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A Strategic Approach to Effectively Manage Supplier Quality within the Construction Industry

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of the requirements for the degree of
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by

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ABSTRACT

The aim of the research is to determine the best practices for supplier quality management (SQM) in the construction industry that ensure that the supplied materials and equipment for construction projects are within the quality requirements. The research is based on three main objectives. The first objective is to describe and assess the process of assuring supplier quality inside and outside the construction industry. The second objective is to develop a framework for the supplier quality process based on the collection of SQM practices from multiple data sources. The third objective is to assess the SQM practices within the developed framework of supplier quality process, and to discuss the development of strategic leadership for SQM.

The contribution of this research can be used by stakeholders in the construction industry to improve SQM within their organizations. Researchers can also benefit from this research to better understand SQM practices within the construction industry.

The findings of the research show that SQM practices outside the construction industry appear to be similar to the existing practices within the construction industry. However, construction organizations with highly effective SQM systems implement the SQM practices more consistently, as compared to the other organizations. Also, construction organizations with highly effective SQM systems focus on quality when selecting their suppliers, and hold joint quality planning with their suppliers because these practices have high impact on quality and are easy to implement. Finally, the research shows that having a quality director that helps create a quality culture for SQM is very important to strategically lead SQM within construction organizations.

ACKNOWLEDGMENTS

This dissertation is dedicated to my parents for their countless support and positive impact on my whole life. Without them, I would never be where I am today. I am grateful to my husband, for his strength, support, encouragement, and sacrifice. I can never find enough words to express my gratitude and appreciation to him. My special thanks to my mother in-law for her support and encouragement in the good and tough days. I also would like to thank my daughter who has brought great joy to my life. This dissertation, and my graduate study, could not have been accomplished without being encouraged by my great family. My deepest appreciation goes to them.

I would like to express my gratitude to my advisor, Kim LaScola Needy, for her ultimate support and guidance throughout my doctorate study. Being advised and mentored by her was a wonderful experience. I cannot thank her enough.

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I would like to acknowledge and especially dedicate this dissertation in the memory of my father in-law, Khaled, who had been supporting me with ultimate encouragement during my graduate study.

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AlMaian, R. Y., Needy, K. L., Walsh, K. D., & Alves, T. (2014). A Qualitative data analysis for supplier quality management practices in the construction industry. Submitted to *The Journal of Construction Engineering and Management* (Received a decision to revise for re-review).

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1. INTRODUCTION

This research is part of the RT (Research Team) 308 project entitled *Achieving Zero Rework through Effective Supplier Quality Practices* supported by the Construction Industry Institute (CII). This project involves a collaborative endeavor between the Department of Industrial Engineering at the University of Arkansas and the Department of Civil, Construction, and Environmental Engineering at San Diego State University. The research team also includes a group of subject matter experts (SMEs) from the construction industry, primarily the engineer-procure-construct (EPC) industry, representing their member organizations in the CII as construction owners, contractors, and suppliers. Each SME brought an average 35 years of experience in the local and global construction market to the research project. In total, 21 organizations specializing in EPC projects participated in this research project. These organizations have each been in the construction industry for more than 70 years, and each have on average about 25,000 employees located across the globe with headquarters in the U.S., Asia, and Europe. The portfolio of projects in which these organizations are engaged range from 600,000 to 10 billion U.S. dollars. In addition to the 21 organizations who participated in this project, nine supplying companies (suppliers) provided important information regarding their supplier systems. These suppliers have each been active in the EPC industry for an average of 49 years. These nine suppliers range in size, with a number of employees ranging from 90 to 9,000, and annual sales ranging from 60 to 3 billion U.S. dollars. Collectively, these SMEs and suppliers brought forth a tremendous wealth of expertise to the research project.

The major research question under study for RT 308 was as follows: "*What are the most effective processes and practices for ensuring that project materials and equipment are produced,* *manufactured, or fabricated in strict accordance with all applicable specifications, and that they are delivered to the project site without any need for rework?*"

This dissertation research evaluates supplier quality management (SQM) practices in the construction industry and from diverse industries by using multiple data sources. The purpose of the evaluation is to identify effective SQM practices that ensure that the supplied materials to construction projects meet the specified level of quality and to promote areas for improving current SQM processes within construction organizations.

The findings of the research show that SQM practices outside the construction industry appear to be similar to the existing practices within the construction industry, such as partnerships with suppliers, and management commitment to improve and support SQM. However, some of the construction organizations are currently not implementing the SQM practices in a consistent manner, such as measuring suppliers' performance and providing feedback to them. In general, construction organizations with highly effective SQM apply SQM practices more consistently and place higher importance on quality planning with higher involvement from top management as compared to other organizations with moderately and least effective SQM. The assessment of the SQM practices from the organizations with highly effective SQM that were identified from multiple data sources show that not all the practices have a similar impact on quality nor are easy to implement. The research shows that using a detailed formula to calculate the efforts of supplier surveillance, updating the project materials specifications and requirements, focusing on quality versus price or schedule, and holding joint quality planning have high impact on quality and are easy to implement. Finally, the research shows that in order to effectively implement the SQM practices within construction organizations, it is necessary to have a quality director who manages the efforts and oversees the work to strategically lead SQM.

The contribution of this research can be used by stakeholders in the construction industry to improve the existing SQM practices within their organizations. Researchers can also benefit from this research to better understand SQM practices within the construction industry.

Research Objectives

The research aim is to determine the effective practices for SQM in the construction industry to ensure that the supplied materials are produced and fabricated without any need for rework. The dissertation also identifies the practices that develop a strategic leadership for SQM.

This dissertation research has three main objectives. The first objective is to describe and assess the process of assuring supplier quality inside and outside the construction industry. The second objective is to develop a framework for the supplier quality process based on the collection of SQM practices from multiple data sources. The third objective is to assess the SQM practices within the framework of supplier quality process, and to discuss the development of strategic leadership for SQM.

Dissertation Format

The dissertation format utilizes the "three-paper model" supported by the University of Arkansas Graduate School. This dissertation consists of five chapters representing publishable papers, and two other chapters representing the introduction chapter of the research and a final chapter for conclusions.

Chapter 1 introduces the research objectives and motivation, and describes the research structure and methodology. This chapter also discusses the contributions of the research effort.

Chapter 2 presents findings from the scholarly literature of the diverse approaches for SQM in the construction industry, and from other industries such as healthcare, manufacturing, aerospace and food. The objective of examining the literature was to recognize practices that can be useful to the construction industry, such as supplier partnerships and product life cycle management.

Chapter 3 contains an investigation of SQM practices currently practiced in construction organizations. The aim of the investigation is to identify effective practices that construction organizations can borrow to improve the existing SQM.

Chapter 4 describes the use of principal components analysis (PCA) to analyze a small sample size and multivariate data. The aim is to quantitatively identify most important practices for SQM.

Chapter 5 describes the development and validation of a balanced scorecard (BSC) framework used to organize SQM practices and help construction organizations effectively implement these practices within their projects. The proposed BSC provides a basis for implementing and measuring the SQM practices in order to compare the performance across multiple projects and to provide opportunities for continuous improvement.

Chapter 6 describes the work performed in analyzing the SQM practices aligned within the BSC in terms of their impact on quality and ease of implementation. This chapter also describes important leadership principles from the literature, and derives important leadership objectives and practices for developing strategic leadership for SQM.

Chapter 7 presents the conclusion of the research efforts and the suggested future work.

Research Motivation

Within the construction industry, SQM is a system of processes and practices applied by the project organization to ensure that the quality of fabricated materials and equipment meet the project's requirements and specifications (Caldas et al., 2012). SQM in the construction industry is complex due to the unique characteristic of each project in terms of its size and life cycle. In addition, each project is supported by a broad and global supply chain involving multiple independent contractors, subcontractors and suppliers. It is challenging throughout the execution of the construction project to ensure that the required equipment, products and materials are produced and delivered to the worksite without any need for rework. Moreover, construction projects are expensive, take a long time to be completed, interfere with the surrounding environment, and are built by dispersed teams and suppliers in a project-based fashion where participants might never have worked with each other before and might never work together again. In addition, construction projects are assembled at their final location making their production nomadic (the "factory" is installed where the product will be built). The product is built to fit the environment and often cannot be relocated, and workers move around the product (as contrasted from assembly lines where the product is most often brought to the worker). All of these conditions define the construction industry and profoundly interfere with processes used to deliver its products, and assure their quality.

Researchers have examined the distinctive nature of the construction industry projects, in which the owner, contractors, subcontractors, and suppliers work together for a specified period of time to complete the project and then move on to work on other projects (Caldas et al., 2012). Singh & Tiong (2005, pg. 62) identified that

"The construction industry is characterized by cost and duration overruns, serious problems in quality standards and safety measures, and an increased number of claims, counterclaims, and litigation. Furthermore, the peculiarity of construction is that no two projects are identical in terms of site conditions, design, use of construction materials, labor requirements, and equipment requirements, construction methods, technical complexity, and level of management skill required."

Jongwoo (2009) determined that construction projects are dynamic and irregular in nature. Also, a typical construction project might involve several purchase orders for thousands of unique items that increase problems of matching and standardization, supplier quality tracking, and fabrication quality errors (Neuman et al., 2014).

Quality is an important aspect in construction projects. Sullivan (2011) believed that quality cannot be addressed by isolated departments and organizations, but rather it must be designed through the entire system. Furthermore, the ability to produce a quality product in the construction process depends on the relationship between the parties involved (Burati Jr. et al., 1992).

Poor SQM will impact the overall quality of the project leading to rework, cost overrun, schedule delays, and other negative consequences related to business reputation. Rogge et al. (2001) determined that high levels of rework disturb schedule targets, reduce productivity, increase cost, and affect quality. Love (2002) and Love & Smith (2003) identified that the major area that contributes to poor organization and project performance is rework.

This dissertation analyzes and describes data collected from important parties within construction projects including owners, contractors, and suppliers in order to identify opportunities for improving the existing SQM. The research effort also seeks to describe and identify the effective SQM approaches within the construction project life cycle that help reducing rework and other quality problems caused by poor SQM.

The dissertation consists of three objectives to be achieved through the research efforts. The first objective is to describe and assess SQM inside and outside the construction industry. The motivation of this assessment is that the construction industry develops its products and activities in a project-based fashion, which is the case for many other industries and organizations, e.g., shipbuilding, aerospace, production of one-of-a-kind and engineered-to-order products, and engineering projects in general. The SQM assessment can help to identify approaches that could be beneficial to the construction industry such as supplier partnerships, and product life cycle management, and determine how these approaches might be adapted to the construction industry. Also, the research effort to achieve the first objective of the dissertation includes in-depth analysis of the current SQM applied by construction organizations within the EPC projects. The purpose of this analysis is that most construction organizations, representing owners and contractors, place high importance on documenting and tracking the quality performance of their suppliers as part of their SQM to improve the quality of the supplied products. However, these organizations still face problems with their SQM evidenced by the large number of rework tasks for the supplied products within the EPC projects. Yeo & Ning (2002) identified that within the EPC projects, the actions are interdependent, the work is split into many units leading to a compound organizational structure, and the unsteady environment compels recurrent changes. This highlights the importance of examining the current SQM practices to explore effective SQM practices to deliver products with the expected level of quality.

In addition, the research effort to achieve the first objective involves a quantitative analysis for SQM practices based on limited number of observations obtained from a data collection instrument. Many construction organizations place high importance on using quantitative analyses to select the effective SQM practices that ensure that the materials and fabricated equipment for the construction project are within quality specifications. However, traditional quantitative analyses methods may be limited because the process of acquiring enough data to conduct the analysis is time consuming and costly. Also, the availability of data to analyze SQM practices is a challenge as construction organizations keep details related to SQM indicators and practices scattered within different departments and within different data collection systems (Walsh et al., forthcoming 2014). The research effort suggests using a quantitative analysis method for small and multivariate data to find the most important SQM practices.

The research findings include proposing a framework for SQM to align the effective SQM practices that span the project life cycle. The framework can be used within SQM as a basis for implementing the practices and for performance measurement. Kagioglou et al. (2001) determined that supplier performance management in the project environment is poorly studied in the construction industry literature. Needy & Ries (2010) identified that the use of consistent quality management practices and quality metrics across the project life cycle form the foundation of effective quality management in the construction industry. Proposing a framework for SQM implementation and performance measurement may help organizations to assess their performance in multiple projects. If this assessment is extended to the organizational level, additional useful lessons can be learned and continuous improvement can be achieved (Costa et al., 2006).

Effective SQM practices are important to improve supplier quality, but not all practices have a similar impact on quality or are they easy to implement. This provides motivation to further study and assess these practices thereby assisting construction organizations with focusing on the key practices and to simplify implementing them within construction projects. Hoskisson et al. (2009) indicated that organizations must select and asses the practices and strategies that add value to the organization and promote improvements. The research also includes a description and analysis of leadership practices that are important for developing strategic leadership for SQM within the construction industry. Strategic leadership includes the process of forming a vision for the future, communicating it to subordinates, motivating followers, and engaging in strategy-supportive activities with subordinates (Elenkov et al., 2005). Strategic leadership is crucial for achieving and maintaining continuous improvement (Vera, & Crossan, 2004).Within the construction industry, Isik, et al. (2010) concluded that leadership strategic plans and decisions have direct influence on the company's performance and project success. Goodman & Chinowsky (1997) determined that construction organizations should create an environment that facilitates leadership and ensures strategic thinking. However, the subject of leadership has limited focus within the construction literature (Toor & Ofori, 2008). The lack of focus on leadership in the construction industry is prevalent not only in academic research but also in practice (Chan & Chan, 2005). This dissertation describes objectives and practices that are necessary for effective implementation of SQM, and important for long-term improvement for SQM within the construction organizations.

Research Methodology

For this research, the main data collection sources are:

1. Literature review,
2. SQM documents (including reports and procedures) from the participating owners and contractors organizations,
3. Structured interviews with contractors,
4. Supplier focus groups,

5. Supplier Quality practices and performance instrument for purchase order (PO) data (PO instrument), and
6. Inspection cost data.

