

- Yes
- No
- I do not know

19. Did the Owner require the contractor to submit & utilize an immediate reporting procedure for accidents and near misses on this project?

- Yes
- No
- I do not know

20. Did the Owner require the contractor to submit a mitigation plan for this project?

- Yes
- No
- I do not know

21. Did the Owner require that subcontractors be included in the project's safety program?

- Yes
- No
- I do not know

22. Did the Owner make it clear that the contractor is ultimately responsible for the safety of his employees?

- Yes
- No
- I do not know

23. Does the contract specify the actions the Owner may take to contribute to safety performance on this project?

- Yes
- No
- I do not know

24. Did the Owner address safety issues in the feasibility study and conceptual design phases?

- Yes

- No
- I do not know

25. Did the Owner require designers to consider construction safety and constructability in this project?

- Yes
- No
- I do not know

26. Did the Owner require the designers to conduct a review of the design for construction safety for this project?

- Yes
- No
- I do not know

27. Did the Owner conduct a review of the design for safety in this project?

- Yes
- No
- I do not know

28. Did the Owner prefer to award a design/build contract to promote safety performance?

- Yes
- No
- I do not know



29. Did the Owner require a pre-construction meeting with contractors to discuss safety issues?

- Yes
- No
- I do not know

30. Did the Owner assign full-time safety representative to this project?

- Yes
- No
- I do not know

31. Did the Owner specify the responsibilities of the site safety representative?

- Yes
- No
- I do not know

32. Did the Owner establish a construction safety unit to monitor contractor safety for this project?

- Yes
- No
- I do not know

33. How frequently does the Owner conduct safety meetings with contractor managerial & supervisory personnel?

- Never

- Monthly
- Weekly
- Daily

34. Does the Owner maintain statistics o contractor accidents and near misses on this project?

- Yes
- No
- I do not know

35. How frequently does the contractor communicate with the contractor's employees about safety on this project?

- Never
- Monthly
- Weekly
- Daily

36. How frequently does the Owner conduct safety audits on the contractor's processes?

- Never
- Monthly
- Weekly
- Daily

37. Did the Owner initiate or implement a safety recognition/reward program on this project?

- Yes
- No
- I do not know

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38. How frequently does the Owner discuss the results of safety audits with the contractor?

- Never
- Monthly
- Weekly
- Daily

Please provide any comments that you may have.

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## VITA

Huang Liu was born in Funan, Anhui, China. After graduation from No. 1 high school in Bozhou, he was admitted to Southeast University pursuing a Bachelor Degree of Project Management, where he received several awards and assistantships to support his studies. During pursuing a Bachelor Degree, he has gained a rich expertise and experience in construction management and real estate development. After gaining Bachelor Degree, he continued to pursue a Master Degree of Management Science and Engineering in Southeast University under the adviser of Associate Professor Lei Zheng. When pursuing Master Degree, he learned and studied numerous issues on construction quality management. The master thesis is about construction service quality, which is a novel research direction. To gain more knowledge and enrich experience, he flew to United States and was admitted to be a doctoral student as a research assistant in civil engineering at the University of Kentucky. He has participated in research project of “Safety Performance through Operational Excellence” funded by CII and completed sub-project of the owner’s role in construction. He has published one paper on 5th International/11th Construction Specialty Conference. He has published another paper in Journal of Construction Engineering and Management. Another journal paper, follow-up research of the first journal paper, has been planned to submit to Journal of Construction Engineering and Management. His research interests include construction management, contract management, claim management, and real estate development.

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