Figure 1 describes the data collection sources.

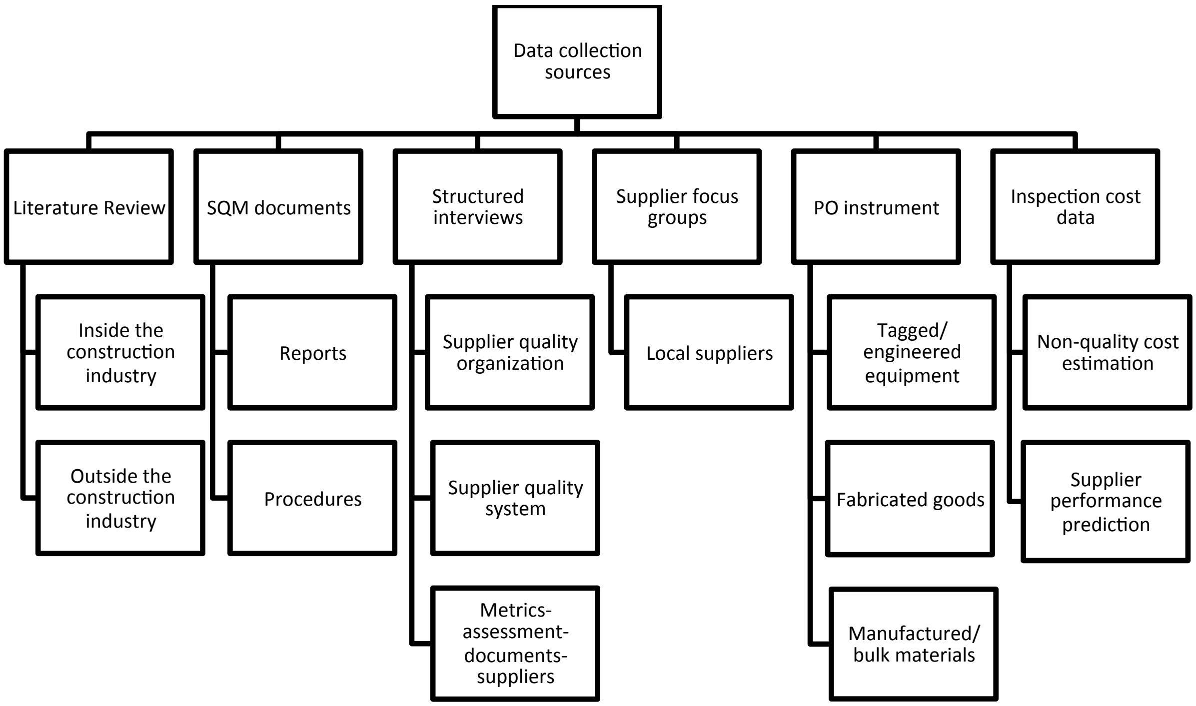

Figure 1: Data collection sources

The dissertation effort focuses on analyzing the literature, structured interviews, SQM documents, and supplier focus groups, and uses the PO instrument and inspection cost data to describe important effective SQM practices. The leading research effort for these two data sources, i.e., PO instrument and inspection cost data, are described in details in Neuman (2014) and Ahmad (2014) respectively. The structured interview and PO instrument appear in Appendix I and II, respectively for reference. Institutional Review Board (IRB) approval has been obtained and also appears in Appendix III. This research has resulted in five publishable journal papers that are at various stages of review as depicted in Table 1. In addition, three refereed conference papers and one presentation have resulted from this work to date.

Contribution	1	2	3	4	5
Dissertation chapter	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Contribution title	Supplier quality management inside and outside the construction industry	A qualitative data analysis for supplier quality management practices within the construction industry	Analyzing effective supplier quality management practices using principal components analysis	Using the balanced scorecard to implement effective supplier quality management practices in the construction industry	Analyzing effective supplier quality management using simple multi-attribute rating technique (SMART) and value focused thinking (VFT)
Data type	Qualitative	Qualitative	Quantitative	Quantitative and qualitative	Quantitative and qualitative
Data sources	Literature	Supplier quality management (SQM) documents, structured interviews	PO instrument	Literature, SQM documents, Interviews, PO instrument, supplier focus groups, inspection data	Literature, SQM documents, interviews, PO instrument, supplier focus groups, inspection data
Research methodology	Literature review taxonomy	Grounded theory	Principal components analysis (PCA), and analytic hierarchy process (AHP)	Cross analysis ,and balanced scorecard (BSC)	Simple multi-attribute rating technique (SMART), and value focused thinking (VFT)
Objective	Describe and assess the process of supplier quality			Develop a framework for the supplier quality process	Assess the SQM practices within the developed framework of supplier quality process, and to discuss the development of strategic leadership for SQM.

Table 1: Summary of the dissertation publishable papers and data

The research includes the use of a supplier quality (SQ) process map that captures the main phases as shown in Figure 2. The detailed description can be found in Alves et al. (2013). The map contains five major processes beginning with planning and selection of the suppliers. Next, execution (of the fabrication along with the development of a supplier quality plan) followed by release from shop for completed purchase orders (POs), i.e., packages of fabricated products. Finally, the map depicts the receipt at site of those products, and mechanical completion representing the stage when products are physically connected in place in the facility, which marks the end of the scope of analysis for this research. Feedback loops are embedded at each step within the process to indicate that occasionally information flows upstream to inform previous activities about their performance. The detailed map is shown in Appendix IV.

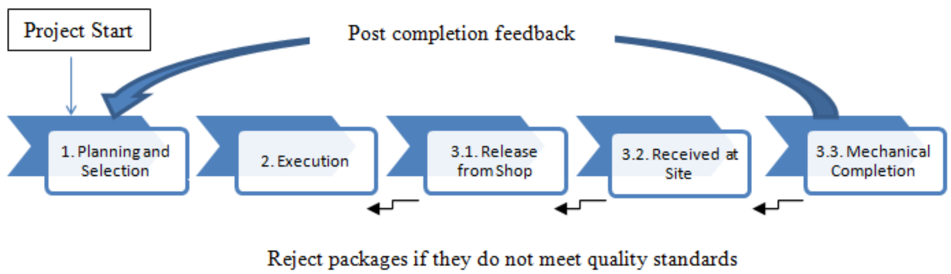

Figure 2: Supplier quality (SQ) process map. Adapted from Alves et al. (2013).

The SQ process map is used within the discussion of the research publishable papers to define the main stages of the SQ process, cross analyze the SQM practices identified from the data sources linking them to the stages of the process map, and also to describe when within the project life cycle these practices can be implemented.

Research Contributions

The contributions of the research include exploring SQM practices inside and outside the construction industry and investigating the current SQM practices from construction organizations to identify the effective practices that ensure the quality of the supplied products. The contributions also involve proposing a framework for implementing the identified effective SQM practices, and assessing those practices within the proposed framework to simplify the implementation process. In addition, the research contributions include examining important leadership principles from the literature that help in developing strategic leadership for SQM within the construction industry.

The dissertation includes five publishable papers reflecting five main contributions. The contribution of the first paper, presented in Chapter 2, involves investigating the practices of SQM inside and outside the construction industry by using literature review taxonomy. The investigation is beneficial to the construction and engineering management by increasing the knowledge of effective SQM practices within the construction industry and within other industries with similar production complexities. Engineering professionals can benefit from these findings by not limiting the investigation to a particular industry. By learning about practices from diverse industries, engineering professionals can use these practices to improve the current SQM in any project.

The second contribution in chapter 3 includes investigating the current SQM practices from construction organizations by using qualitative data analysis techniques of grounded theory. The research can benefit academic researchers and professionals in construction management by helping them learn about qualitative data analysis techniques, because several sources of information (data) within construction projects are in qualitative forms such as inspection reports, suppliers' bids, and request for information reports. These data can be interpreted and presented to management using qualitative data analysis techniques to help examine important relationships among the data, thus conclusions can be easily drawn. Also, the second paper discusses current SQM practices and classifies these practices according to the effectiveness of SQM of the organizations sampled in order to recognize what the organizations with highly effective SQM are presently practicing. The construction organizations can adopt these practices to improve their current SQM systems. In the second contribution of the research, the effective SQM practices are also summarized within the phases of the supplier quality process in order to help construction organizations implement these effective practices within the project life cycle.

The third contribution is discussed in chapter 4. It involves using principal components analysis (PCA) to analyze SQM practices in organizations with highly effective SQM based on in-depth analysis of the PO instrument described in Neuman (2014). The research proposes the use of PCA to analyze data with small sample size and with a relatively large number of variables. The research also includes an analysis method, analytic hierarchy process (AHP), based on expert judgment that can be used to support the conclusions drawn from small sample size analyses, and to understand the relative importance of the SQM practices. The findings of this paper can benefit the researchers and professionals in the construction industry to invest in the most important SQM practices in order to implement them within construction projects.

The fourth contribution of the research is presented in chapter 5, and it includes proposing the use of balanced scorecard (BSC) framework for implementing the effective SQM practices during construction projects. The proposed framework is beneficial in assisting organizations in improving their current SQM. At the end of each project, the practices within the BSC can be assessed based on how well the goal was achieved given the utilization of these practices. Applying the BSC within construction projects can also help organizations compare project performance across multiple projects, thus suggesting areas of improvement.

The fifth contribution in chapter 6 of the dissertation includes analyzing SQM practices within the BSC framework according to their ease of implementation and impact on quality by using simple multi-attribute rating technique (SMART). This analysis can guide construction organizations assessing their SQM practices given their current capabilities to perform the practices and their effect on the SQM quality. The fifth contribution also involves synthesizing leadership principles based on examining literature sources and developing leadership objectives and practices using value focused thinking (VFT) to help create strategic leadership for SQM within construction organizations. The findings from this contribution can help construction organizations select consistent SQM practices that have high impact on quality and are simple to implement across the construction projects and to recognize important leadership practices that help improve the current SQM and promote a positive long-term impact for project quality.

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2. SUPPLIER QUALITY MANAGEMENT INSIDE AND OUTSIDE THE CONSTRUCTION INDUSTRY

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Abstract

Supplier quality management (SQM) inside the construction industry is complex given the one-off nature of projects and the enormity of project size and life cycle. The resultant supply chain that supports these projects is extremely broad and deep, creating unique challenges with managing a network of hundreds and even thousands of independent contractors, sub-contractors and suppliers that often span the globe. It is a continual challenge to ensure that the project equipment, products and materials that are produced are not in need of rework. This paper summarizes findings from the literature of diverse approaches for SQM in the construction industry, and from other industries such as healthcare, manufacturing, aerospace and food. The aim is to identify approaches that could be beneficial to the construction industry such as

supplier partnerships, category captain management, and product life cycle management, and determine how these approaches might be adapted to the construction industry. Engineering managers are challenged to improve SQM within an environment of limited resources. By investigating the effective practices of SQM inside and outside the construction industry, the engineering manager can borrow these practices and implement them. In the future, researchers will synthesize the findings of the literature review with other data sources including structured interviews, focus groups, and survey.

Keywords

Supplier Quality Management, Construction Industry, Supply Chain, Rework.

EMJ Focus Area

Quality Management, Strategic Management.

Introduction

The construction enterprise consists of the delivery of a staggering number of items, including bulk materials, and fabricated components, to a construction site, where they are installed in their final location. Each project is sustained by a broad and global supply chain involving multiple independent contractors, sub-contractors and suppliers. Due to the number of organizations involved and their different levels of sophistication, it is difficult throughout the execution of the construction project to ensure that the required equipment, products and materials are produced and delivered to the project site without any necessity for rework.

This paper describes findings from a research project sponsored by the Construction Industry Institute (CII), and led by a multi-disciplinary team of academic researchers from industrial and civil engineering, and subject matter experts (SMEs) representing construction owners, contractors, and suppliers. CII Research Team 308 (RT 308) addresses a primary research question, namely "*What are the most effective processes and practices for ensuring that project materials and equipment are produced, manufactured, or fabricated in strict accordance with all applicable specifications, and that they are delivered to the project site without any need for rework?*"

The data for this paper come from the archival literature to describe the process of assuring supplier quality inside and outside the construction industry.

The Construction Industry and Supplier Quality Management

Supplier quality management (SQM) is a system of processes and practices applied by the project organization to ensure that the quality of fabricated materials and equipment meet the project's requirements and specifications (Caldas et al., 2012). SQM in the construction industry is complex due to the uniqueness of every project in terms of its scope and life cycle.

The motivation of studying SQM in the construction industry comes from the distinctive nature of the construction industry. The following points summarize important findings from the construction literature:

- The construction product is extremely integrated requiring the management and cooperation of many independent groups and organizations. Quality cannot be addressed by isolated departments and organizations, but rather it must be designed through the entire system (Sullivan, 2011).
- Construction projects are dynamic and irregular in nature. Successful planning and execution benefit from relying on past experiences and lessons-learned (Jongwoo, 2009).

- The role of the construction industry is to provide facilities that meet customers' needs (Burati Jr. et al., 1992).
- "The construction industry is characterized by cost and duration overruns, serious problems in quality standards and safety measures, and an increased number of claims, counterclaims, and litigation. Furthermore, the peculiarity of construction is that no two projects are identical in terms of site conditions, design, use of construction materials, labor requirements, and equipment requirements, construction methods, technical complexity, and level of management skill required." (Singh & Tiong, 2005, pg. 62).
- A major area that contributes to poor organization and project performance is rework (Love, 2002, Love & Sohal, 2002), and high levels of rework disturb schedule targets, reduce productivity, increase cost, and affect quality (Rogge et al., 2001).

In summary, construction projects are expensive, bulky, take a long time to be completed, interfere with the surrounding environment and neighborhoods, and are built by dispersed teams and suppliers in a project-based fashion where participants might never have worked with each other before and might never work together again. Moreover, construction projects are assembled at their final location making their production nomadic (the "factory" is installed where the product will be built). The product is built to fit the environment and often cannot be relocated, and workers move around the product (as contrasted from assembly lines where the product is most often brought to the worker). All of these conditions define the construction industry and profoundly interfere with processes used to deliver its products, and assure their quality.

An abridged mapping of the supplier Quality (SQ) process is depicted in Figure 1 and described in detail in Alves et al. (2013). The map contains five major processes beginning with planning and selection (of the suppliers). Execution (of the fabrication along with the supplier quality plan) follows with subsequent processes depicting release (packages) from shop, received (packages) at site, and mechanical completion. Feedback loops are embedded at each step within the process, and suppliers are informed of non-conformities and deviations when these are identified. Additionally, suppliers' performance can be evaluated and taken into account by procurement in future acquisitions.

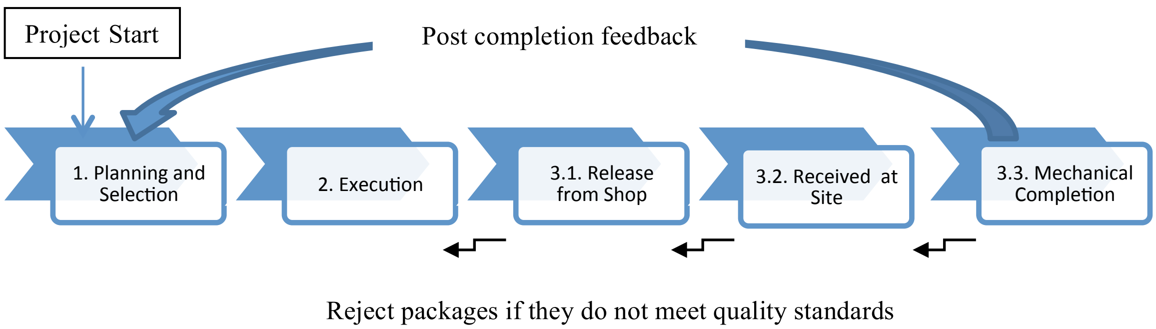

Figure 1: SQ process map. Adapted from Alves et al. (2013).

With regard to the construction supply chain, it is important that the supply chain members involved in the project (contractors, and suppliers) understand what exactly is needed to achieve the required level of quality in different stages of the process. The construction supply chain may involve multiple tiers of suppliers from across the globe adding complexity for any construction project with respect to ensuring supplier quality. Accordingly, supply chain management in the construction industry is critical for the success of SQM and the overall performance of the project. This is not unique to the construction industry. For example, consider the work done by Bounken (2011) in the information technology industry where the author defines the supply chain as a network of material, information, and service operations built up to improve supply transformation and demand. Bounken considers that the supply chain management function must harmonize the processes among the chain partners, focus on a small number of closer suppliers, and exchange the necessary information across the chain to enhance the performance and improve the quality.

Literature Review Methodology

The literature review for this research was conducted based on an intensive examination of the scholarly literature and CII body of knowledge for the subject, supplier quality in the construction industry. The literature review also includes an investigation of quality practices and methods outside the construction industry for companies and industries known for having effective SQM practices. The literature review was supplemented by input from the subject matter experts (SMEs) who were RT 308 team members. Each of the SMEs bring decades of experience within the construction industry in the local and global markets.

This research used a taxonomy of literature review described in Cooper (1988). The taxonomy is a systematic categorization for the literature research effort based on the following characteristics: focus, goal, coverage, and organization. The description of the literature review taxonomy of this research is described next.

The Focus: With regard to the first characteristic of the taxonomy, it can be on research methods, or practices and applications (findings). In this research, the focus is on the practices and approaches of SQM discussed in the literature.

The Goal: The goal of the literature review can be integration, or criticism. In this paper, the goal is to conduct an integrative literature review that generates new knowledge about the topic of supplier quality management. As described by Torraco (2005), integrative literature review is a form of research that reviews and synthesizes literature on a topic in an integrated way such that new perspectives or frameworks on the topic are generated. For the scope of this research, the literature review started by defining four broad areas of study as depicted in Table 1: supplier quality organization, supplier quality system, management's role in SQM, and supplier quality assessment.

Area	Examples of practices within each area
Supplier quality organization	• Internal QMS implementation • Quality personnel development
Supplier quality system	• Partnership with suppliers • Supplier support
Management's role in SQM	• Top management involvement and support
Supplier quality assessment	• Supplier performance measurement • Supplier selection management • Risk management

Table 1: Areas of literature examined

As shown in Table 1, each area has examples of practices in the literature. These four areas were selected for use in formulating a data collection protocol to collect further data from construction organizations in later stages of this research via structured interviews. Also, these areas alongside their relevant practices were chosen to be included in the literature review based on extensive discussions with the SMEs involved in this research, due to the importance of these areas for the construction supply chain. Initially, the discussion started with SQM practices in the construction industry from an organizational standpoint (supplier quality organization) which was originally centered on contractors' and owners' (i.e., those who hire suppliers) internal processes to improve SQM. As the research project unfolded, RT308 academics and SMEs interacted through several face-to-face meetings and conference calls to discuss the findings of the literature review. The continuous process of presentation of findings, discussion, and synthesis resulted in further areas being included for investigation, namely: supplier quality system, management's role in SQM, and supplier quality assessment, in addition to supplier quality organization. The SMEs shared their experiences within these areas, and were eager to know what other practices in the literature support SQM.

In a nutshell, the supplier quality organization involves internal approaches within the organization related to SQM. Neuman et al. (2014) argued that high levels of quality are only achievable when organizations implement quality management procedures and standards with strong management support for quality development across all levels of the supply chain and, more importantly, in a consistent fashion. The second area of the literature is related to the supplier quality system which concerns the efforts to develop suppliers' products through collaboration and support. Modern trends for managing supplier quality are geared towards supporting suppliers' processes, effectively managing the relationships between the organization and the suppliers through strategic partnerships, and collaboration efforts to enhance the overall quality of the supply chain to promote continuous improvement (Batson, 2008; Liker 2004; Liker & Hoseus 2008). The third area of the literature is management's role in SQM which is a crucial area for managing supplier quality within supply chains, because it describes how organization's leadership can impact SQM. With respect to reducing quality problems in construction projects, Smith & Jirik (2006) concluded that if management is committed and involved to improving quality by allocating time and resources into an effective system, then the non-quality consequences will decrease. Similar findings related to the importance of management's role for achieving high levels of quality were extensively discussed in Needy & Ries (2010), Chase (1993), and Isik et al., (2010). Additionally, Neuman et al. (2014) found qualitative and quantitative evidence in construction organizations related to the importance of upper management support to SQM practices and how they help decrease non-conformances (i.e., quality problems).The fourth area of the literature is related to supplier quality assessment which involves utilizing supplier selection and performance measurement that help evaluate and predict supplier's performance. In general, supplier selection is an important aspect for supply chain management, and the selection decisions should focus on the supplier capability to deliver the required level of quality rather than solely on cost (Linn et al., 2006; Liker, 2004). Ahmad (2014) concluded that selecting suppliers with high capability to deliver quality products will ultimately reduce the cost of fixing problems in later stages of construction projects. In addition, supplier quality assessment and its use to support procurement decisions and risk management are essential assessment approaches within supply chain management (Flaig, 2002; Lin et al., 2006; Baston, 2008; Isik et al., 2010; Azambuja & O'Brien, 2012).

The Coverage (Inclusion Criteria): The coverage of the literature is related to the extent of covering the relevant work of the literature focus and goal. In this study, after identifying the four major areas of study, a literature examination was conducted within the construction literature and CII body of knowledge. The literature review was conducted using a number of databases including Ebsco Academics Search Complete, ProQuest Research Library, and ABI/Inform Complete. The inclusion criteria for selection were based on peer-reviewed scholarly publications that are written in English. The articles were selected after reading their abstracts and determining their relevancy to SQM within construction. The selected articles were then examined in-depth to determine if they add new knowledge in terms of identifying SQM practices. While examining the articles, additional relevant articles were selected from the articles' reference list. Further, the literature review findings were constantly presented to the SMEs to determine their inputs regarding the literature review method and to provide more guidance on finding the relevant SQM practices. A limitation of the literature review was that the focus and goal of the study were centered on practices that support the management of quality. While this can be an extremely broad topic, as any practice and every practice can influence the quality of products and services delivered, the authors focused on practices that can be directly related to managing supplier quality and their potential applicability to construction projects.

The same methodology was applied for finding scholarly articles related to SQM practices outside the construction industry. Initially, the scope of search was limited to peer-reviewed scholarly publications; however, because of the limited sources available that describe SQM from multiple industries, the search was broadened to include examining companies' websites from multiple industries that are known by their effective SQM. The inclusion of the examined industries was based on the possibility that their SQM practices can be adapted and successfully applied to the construction industry. In addition each industry has its own motivation for inclusion as described in later section of this paper. Also, the SMEs were actively involved in the process to include/exclude examples from several industries reviewed for this study.

The Organization: There are many formats for organizing the findings of the literature review, such as the chronological, or conceptual based on the interested areas of literature examination. To organize the findings of the literature of this research, the SQM practices identified from the literature examined inside and outside the construction industry were mapped onto the SQ process map presented in Figure 1 to indicate where they could be implemented and practiced. In addition they are classified according to the four major areas of the literature examination.

The discussion of the SQM literature in this paper is broken into two main sections. The first section discusses SQM inside the construction industry with findings presented according to the four areas of study as described in Table 1. The second section discusses SQM outside the construction industry, described according to each industry.

Supplier Quality Management Inside the Construction Industry

We examined the construction industry literature to identify the important practices of SQM as described next.

Supplier Quality Organization

Construction companies understand the importance of documenting and implementing quality management systems (QMSs) in their work. A study done by Lo (2002) ranks the benefits of QMS from a number of construction companies' perspective. The top five benefits of QMS according to the participating companies in the study are: increased business, reduced project cost, reduced rework and scrap, improved quality of work, and smoother business operations.

The education background and training of quality personnel is critical for any construction organization. One of the important considerations related to education and training for the quality function in organizations as determined by Arditi & Gunaydin (1997) is that the organization must determine the root causes of rework and then design training programs aimed at reducing or eliminating the causes.

By having a complete understanding of their internal quality systems, organizations can better ensure successful external relationships with their contractors, suppliers and other stakeholders involved in any project. QMSs are important for all construction companies to manage their internal quality processes and to manage the quality of their suppliers.

Supplier Quality Systems

Arditi & Gunaydin (1998) studied factors that affect process quality of building projects. They report that the capability to produce a quality product is highly dependent on the strength of the relationship among the parties involved in the construction process, in particular the relationship between the organization and supplier. Additional factors within the supplier quality system found in the literature focus on building supplier partnerships, providing support to suppliers, and using supplier quality surveillance (SQS).

Partnership with Suppliers. Peters (1987) recommends that organizations reduce their supplier base and develop mutually beneficial partnerships with their suppliers. Healthy supplier partnerships are important to succeed in the construction industry (Arditi & Gunaydin, 1998). Lazar (1997) describes the importance of building healthy partnerships between owners and contractors. Thomson et al. (1996) identify that the organization should establish a collaborative relationship with a "preferred" supplier, especially when this relationship will span multiple construction projects over a long period of time. Working together in a cooperative environment under mutual goals of successful project completion avoids future problems of dissatisfactions, claims, and litigation. However, disadvantages of partnerships may include: ineffective cooperation due to conflicting objectives and lack of trust between the organization and supplier. Also, the organization could face difficulties in setting performance measures for the partnership effectiveness. When left unchecked these disadvantages may lead the organization to fulfill a long term commitment with a possibly inadequate supplier. Crane & Felder (1999) state that the partnering process should include partnering objectives and measures. Partnering objectives are strategic criteria for the entire relationship, and partnering measures are management tools to ensure progress toward objectives and desired results.

A more recent form of partnership between construction actors (owners, contractors, designers, and major suppliers) is the integrated project delivery (IPD) form of contract to organize project teams based on relational contracting principles (i.e., long term relationships as opposed to transactional/one-time interactions). The IPD format promotes “shared pain and gain” where actors collaborate to meet the owners’ needs and the focus is the project and not individual firms. The team wins and loses money together which promotes collaboration to make the project profitable for all and to avoid failures (Darrington et al., 2009).

If a partnership involves conflicting goals and lack of trust, it will not achieve effective results. Harper & Bernold (2005) investigated a number of companies in the capital project market and identified what they describe as the key barriers to supplier partnership. These barriers are: conflicting goals that prevent common vision and a win-win working relationship; and resistance to change by the organization and supplier that affect the improvement of their relationship.

Tommelein et al. (2003) examined the construction supply chain and identified examples of partnerships between owners, suppliers, and contractors aiming at improving product quality, delivery lead times, reliability of delivery, and reduced levels of inventory to meet demand. Some of these partnerships require early supplier involvement in product design and fabrication, vendor management of site inventories, definition of preferred supplier agreements, and constant assessment of supplier performance and feedback.

Supplier Support. Needy & Ries (2010) studied organizations with effective quality management systems. They conclude that successful construction organizations are proactive concerning their suppliers’ QMS and develop their suppliers through training. These construction organizations offer their QMS to be used by the supplier organizations for completing project quality objectives in the absence of a supplier QMS.

Supplier Quality Surveillance. One of the challenging tasks for any construction project is to ensure supplier quality, especially if there are multiple tiers of suppliers. Supplier quality surveillance (SQS) is one of the common methods used to ensure supplier quality. This method has both advantages and disadvantages. Singer et al. (1989) in their study of the construction of nuclear power stations, analyzed surveillance as a method to ensure supplier quality. They cite making the supplier accountable for quality and preventing construction delays to be important advantages of surveillance. However their research indicates that the surveillance method may lead to unexpected errors unless the supplier is closely supervised. Also, communication can be a challenge when there are many tiers of suppliers involved in the project. They conclude that despite it being difficult to estimate the required degree of surveillance needed in a project, this process can be effective in producing quality results when properly implemented. In general, it is true that the more you look the more you find, and that was confirmed in Ahmad's (2014) work which evaluated the effect of surveillance in construction projects. The more surveillance was added to the process shown in Figure 1, the more non-conformances were found and corrected. Moreover, Neuman (2014) observed a direct relationship between tracking the surveillance effort, as well as rating supplier performance after execution, and finding and correcting non-conformances.

Other methods may be found in the literature for ensuring supplier quality, such as partnership with suppliers (as mentioned earlier in this paper), and supplier support and development training (Tommelein et al., 2003). Organizations should identify the pros and cons of each method before implementation to avoid any future problems of rework. In general, any chosen method to ensure supplier quality requires consistent feedback among the parties involved, as well as clear objectives and technical specifications.

Management's Role

Lo (2002) identifies a number of difficulties with properly implementing a QMS such as: lack of involvement from top management, and inconsistency in inspection procedures. Research conducted by Needy & Ries (2010) found that effective quality management in the capital facilities delivery industry requires:

1. Consistent and demonstrable management commitment.
2. Capable and consistent quality management processes.
3. Integrating and aligning quality management and project execution processes.
4. Providing frequent and relevant quality management training opportunities for employees in order to maintain the required level of competence.
5. Cultivating partnerships with suppliers and contractors across the project life.
6. Establishing, communicating and using quality metrics across the project life cycle.

These findings highlight the importance of management commitment to quality objectives in current and future projects.

In a similar fashion, Chase (1993) described common elements of management roles used by construction organizations to improve quality. The elements include top management involvement and commitment, the use of formalized process improvement techniques, helping suppliers and subcontractors improve, and striving for continuous improvement. Shiramizu & Singh (2007) present three main roles to be undertaken by management in order to maintain quality within the organization, including: motivating employees through empowerment, investing money and time in training, and supporting core values in employees to sustain quality.

The literature related to the importance of management for improving quality is wide and broad. Despite several methods that the management may use to support quality, consistent commitment and support are the essentials for any management role. Additionally, Neuman et al. (2014) indicated that companies with upper management involvement in the SQM reportedly find non-conformances earlier in the process depicted in Figure 1 and are viewed by their peers as high performing organizations when it comes to SQM practices.

Supplier Quality Assessment

Harper & Bernold (2005) rank the top five performance measures to assess supplier performance, based on surveying a number of contractors. The top five performance measures that arose from this survey are: quality of work, delivery delays, past working relationships, cost competitiveness, and technological capability. Supplier quality assessment may involve several challenges. Songhori et al. (2011) point out that globalization has brought several challenges to designing an effective supplier selection strategy and selecting the right suppliers which are to become part of the organization's supply chain. The authors conclude that effective supplier selection and evaluation processes can directly impact supply chain performance, resulting in improved outcomes to the organizations. However, as discussed by Azambuja & O'Brien (2014), decision support systems to aid in supplier selection in construction organizations might not be available, especially in the area of engineered equipment.

Risk management is a major component of project management due to the complex, dynamic, and difficult nature of construction projects. Consequently, supplier quality assessment is also part of managing risks in construction projects. According to Isik et al. (2010), risk in a construction project is unavoidable and significantly affects the project performance, quality, and budget. However, risk can be minimized by proper risk management to reduce its undesirable affects. Ford et al. (2005) noted that many managers are more concerned with making quick fixes to current problems rather than implementing long-term solutions for improving organizational performance. Top management must mitigate the risks associated with myopic and short-term solutions and instead commit to decisions resulting in long-term benefits for the organization. Along these lines, the IPD contract mentioned earlier also supports the sharing of risks associated with a project by ensuring that all stakeholders are actively involved in minimizing risks instead of just transferring the risks to specific parties in a project (Darrington et al., 2009).

Supplier Quality Management Outside the Construction Industry

We examined supplier quality management practices from diverse industries outside the construction industry to identify relevant practices which may be able to be adapted and successfully applied to the construction industry. These outside industries include healthcare, manufacturing, aerospace, shipbuilding, and the food and restaurant industry. The healthcare industry is examined because quality problems with the supplied materials and equipment may cause adverse consequences in healthcare processes and ultimately affect or even cost human lives. The manufacturing industry is studied because of its reputation for a complex supply chain much like the one that supports the construction industry and its need for thousands of items (engineered or commodity) in any single project. The aerospace industry is examined due to its complex supply chain and because even minor safety and quality errors potentially can lead to serious consequences to passengers and crew members resulting in loss of life and significant financial losses. The shipbuilding industry is studied because the production process is sophisticated and very customized (like in the construction industry) and the error tolerance is very low. Additionally, the shipbuilding and aerospace industries products are bulky, very expensive, and assembled in a fixed position (with workers moving around the product) like construction projects. The motivation of examining the food and restaurant industry is that this industry has great challenges to ensure consistency in a dispersed supply chain (like construction supply chains) and maintain the safety and quality of the food served. A decrease in quality standards will result in losing customer-base and reputation damage. SQ practices from these industries cut across the supplier quality organization, the supplier quality system, the role of management in SQM, and supplier quality assessment as categorized in Table 1.

Healthcare Industry

The equipment supplied for the healthcare industry may include bulk materials containing sophisticated components that may be customized for each order. Trombetta (2007a) reports findings from a study indicating that supplies represent the second highest expense for hospitals after labor cost. This study goes on to report that a common practice for healthcare manufacturers and suppliers to hospitals is to send representatives to hospitals to meet with representatives of the hospitals' purchasing departments. A modified approach is to establish a partnership between hospitals and suppliers, thereby becoming a value-added partner, contributing to the customer's (hospital) efficiency and profitability.

Trombetta (2007b) proposes the category captain management (CCM) method to define the supplier/manufacturer as a true, legitimate business partner with the buyer. Desroches et al. (2003) define CCM as an arrangement where a supplier, often the category (product type) leader, takes on a significant role in the management of the category, including brands of competitors. CCM is widely used in the health and pharmaceutical industries, especially when the product uniqueness is not significantly important. In other words, if the hospital/pharmacy products do not have unique features among the other competitors, the CCM approach is usually applied. The key organizational principle for the CCM as determined by Trombetta (2007b) is to develop a strong relationship in which the supplier takes the effort to know how to operate the buyer's (hospital/pharmacy) business and to effectively face any coming challenges.

The healthcare industry literature also identifies important approaches to maintain strong relationships and partnerships with the suppliers. For example, Hollyoake (2006) described the importance of targeting strategic suppliers that have proper capabilities (sufficient resources, and excellent performance) to form long-term partnerships. In addition, partnership policies and decisions in healthcare must be supported by management. Wright & Taylor (2005) addressed partnership policies with suppliers in the healthcare industry to be supported and motivated by management.

Manufacturing Industry

Most of the items/raw materials delivered to manufacturing sites are large in number and from various suppliers and sub-suppliers from different locations globally. Watkins (2005) observed various manufacturing companies from around the world and developed a collection of observations and recommendations for assessing the operational management of a supplier as shown below:

- Assess the overall capabilities and limitations of a supplier, such as performance metrics, financial metrics, and certifications.
- Describe the effectiveness of the management system based on clear objectives.
- Conduct a detailed review of current and historical concerns. The review may include assessing what the organization considers normal vs. unexpected failure.

- Evaluate approaches to operational planning, with particular focus on manufacturing product and process metrics and the use of superior quality planning, and methods.

The article suggests the following practices for quality management:

- Potential suppliers should be assessed carefully by identifying and evaluating cultural barriers, technical capabilities, as well as financial resources.
- Analyze the end user (customer) satisfaction measures by surveys or performance benchmarking.
- The supplier personnel capabilities must be assessed to determine if they will be adaptive to the customer requirements.

Another manufacturing example is the electronic systems and equipment manufacturing that often involves several suppliers and sub-suppliers in the supply chain. Forker & Hershauer (2000) conducted a study that examines the effect of suppliers' internal quality management practices and buyers' supplier development practices on customer satisfaction, supplier satisfaction, and supplier quality performance. The authors surveyed the population of direct materials suppliers for a common customer manufacturer of electronic systems and equipment. The sample size was 181 pairs of matched survey replies from both buyers and suppliers. Recommendations from the study include:

- Regular performance feedback to the firm’s suppliers, also monthly and yearly solicitations to suppliers to rate its conduct as a business partner.
- Quality focus (versus price or schedule) in the selection of suppliers.
- Trust of a few loyal suppliers.
- Involvement in the suppliers' product development process.

- Extension of long-term contracts to the suppliers by the customer.
- Clarity of specifications provided to suppliers.

The authors concluded that clarity, transparency, and control of quality management and supplier development programs are the key factors that lead to mutual satisfaction between buyers and suppliers.

A study within the electronic manufacturing field by Forker et al. (1997) identified the importance of the internal QMS of the companies on improving supplier quality performance. The study encouraged the electronic manufacturing companies to improve their quality departments developing employees and training them in order to better manage the external relationships with their suppliers.

With regard to the external relationships with suppliers, Agus (2011) identified the importance of proper information sharing and partnership within the supply chain to improve the quality of products in the general manufacturing industry. Similar findings within semiconductor manufacturing were discussed by Wu et al. (2011). The authors argued that cooperation and strategic alliances with suppliers will increase the operational performance of the supply chain.

Regarding the automotive industry, which can be viewed as a large subset of the manufacturing industry, lessons from one of the largest car automakers abound in the literature. Practices developed and deployed by Toyota to promote SQM are discussed by Liker (2004) and Liker and Hoseus (2008) to cite two of the more recent publications on the topic. The review of SQM practices employed by Toyota deserves a study of its own; however, we chose to report some which might be directly applicable to construction. Liker (2004) stresses the importance Toyota places on developing its supplier base to assure quality in at least three principles described in his book: “Build a culture of stopping to fix problems, to get quality right at the first time”; “Respect your extended network of partners and suppliers by challenging them and helping them improve”; and “Go and see for yourself to thoroughly understand the situation”. While these principles seem like generic statements they actually call for a direct and immediate observation of processes and suppliers seeking to understand how they work and fail so that they can be continuously improved. Problems should be immediately corrected as they are spotted and production should not continue until a root cause is found and the problem eliminated. Toyota suppliers undergo extensive periods of testing and evaluation, and before they are considered suppliers, they are tasked with developing products for the automaker and their technical capability is challenged before a purchase order is released. Engineers from Toyota and its suppliers spend periods in each other’s shops and offices to learn about their practices and are encouraged to share their knowledge to develop better products. Additionally, Toyota takes great care while recruiting and developing its workers and suppliers (Liker & Hoseus, 2008; Morgan & Liker, 2006). Mentoring activities between senior and junior staff, constant training and development of technical proficiency in the processes and products used, the use of visual management and two-way communication are important practices used by Toyota to build a culture of continuous improvement and the delivery of quality products.

Aerospace Industry

High quality standards are critical within the aerospace industry due to the important safety regulations, and high consequences for failure resulting in potential litigations. As one of the world’s largest aerospace manufacturers, Boeing is an obvious company to examine. At Boeing, suppliers are managed throughout the product life cycle.

Successful partnership with their suppliers through a SQS system builds a proactive approach to improve suppliers' quality. Boeing's SQS tools include: product assessment (PA), quality process assessment (QPA), and manufacturing process assessment (MPA) (Boeing Supplier Quality Surveillance, 2012).

SQS activities are executed by supplier quality representatives from Boeing, and are conducted at the supplier's facility or the supplier subcontractor's facility under the agreed provisions that address Boeing's right of surveillance and review of goods, procedures, and practices (Boeing Supplier Quality Surveillance, 2012).

Prior to Boeing performing its own assessment, the following actions have to be performed by the supplier in advance:

- Review the checklist(s) prior to the on-site visit by the Boeing supplier quality representative
- Provide admission to the applicable process documentations, and training records
- Prepare the relative process performance data for the processes under assessment
- Inform knowledgeable personnel to be available during assessment, and
- Provide contact information for the local regulatory agency representative when requested (Boeing SQS Supplier Presentation, 2010).

The major benefits of this system are:

- Support monitoring the suppliers without hindering the production process, and help improve the supplier's procedures.

- Provide information regarding the supplier's processes to the supplier, Boeing, and the other parties involved including Boeing's customers and regulatory agencies (Boeing SQS Supplier Presentation, 2010).

Another example for suppliers monitoring and improvement is found in NASA, where the suppliers are supervised through frequent visits to their facilities by NASA's employees (NASA's Academy of Program and Project Leadership (APPL), 2000). During these visits, NASA assesses the strengths and weakness of the suppliers and designs long-term agreements for supplier performance improvement.

With regard to supplier selection within the aerospace industry, Dietrich & Cudney (2011) identified the importance of the initial assessment for the suppliers' technical capabilities to improve the supply chain outcomes (collaborations and quality delivery). Similar conclusions were found by Gordon (2006) who discussed the necessity to assess the suppliers' capacity and capability during planning and selection to ensure effective management of the aerospace supply chain.

Shipbuilding Industry

Ensuring high quality in the shipbuilding industry is critical, and challenging to achieve given the product complexity, high degree of customization and stringent safety requirements. Sawhney et al. (2007) observed many parallels between the construction industry and the shipbuilding industry. Like the construction industry, the shipbuilding industry depends on a global supply chain of partners and suppliers to help develop and manufacture new ships. Proper communication and information exchange between the primary parties during the product life cycle is important to avoid missing any valuable information that may impact the quality of the final product. One successful example of a technological tool to support communication is Siemens PLM Software® a product lifecycle management (PLM) platform for the shipbuilding industry (Siemens PLM software, 2013). The purpose of this software/platform is to minimize miscommunication and rework complexities. This is particularly important to facilitate collaboration among all partners and suppliers in the shipbuilding supply chain. The idea behind the software is to create an integrated and synchronized environment linking designers, production team, and suppliers to improve shipbuilding productivity (Siemens, 2012).

The benefits of creating a common platform among the involved parties in shipbuilding are:

- Enabling companies to securely share the relative project information with partners and suppliers.
- Updating partners and suppliers with any changes.
- Providing access to the production technical information.

Similar findings with regard to effective communication and information exchange in the shipbuilding industry were discussed in Sawhney et al. (2007) study for supply chain integration in the global shipbuilding industry. Primo & DuBois (2012) also emphasized the importance of enhancing the technological capabilities in knowledge sharing among the shipbuilding supply chain members. Moreno's (2009) research examined the shipbuilding production methods and compared them to those that are implemented in the construction industry. To improve construction production methods, Moreno recommended learning from shipbuilding practices with regard to supply chain management integration and automation.

Food and Restaurant Industry

We discuss examples of two companies: Starbucks® and Chipotle® that are known for a reputation of effectively managing their supply chain in the food and restaurant industry. At Starbucks, ensuring the quality of the supplied coffee beans requires an advanced supplier management system. Austin & Reavis (2004) observed that specialty coffee comes from mid-sized farms (suppliers), and farm owners don't have sufficient business and communication skills to provide coffee beans within the quality standards for Starbucks. So, Starbucks conducted an alliance with Conservation International, a non-profit organization, to provide training and support to farmers in order to maintain the quality and environmental standards of coffee tree growing and production. In addition, the farmer (the supplier) selection includes several criteria to be met in order to become a preferred coffee supplier with priority for future purchasing. As a result, Starbucks maintains the reputation of providing high quality coffee and social responsibility through its supplier management system. As described by Austin & Reavis (2004) and US Labor Education in the Americas Project (2007), Starbuck's criteria to choose the preferred coffee supplier employ a point system as follows:

- Environmental impact: soil management, water reduction, clean water, use of shade, waste management (50 points)
- Social conditions: health and safety, living conditions (30 points)
- Economic issues: long terms relationships, economic transparency throughout the supply chain (20 points)

At Chipotle, new concepts for managing their food suppliers are defined. Chipotle's 2012 annual report suggests the following practices for supplier quality:

- Supplier Relationship: Chipotle works closely with its suppliers to make sure that it sources consistent and low-cost inputs from sustainable sources "We have established close relationships with some of the top suppliers in the industry, and we actively maintain a limited list of approved suppliers from whom our distributors must purchase." (Chipotle, 2012, pg. 5).
- Supply chain: "Maintaining the high levels of quality we expect in our restaurants depends in part on our ability to acquire high-quality, fresh ingredients and other necessary supplies that meet our specifications from reliable suppliers. Our distribution centers purchase from various suppliers we carefully select based on quality and their understanding of our mission, and we seek to develop mutually beneficial long-term relationships with suppliers." (Chipotle, 2012, pg. 6).

Literature Findings from Inside and Outside the Construction Industry

The findings from the literature examination of SQM inside and outside the construction industry are summarized in four areas that were described in Table 1. These findings are also mapped onto the SQ process map, depicted in Figure 1, in order to be adapted by construction professionals. Tables 2 and 3 summarize the findings of the literature review inside and outside the construction industry respectively.

Literature review area	Literature source	Findings (SQM practices)	Location on SQ map (Figure 1)	Comments
Supplier quality organization	Lo (2002); Arditi & Gunaydin (1997)	• Internal QMS implementation • Quality personnel development	2. Execution, *through* 3.3. Mechanical completion	Implementing internal QMS ensures better external relationships with suppliers
Supplier quality system	Peter (1987); Arditi & Gunaydin (1998); Lazar (1997); Thomson et al., (1996); Crane & Felder (1999); Darrington et al. (2009); Harper & Bernold (2005); Tommelein et al. (2003)	• Partnership with suppliers and developing a preferred and dependable supplier base	1. Planning and selection	Mutual goals should be defined
	Needy & Ries (2010); Tommelein et al. (2003)	• Supplier support and development	2. Execution	Construction organizations should support their suppliers
	Singer, Chirchill, & Dale (1989); Ahmad (2014); Neuman (2014)	• Supplier quality surveillance	2. Execution & 3.1. Release from shop	
Management's role in SQM	Lo (2002); Needy (2010); Chase (1993); Shiramizu & Singh (2007); Neuman et al. (2014)	• Management commitment and support to SQM	All stages	
Supplier quality assessment	Harper & Bernold (2005)	• Supplier performance management	2. Execution, *through* 3.3. Mechanical completion	
	Songhori et al. (2011); Linn et al., (2006); Azambuja & O'Brien (2012)	• Supplier selection and evaluation process	All stages	Effective supplier selection positively impacts supply chain performance
	Isik et al., (2010); Ford et al., (2005); Darrington et al. (2009)	• Risk management	All stages	Risk management reduces the occurrence of undesirable results

Table 2: Literature review findings of SQM inside the construction industry

Literature review area	Industry	Findings (SQM practices)	Location on SQ map (Figure 1)	Comments
Supplier quality organization	Manufacturing	• Internal QMS implementation • Quality personnel development	2. Execution, *through* 3.3. Mechanical Completion	Promoting a culture of continuous improvement
Supplier quality system	Healthcare	• Partnership with suppliers	1. Planning and selection	The supplier should have high qualifications
		• Suppliers as true business partners (Category Captain Management)	1. Planning and selection	
	Manufacturing	• Regular performance feedback to the firm's suppliers • Direct observation of processes with immediate fixing for quality problems.	2. Execution	Observe and document the supplier work. Types of documents may involve: Non-conformance Report (NCR), & Corrective Action Report (CAR)
		• Supplier development (mentoring, development of technical proficiency, respect and challenge suppliers) • Extensive training with workers exchange to learn about owner/supplier processes.	1. Planning and selection	Promoting transparency and open communication to develop and fabricate products from the start.
	Aerospace	• Suppliers' capabilities assessment and improvement • Supplier quality surveillance (SQS)	1. Planning and selection *through* 3.1. Release from shop	Similarities with the construction industry, i.e., product bulky, expensive, thousands of parts
	Food and Restaurant	• Supplier alliance, training and support • Long-term relationship with suppliers	1. Planning and selection & 2. Execution	Develop mutually beneficial long-term relationships with reliable suppliers
Management's role in SQM	Manufacturing	• Cultural barriers evaluation for global suppliers • Clear objectives definition by the management	1. Planning and selection	Develop relationships with a long-term view.
Supplier quality assessment	Manufacturing	• Selection of suppliers (quality focus) • Assessment of supplier's capacity and capability.	1. Planning and selection	Supplier commits to developing products which are analyzed during selection.
	Aerospace	• Assessment of supplier's capacity and capability	1. Planning and selection	
	Shipbuilding	• Proper communication and information exchange (product life cycle management)	2. Execution, *through* 3.3. Mechanical completion	

Table 3: Literature review findings of SQM outside the construction industry

As described in Tables 2 and 3, the construction industry and the other industries studied, in particular manufacturing, place an importance on developing their internal quality systems to ensure better relationships with their suppliers. With regard to the supplier quality system, the construction industry and the other industries studied form partnerships with suppliers and create opportunities to train and develop them. The aerospace industry implements supplier quality surveillance within their SQM. Within the manufacturing industry, we found that management works to define clear objectives and evaluate cultural barriers for global suppliers. For supplier quality assessment in manufacturing, we found the focusing on quality while selecting the suppliers and work to develop suppliers by challenging them to show what they can deliver. In the construction industry, we found that supplier selection and performance management impact the project performance. Also, proper risk management is a critical practice in project management. Along these lines, new forms of contract are being developed in construction to ensure that profits, losses, and risks are shared forcing every project stakeholder to have “skin in the game” and aim for project success instead of only looking after their own business. Within the shipbuilding industry, we noted evidence of the importance of proper information exchange methods for the involved project participants.

Conclusions

The construction industry consists of diverse projects that use different types of supplied bulk materials and equipment that have to be fabricated and delivered to the project site with a high level of quality. Supplier quality management in the construction industry is challenging due to project diversity in terms of size and life cycle, and the supply chain being both broad and deep. This paper examines supplier quality in the construction industry and suggests some efficient practices of supplier quality management outside the construction industry. The objective is to recognize practices that can be useful to the construction industry such as supplier partnerships, and product life cycle management, and determine how these practices can be implemented in the construction industry within the SQ process map, shown in Figure 1. The discussion with the SMEs revealed that the practices found from outside the construction industry appear to be similar to the existing practices within the construction industry. However, the SMEs believe that some practices are not currently implemented in the construction industry in a consistent manner such as providing feedback to suppliers, and supplier performance management. Further investigation is needed to determine a thorough analysis from multiple data sources to describe the existing SQM in the construction industry.

In summary, the primary lessons learned from with regard to improving SQM:

- Develop and respect close relationships (partnerships) with suppliers and challenge them to improve the goods supplied.
- Involve fewer, more dependable suppliers.
- Implement a feedback system between the buyer and supplier with supplier improvement opportunities based on measurable objectives.
- Constantly observe processes directly at the supplier facility while offering development opportunities to the supplier.
- Develop a careful supplier selection process focusing on quality aspects, and visit suppliers' facilities during selection (if possible exchange workers) to collaboratively develop products and to assure quality requirements are known.
- Mentor and develop suppliers' workforce to be technically capable of delivering quality products. While this might not be possible for the extended supply chain, priority can be given to first tier suppliers and to those areas deemed most critical.

- Ensure top management involvement and commitment. Implement contractual arrangements and mechanisms that promote the success of the project by making all participants accountable ("have skin in the game") by sharing risk, profits, and losses.

Implications for the Engineering Manager

This paper investigates the practices of SQM inside and outside the construction industry. The construction industry develops its products and activities in a project-based fashion, which is the case for many other industries and organizations, e.g., software, defense, consulting, production of one of a kind and engineered to order products, government organizations (e.g., NASA, Armed Forces), and engineering projects in general. Accordingly, the discussion and the findings presented can be extended to other environments which operate in a project-based fashion and/or have products that bear similarities to construction projects, e.g., ships, airplanes, rockets.

SQM is a critical aspect of engineering management; therefore, it is beneficial that engineering managers be aware of effective SQM practices from multiple industries that can be implemented to improve engineering products and services. Engineering managers can benefit from this research to effectively manage suppliers in the supply chain of any project within construction, healthcare, and automotive just to name a few. Most engineering managers face the challenge of improving the performance of their suppliers within the constraints of limited resources of time, budget, and technical capabilities. By investigating the effective practices of SQM inside the construction industry, the engineering manager can develop plans to enhance suppliers performance through effective training and education for quality personnel to determine the root causes of poor quality problems, strategic supplier selection processes to overcome quality problems, and long-term partnership decisions with suppliers to build a trusted supplier base for future projects. In addition, the paper provides important information to engineering managers about SQM from outside the construction industry such as healthcare, aerospace and food industry. For example, engineering managers can adopt the efforts to develop and establish long-term agreements (partnerships) with suppliers that are practiced in the food industry to secure high quality supplies of raw materials and products in the long run. As important as partnerships, proper communication and information exchange are critical aspects to consider by engineering managers. The paper presents an example of project information synchronization software from the shipbuilding industry that is used to effectively exchange project information. It is important to the engineering manager to assure that information is clear and shared on time by all the parties involved in any project, especially if these parties are located globally. In summary, engineering managers must understand the importance of not limiting the investigation of a particular industry when learning about SQM. By benchmarking practices from diverse industries, engineering managers can use the practices identified from multiple industries to improve the current SQM in any project.

Limitations and Future Work

This research was based on a literature review taxonomy with a goal of integrative review to increase the knowledge about SQM and to propose practices that can be implemented in the construction industry to improve SQM. The literature review focused on the SQM practices inside and outside the construction industry found on each examined source. The identified practices from each industry are limited to what we found in the reviewed sources. There could be other effective practices from a particular industry, for example manufacturing, that may be available in other sources that were not included in our review. This research did not also examine the cost aspects of quality in the literature.

The SMEs of the team determined that most of the identified practices in this research are applicable or already have been practiced in the construction industry. However, there is always a persistent pressure to choose suppliers with minimum cost, the strategic choice of low cost suppliers can lead to poor quality and a high number of rework tasks. The future work of this research may include cost implications of supplier quality that help engineering managers support their strategic decisions of supplier selection to avoid future quality problems in construction projects.

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3. A QUALITATIVE DATA ANALYSIS FOR SUPPLIER QUALITY MANAGEMENT PRACTICES WITHIN THE CONSTRUCTION INDUSTRY

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Abstract

The process of assuring the procured and fabricated materials for an engineer-procure-construct (EPC) project are within their quality requirements is challenging because nearly every EPC construction project is complex and distinctive from previous projects in terms of its size, supply chain, and materials usage. In particular, EPC projects include contractors, subcontractors, and suppliers who collaboratively perform the engineering design for the project, procure the required materials and equipment, and then construct. Many (or most) construction organizations, representing owners and contractors, place high importance on documenting and tracking the quality performance of their suppliers as part of their supplier quality management (SQM) to ensure that procured and fabricated materials are within the quality specifications. However, these organizations still face problems with their SQM evidenced by the large number

of rework tasks and replacement efforts for the supplied materials in the EPC projects. This highlights the importance of investigating the current supplier quality practices to explore effective practices to deliver products with the expected quality and zero rework. In this paper, six structured interviews were conducted with contractors, and 92 SQM documents including procedures and reports from 21 owners and contractors in the EPC industry were analyzed to identify the current practices used by these organizations with regard to SQM, and the most effective practices that construction engineering managers could borrow to improve the existing SQM in the EPC projects.

CE Database Subject Headings

Construction Industry, Contractors, Owners, Engineer-Procure-Construct (EPC), Supply Chain Management (SCM).

Keywords

Supplier Quality Management (SQM), Rework, Construction Supply Chain, Supplier Quality (SQ) Process Map, Qualitative Data Analysis, Grounded Theory.

Introduction

This paper presents findings from a research endeavor supported by the Construction Industry Institute (CII), and led by the Research Team 308 (RT 308) representing academic researchers from industrial and civil/construction engineering. The research team also involved a group of subject matter experts (SMEs) from the EPC industry, representing their member organizations in the CII as construction owners, contractors, and suppliers. Members from 21 organizations participated in this research project, and each team member brought multiple years of experience in the local and global construction market. The major research question under study can be stated as follows: *What are the most effective processes and practices for ensuring that project materials and equipment are produced, manufactured, or fabricated in strict accordance with all applicable specifications, and that they are delivered to the project site without any need for rework?* Data were collected from a range of quantitative and qualitative sources including a literature review for supplier quality management (SQM) inside and outside the construction industry, (AlMaian et al., 2013), SQM documents provided by participating organizations, focus group meetings with representatives of supplier organizations, purchase order (PO) data collection instrument, and a series of structured interviews. The two main data sources that are the subject of this paper are the SQM documents and structured interviews.

The project started with the development of a process map depicting the main stages of supplier quality in EPC projects by collecting information from the SMEs through face-to-face meetings, site visits, and other documented sources. Figure 1 depicts a high-level process map of the supplier quality (SQ) process. The map contains five major processes beginning with planning and selection of the suppliers. Execution (of the fabrication along with the supplier quality plan) follows with subsequent processes depicting release of completed purchase orders (POs), i.e. packages of fabricated products, from the supplier's shop, receipt of those packages at the construction site, and mechanical completion (products are physically connected in place in the facility), which marks the end of the scope of analysis for this project. Feedback loops are embedded at each step within the process. Details of this SQ process can be found in Alves et al. (2013).

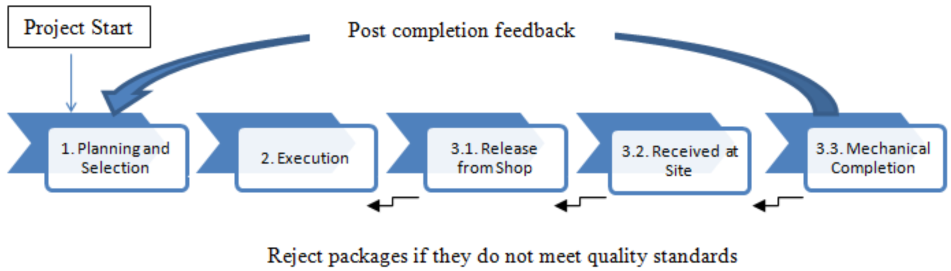

Figure 1: Supplier quality (SQ) process map. Adapted from Alves et al. (2013).

The SQ process map is used in this paper to define the main stages of the SQ process as described by the SMEs and to locate the practices described by the various data sources on the map.

The purpose of this paper is to identify effective practices to manage supplier quality that can be used by professionals in the construction industry to improve their SQM and reduce the need for rework and replacements in the field. The findings of this research will benefit the design, construction, supplier, and management professionals and researchers in the construction industry to explore the applicable practices that would help to improve existing SQM practices in EPC projects.

Background on EPC Supply Chain

An engineer-procure-construct (EPC) project is a complex process involving a set of products (materials, equipment), services, and construction tasks designed specifically to complete a particular output for a customer within a certain period of time: a building, a power plant, a turnkey factory, or the like (Cova & Hoskins, 1997). In EPC projects, owners, contractors, subcontractors, and suppliers collaborate for a definite period of time to deliver the project to the client and then move on to other projects (Caldas, 2012). Yeo & Ning (2002) recognized additional distinctive characteristics of EPC projects: the actions are interdependent, the work is split into many units leading to a compound organizational structure, and the unsteady environment compels recurrent changes.

Supplier quality management (SQM) in the EPC project is a key factor of the overall project success with respect to quality (Tommelein et al., 2003; Needy & Ries, 2010). SQM is a system of processes and practices applied by the project organization to ensure that the quality of fabricated materials and equipment meet the project's requirements and specifications (Caldas et al., 2012). SQM in the construction supply chain depends largely on how the members involved in the project (contractors, subcontractors, and suppliers), understand what exactly is needed to achieve the required level of quality. Each member acts as a functional area within the chain with an integrated linkage between each member and the others. The construction supply chain members may involve multiple tiers of suppliers adding complexity for any EPC project with respect to ensuring supplier quality. An illustration of the process flow diagram for the supply chain of a construction project appears in Figure 2.

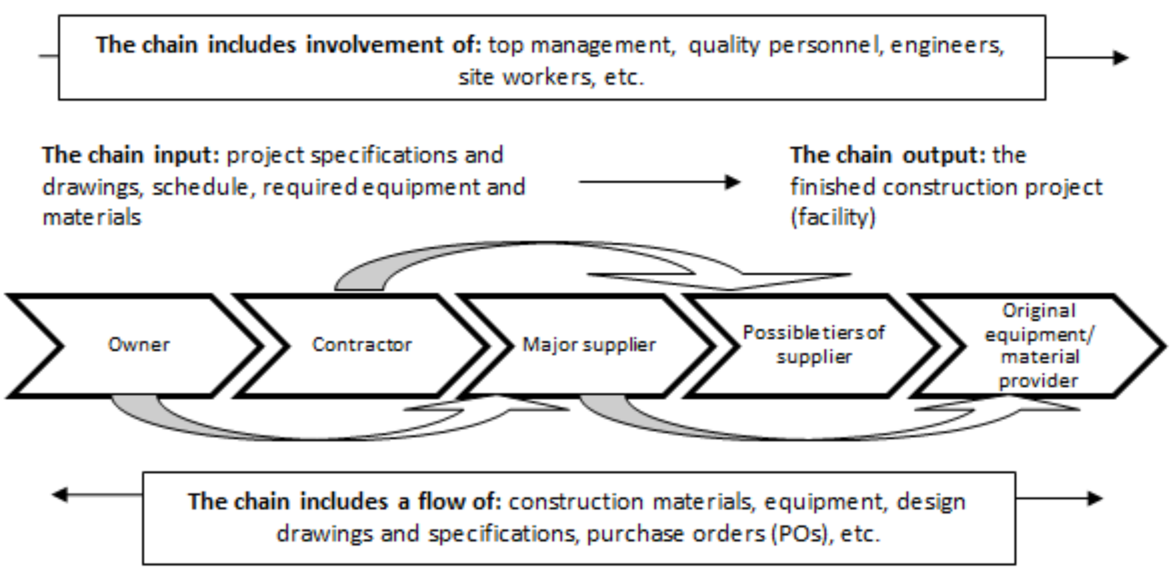

Figure 2: The process flow diagram for the supply chain of a construction project

The Council of Supply Chain Management Professionals (2012) contends that supply chain management (SCM) is an integrating function that links major business function processes within and across companies into a consistent and high-performing business model.

Qualitative Data Analysis

The data in this research came from two main sources (the structured interviews and SQM documents) that were collected in written or verbal form, and then summarized in narrative form. Schutt (2012) summarized the major features of qualitative data analysis in which the focus is on meanings not quantifiable issues, the study is in depth, and the goal is to come up with a detailed description rather than measurement of particular variables. In this research, qualitative approaches for data analysis are considered the most appropriate methods for analyzing this type of data because the study does not depend on specific variables for analysis, but rather on concepts and meanings. Therefore, the focus of this study is to draw conclusions based on detailed understanding and discovery of relationships between the concepts.

In order to achieve reasonable conclusions, an effective qualitative data collection protocol should use a systematic process for data collection, a planned method and documentation for data analysis, in addition to a multiple-person contribution for verification (Srnka & Koeszegi, 2007). In this research, we used systematic methods for data collection and analysis. As the research progressed, the data analysis was presented to the SMEs to obtain feedback, interpretation and validation of findings.

Along these lines, Schutt (2012) determined the steps for qualitative data analysis, which were used as guidance in this research. According to Schutt, the data analysis process starts with documenting the data collection process, and ends with validation and reporting. An overview of the qualitative data analysis process is presented in Figure 3.

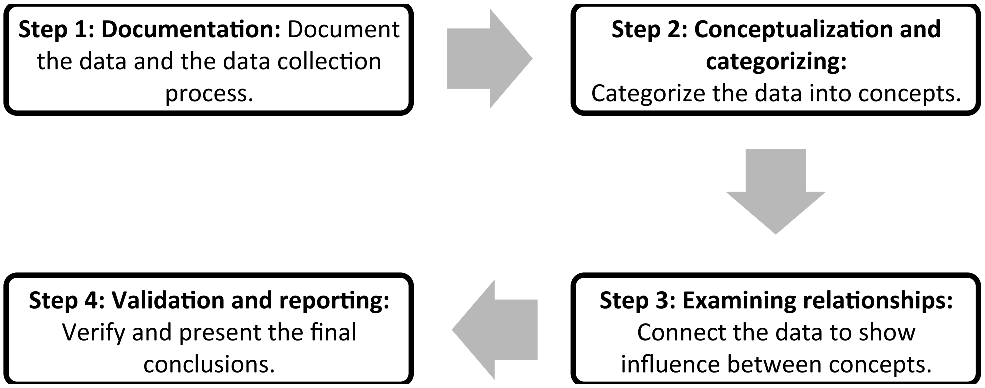

Figure 3: An overview of the qualitative data analysis process. Adapted from Schutt (2012).

Grounded Theory

The data analysis process should identify the appropriate approach for analyzing the data. In this research, grounded theory was used in the data analysis. Grounded theory uses systematic and in-depth comparison of text segments to make thematic arrangement and theory from a body of text (Guest & Mitchell, 2012). This analysis method involves constructing inductively an organized theory that is supported by the observations (Schutt, 2012) and the researcher identifies the emergent themes and categories of the qualitative data under examination through inductive analysis. A summary of the data analysis procedure using the appropriate Grounded theory techniques for this study is depicted in Figure 4.

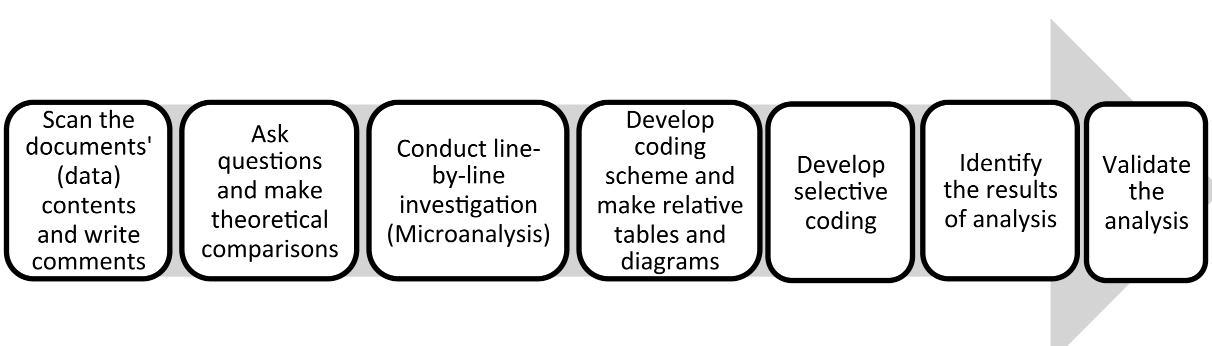

Figure 4: Data analysis process using the appropriate grounded theory techniques

According to Strauss & Corbin (1998) asking questions is one of the basic operations in grounded theory; it helps researchers understand the variations within the several cases of the data collected, and guides researchers in outlining the basic concepts that can be drawn from data. The researchers then can start making theoretical comparisons to discover both variations and general patterns (similarities) in the data under study.

Strauss & Corbin (1998) determined that grounded theory involves the process of *Microanalysis* which is a detailed line-by-line investigation to produce initial categories. Each category has its own *property*, which defines the meaning of the category and its characteristics. The category also has dimensions that define the range of possible values of a category, for example the dimensions of a company type for the construction organizations in this research are owner and contractor. The microanalysis evolves through the study to include a coding technique in which data are broken-down, conceptualized, and integrated to form an analysis structure that helps in obtaining conclusions and findings from the data (Strauss & Corbin, 1998). The coding technique could be in the form of open coding in which the categories and their dimensions are discovered through line-by-line examination of data (microanalysis). The selective coding technique is performed in an advanced stage of data analysis in which a category is chosen among the existing categories to be central for the purpose of integrating the analysis findings and building conclusions. Coding also involves developing the necessary diagrams and tables that show relationships among the categories. Once the analysis is completed and appropriate conclusions are obtained, the researcher can validate the method of analysis and the resultant conclusions.

An important point about grounded theory is that the intent is not always to develop a dense and integrated theory. Strauss & Corbin (1998) explained that the aim of grounded theory is to develop a description of the data, obtain a conceptual ordering, or discover categories from data. Conceptual ordering is defined as “the organization of data into discrete categories according to their properties and dimensions and then using description to elucidate those categories” (Strauss & Corbin 1998, p.19). In this research, the purpose of using grounded theory is to follow a systematic data analysis process, as shown in Figure 4, which assists in developing a conceptual ordering and rich description of the data.

In summary, this research combines the qualitative data analysis process adapted from Schutt (2012), as shown in Figure 3, to perform the data analysis with the grounded theory method. Figure 5 illustrates this integrated approach.

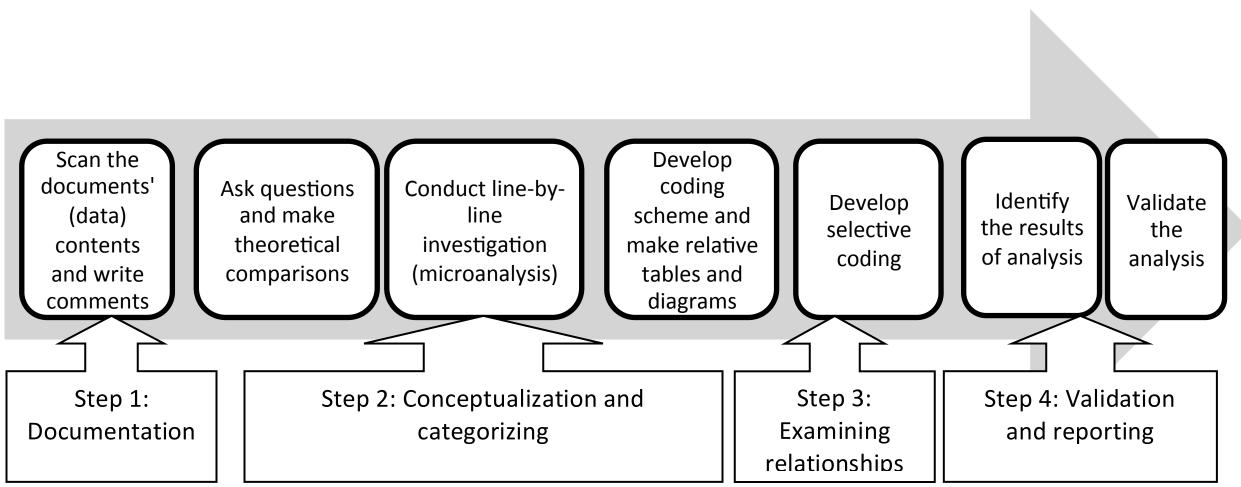

Figure 5: Grounded theory method with the process of qualitative data analysis

Research Methodology

The SQM documents and structured interviews were analyzed using the steps described in Figure 5. The SQM documents were used to analyze the current practices for SQM in construction. These documents include reports and procedures used by construction organizations as part of their SQM practices such as supplier performance evaluation forms, inspection reports, and quality problems notices. The structured interviews were used to learn in-depth about the supplier quality process and compare the current practices among the organizations that have been interviewed. The detailed analysis of the SQM documents and structured interviews is described next.

Step1: Documentation

SQM Documents

The academic team asked the participating organizations to provide documentation pertaining to their SQM processes and procedures. These documents were reviewed and catalogued according to the organization type (owners and contractors, with suppliers being included in the contractors category per CII's standards).

The research team includes 21 construction organizations, including 7 owners and 14 contractors. The total number of documents provided for analysis was 92, including 50 reports and 42 procedures. A summary of the number and type of documents provided is shown in Figure 6.

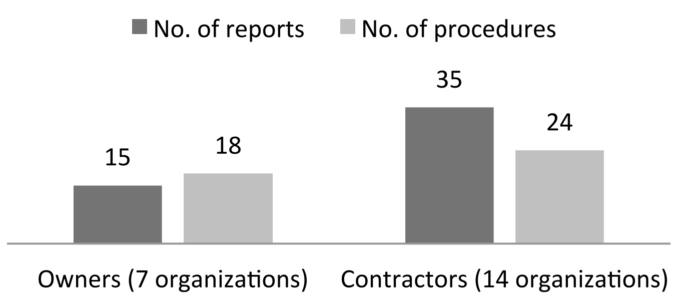

Figure 6: Summary of the provided documents

The SQM reports are written documents to record quality issues such as non-conformances (NCs), and required corrective actions. Examples of these reports are: construction quality assurance survey, supplier quality assessment, quality surveillance report, and source inspection report. The SQM procedures are written documents that define a specific process or describe a set of requirements that should be followed during the procurement, fabrication, and delivery of products/services. Examples of these procedures are: operations handbook-subcontract management, inspection procedure, and post award procurement process.

Structured Interviews

Interviews were conducted on a voluntary basis in a face-to-face setting, or via phone using a structured interview data protocol. The team documented the structured interview findings and recorded the date, time, and location of each interview. The interview questions were grouped into seven sets, including: supplier quality organization, supplier quality system, metrics, data, assessment, supporting documents, and suppliers.

Step 2: Conceptualization and categorizing

SQM Documents

The documents were examined to determine a high level categorization to assist with developing a detailed analysis of the SQM documents gathered. While examining the documents, a number of theoretical questions were asked to help in building the main categories of analysis and to identify the variations among the documents. The criteria for identifying the theoretical questions were as follows:

- Questions were derived from the contents of the documents (Figure 7) to group the contents into a reasonable number of categories that include main ideas. Categories were planned to be used for cross analysis among the other data sources, such as location on the SQ process map.

- Questions should have answers that can converge into a definite number of responses (dimensions) and can assist in the comparison among the documents. Some questions were initially asked for comparison such as date of reports, frequency of inspection, and number of people involved in the inspection. In the case of reports, these questions were excluded because the answers were not available in the documents.

Figure 7 presents the main questions asked for each type of document (report and procedure).

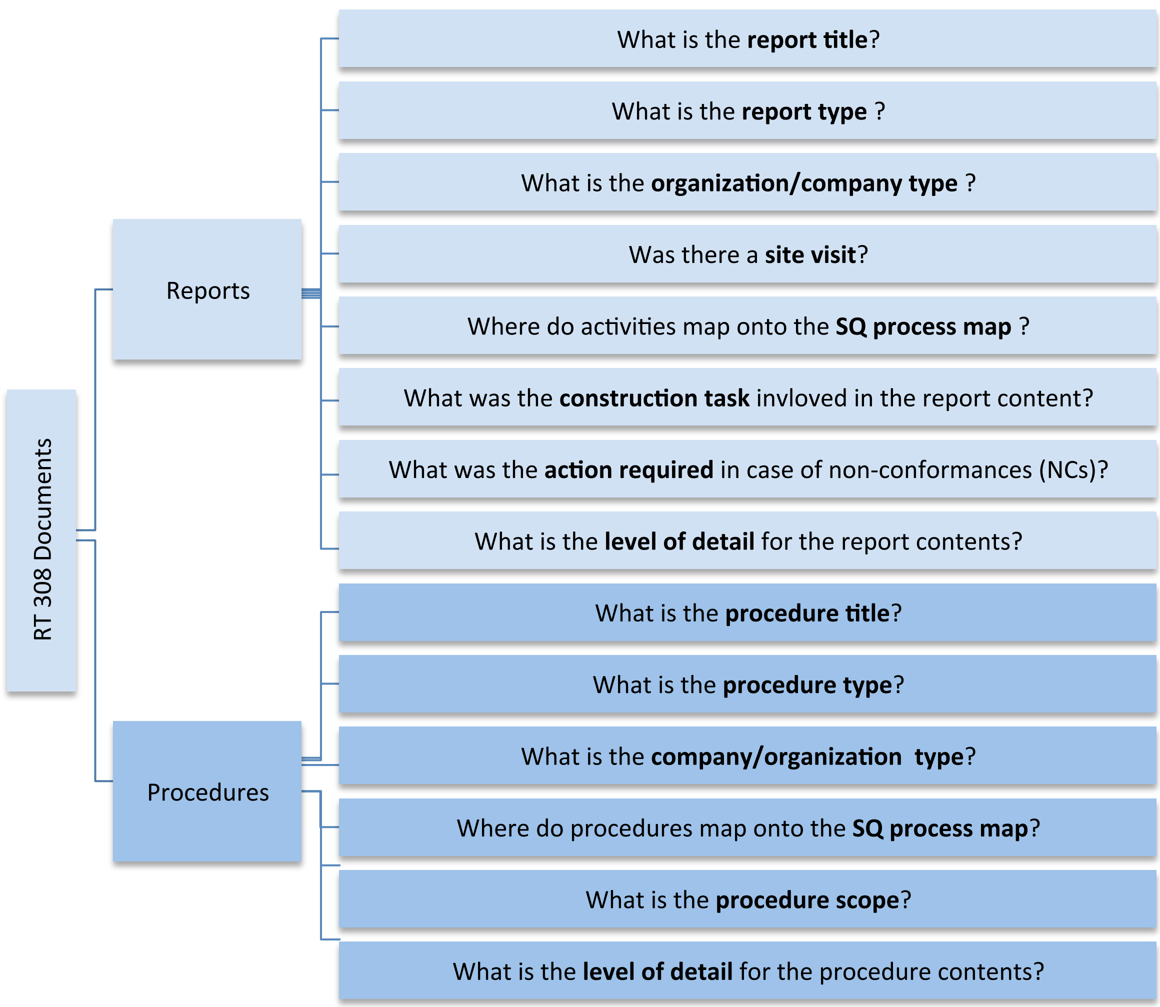

Figure 7: Theoretical questions for the documents

After identifying the questions, the documents were then compared to build the main categories around the questions and to identify the possible answers. Comparison was performed through examining the contents of the documents. The depth of examination increased at each iteration in which the documents were checked, beginning with general review of the contents and writing related comments, and ending with line-by-line review (microanalysis). An open-coding technique of grounded theory was used in analyzing the documents. In open-coding, the categories and their dimensions are discovered and titled (Strauss & Corbin, 1998). In this analysis, there were no predetermined categories and dimensions prior to examining the data; the categories evolved from the data (reports' and procedures' contents). Table A-1 in the Appendix depicts a template including the main categories that were used to complete the data analysis. When the company provided more than one document, additional columns were added under the company heading cell. Table 1 and 2 represent the open-coding for the reports and procedures including the categories and their dimensions. The description (property) for each dimension is presented in Tables A-2 and A-3 in the Appendix.

Category	Possible dimensions
1. Company type	Owner
	Contractor
2. Report type	Inspection report
	Follow-up
	Checklist/ Progress report
3. Location on SQ process map (Figure 1)	Assessment of criticality
	Planning and selection
	Execution
	Release from shop
	Received at site
	Mechanical completion
4. Site visit	Yes
	No
	N/A
5. Construction task	Welding
	Parts
	Miscellaneous
	N/A

Table 1: Open-coding for reports (categories and dimensions)

Category	Possible dimensions
6. Action required for Non-Conformances (NCs)	Repair
	Rework
	Replace
	Accept as is
	Others
	N/A
	No NCs
7. Level of details	High
	Med
	Low

Table 1 (Cont.): Open-coding for reports (categories and dimensions)

Category	Possible dimensions
1. Company type	Owner
	Contractor
2. Procedure type	Procedure
	Flowchart
	Lesson
	Procedure and flowchart
3. Location on SQ process map (Figure 1)	Assessment of criticality
	Planning and selection
	Execution
	Release from shop
	Received at site
4. Scope	Inspection
	SQS level according to criticality
	QA planning for equipment and material procurement
	Supplier qualification, selection, and quality planning
5. Level of details	High
	Med
	Low

Table 2: Open-coding for procedures (categories and dimensions)

To determine the level of detail for the documents, a rubric of scores was developed for the reports and procedures to assign a level for each document examined. This qualitative research method is called scaling (Miles & Huberman, 1994) whereby the documents' contents are scaled to consistently appraise and compare the contents. If the document has a total score between 4 and 5, then the level of details is high, if 3, then medium, and if 0 to 2, then the level is low. Table 3, 4, and 5 describe the rubric of scores.

Category	Description	Score (0-1)
Administration	The report includes the date, location, date of previous visit, upcoming prospective visit, and contact information.	
Usability	The report is easy to use.	
Responsibility	The report identifies the responsibilities of the administrative task or corrective actions that need to be taken as part of the supplier quality process.	
Impact	The report includes a description of quality impact on project management. That includes impact on cost, comparison between actual and planned, and relative comparison to previously agreed specifications on purchase order or contract.	
Illustration	The report includes illustrative pictures and/or drawing for the non-conformances or other issues that help in monitoring supplier quality	
	Total Score	0-5

Table 3: Level of details rubric of scores: Reports

Category	Description	Score (0-1)
Administration	The procedure has an issue and revision date, and indicates the department responsible for issuing the procedure	
Supportive documents	The procedure identifies a section for supportive documents for further reading if necessary	
Clarity	The procedure has clear definitions for the acronyms and/or glossary of terms	
Description	The procedure has clear description of the intended subject. The reader can easily understand the procedure content.	
Illustration	The procedure has some illustrative materials to help the user in implementing the procedure (drawings, illustrative examples)	
	Total Score	0-5

Table 4: Level of details rubric of scores: Procedures

Level of detail	Score
High	4-5
Med	3
Low	0-2

Table 5: Level of details possible scores

Structured Interviews

A total of 29 interview questions were grouped into seven sets that focus on several aspects of SQM. Each set of questions in the interview was categorized into main concepts to build a high level categorization that would help in the analysis. After conducting the six interviews and examining the resulting data, i.e. microanalysis of the interview responses, a coding scheme was developed for the purpose of comparison among the organizations interviewed. Figure 8 presents the categorization for each set of questions with the coding scheme highlighted in bolded text.

Figure 8: Interview sets of questions (categorization and coding scheme)

Step 3: Examining Relationships

SQM Documents

After classifying the documents and their contents into categories, the template in Table A-1 in the Appendix was completed in an Excel spreadsheet, and imported into a qualitative data analysis software package named QDA Miner® (version 4). QDA Miner® is a qualitative data analysis software package used for coding and analyzing collections of documents (Provalis

Research, 2014). Descriptive details of the categories for the sample documents collected are presented in Figures 9 thru 12. The description of the categories and their dimensions is presented in Tables A-2 and A-3 in the Appendix.

Figure 9 shows that the reports examined are mainly inspection reports, representing 68% of the total sample of reports. The SMEs response to this percentage was that the main focus in the SQM is for inspection purposes that are often documented in these reports. The demographics of the procedure type are 64% for detailed written description that illustrates a certain process, and only 10% for lessons learned. When queried the SMEs stated that construction organizations rarely shared the lessons learned from previous and current projects in their internal database due to compressed project schedules and concern that this information might later be used as evidence of admission of guilt in future litigation.

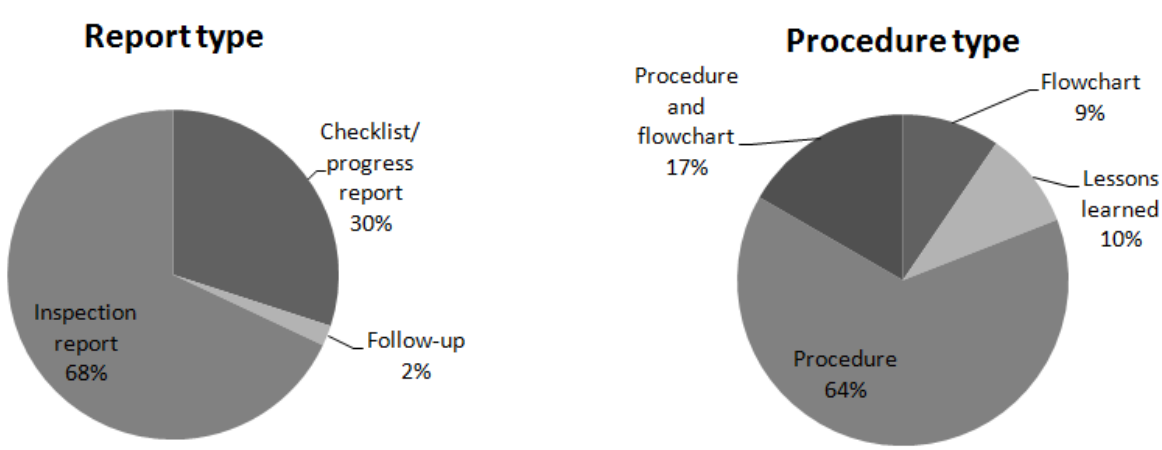

Figure 9: The demographics of the type of reports and procedures

Figure 10 represents the main construction task for the reports, and the scope of the procedures that were sampled and analyzed. The results show that 25 reports (50% of the total reports) are for parts and 13 reports (26%) are for multiple construction tasks (miscellaneous). For procedures, about half of the examined procedures focused on inspection instructions.

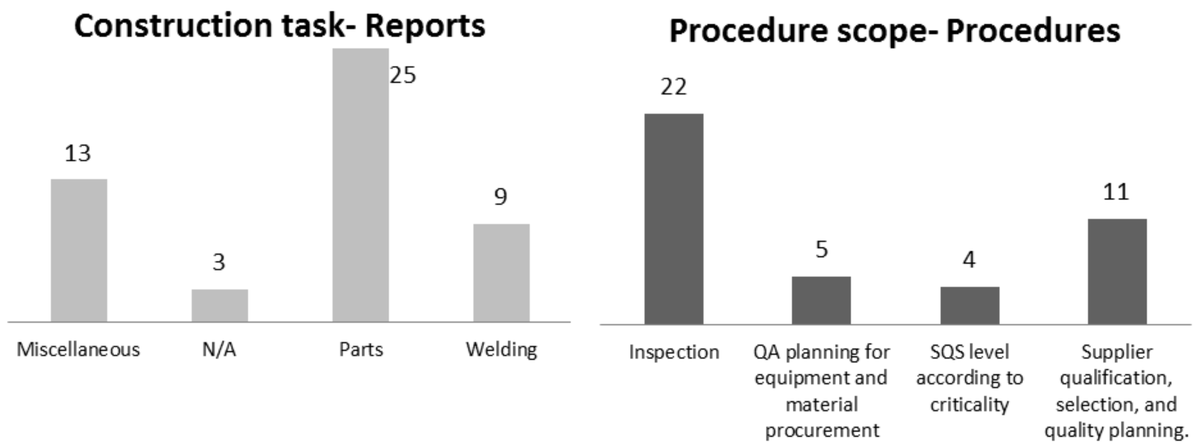

Figure 10: The demographics of the construction task and procedure scope

As shown in Figure 11, the level of detail for the reports is high to medium (78% of the reports) which reflect good documentation of SQM processes and practices. A similar result was observed for the procedures examined indicating that more than 60% of them have high level of detail.

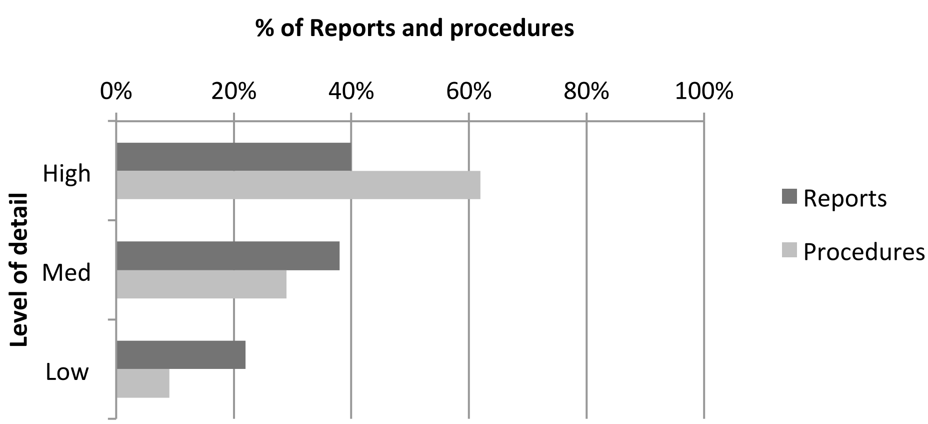

Figure 11: The demographics of the level of detail for the examined reports and procedures

Analysis of the reports indicates that 70% of the examined reports were for site visit to the supplier's facility (as presented in Figure 12). The majority of the sample reports (66%) reflected quality problems for repair, replace, rework, and accept as is. Only 10% of the reports represented cases of perfect supplier practice (no non-conformances being detected).

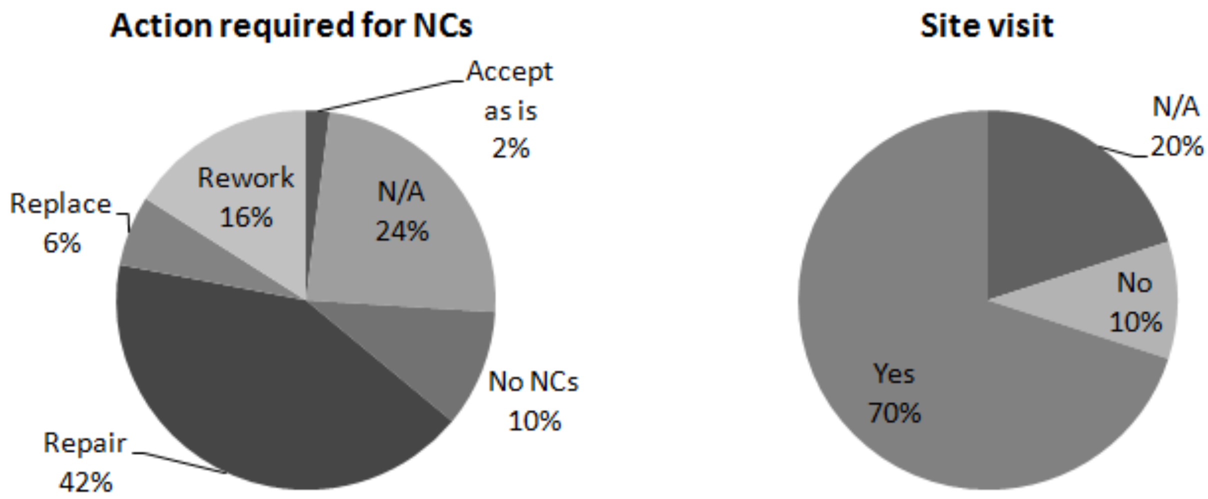

Figure 12: The demographics of action required for Non-Conformances (NCs) and site visit - Reports

To describe the common focus of the SQM documents with regard to the SQ process, they were mapped onto the SQ process map (location on SQ process map, category 3 in reports and procedures).The location on SQ process map forms the main category for the selective coding process in grounded theory. Figure 13 depicts the location of the reports and procedures examined on the SQ process map. In some cases, SQM documents can be located on a particular phase within the SQ process map such as planning and selection, while the others span more than one phase such as planning and selection to Execution (the last 4 columns of Figure 9 are for SQM documents having the latter case).

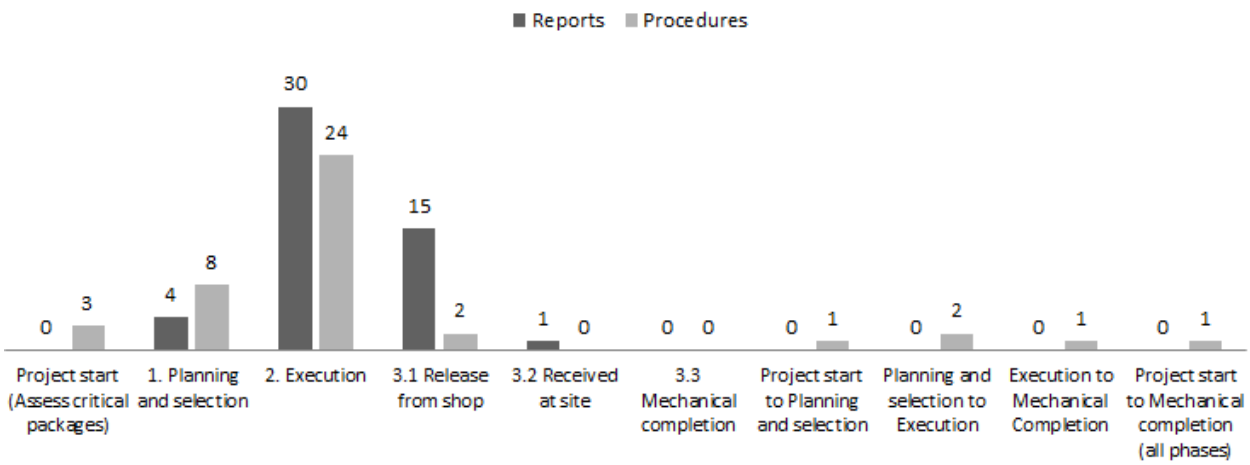

Figure 13: The demographics of the location on SQ map for the reports and procedures

As shown in Figure 13, most of the documentation gathered was clustered in the execution phase of the SQ process map for both reports and procedures.

In summary, most of the reports examined were inspection reports with mostly a high-medium level of detail. More than half of the gathered reports described quality problems, mainly repair and rework, along with site visits to the supplier facility for inspection purposes. The collected sample of procedures has a high level of detail and mainly describes inspection processes.

Structured Interviews

Contractors interviewed using the structured interview protocol were classified into three main groups according to their responses of the level of maturity of their SQ system, Set 5 of the interview questions as shown in Figure 8. This classification helped in making comparisons and forms the selective coding of the grounded theory. The interview question that was used for selective coding was *"Would you consider the supplier quality system at your company to be highly mature?"* Contractors responded to this question describing the maturity and effectiveness of the SQ system (or SQM as defined by Caldas et al. 2012) within their organizations. Not all contractors indicated their SQM was mature. They considered themselves in the incipient period pointing out that their SQM was benchmarked to be least effective against other construction organizations with highly effective SQM. Table 6 provides the main dimensions based on the response of the interviewed organizations.

Interview question (selective coding)	Dimensions	Organizations' answers
Would you consider the supplier quality system at your company to be highly mature? Code: Level of SQM maturity (effectiveness)	Not mature: **Organizations with least effective SQM.**	No. Incipient period.
	Somewhat mature: **Organizations with moderately effective SQM.**	No. We're in the middle.
	Highly mature: **Organizations with highly effective SQM.**	Yes. We're a benchmark for the industry.

Table 6: Selective coding for the interview questions

After classifying the organizations interviewed using the three dimensions, the responses for each set of questions were organized into organizations with least effective SQM, organizations with moderately effective SQM, organizations with highly effective SQM. Tables 7 through 9 show the responses followed by an interpretation for each. The bolded text in the tables describe the categorization for each set of the interview questions as described in Figure 7, and highlight the differences among the interviewed organizations.

		Organizations with least effective SQM	**Organizations with moderately effective SQM**	**Organizations with highly effective SQM**
Set 1: Supplier quality organization	SQ in **Organization chart**	Part of procurement and quality management.	Part of procurement.	Part of procurement.
	Top management role	• **Senior directors of procurement**, engineering and Quality lead the SQ	• Senior leadership, which is **subset of procurement**, reviews SQ	• Sets the **vision and policy, directions**, and **leads Improvement initiatives** (formal causal analysis.)
	SQ **personnel**	Local and global.	Local and global.	Local and global.
Set 2: Supplier quality System	**Decisions** to choose suppliers	Procurement and Engineering choose suppliers.	Procurement, project manager and the client choose suppliers.	Procurement and engineering choose suppliers.
	Process to select suppliers	• Based on survey, quality audits, and re-qualification form.	• Based on technical and commercial evaluation.	• Based on technical, commercial evaluation, surveys and ratings. • Classification **of strategic and non-strategic suppliers.**

Table 7: Set 1 and 2 of the interview questions

		Organizations with least effective SQM	Organizations with moderately effective SQM	Organizations with highly effective SQM
Set 2 (Cont.): Supplier quality System	**Supplier** removal	• Based on poor performance.	• Corruption and using **color score** for suppliers.	• Based on poor performance on multiple projects (performance lists).
	SQS	• Use inspection based on criticality, but there isn't written procedure.	• Use inspection **formula** and coordinators.	• **Use database** on supplier history, and evaluate by **multiple disciplines**
	Other tools for SQ	• Form SQ team for high criticality items.	• Use engineering reviews (documents).	• Use audits and surveys.

Table 7 (Cont.): Set 1 and 2 of the interview questions

The results in Table 7 indicate that the SQM is mainly within the procurement division for all organizations, but for organizations with highly effective SQM, top management sets the vision, policy and direction for the organization, and initiates improvement to the process. For the supplier quality system, organizations with highly effective SQM differ from other organizations in terms of having a careful process to select their suppliers, and maintaining a classification for strategic and non-strategic suppliers. In addition, they use performance lists to track performance, decide which suppliers should be removed, and keep a database that is shared and evaluated throughout their organization to analyze suppliers' work on pervious projects.

		Organizations with least effective SQM	Organizations with moderately effective SQM	Organizations with highly effective SQM
Set 3: Metrics	Supplier performance **metrics**	• Use NCs report, but there's no designated procedure.	• Use supplier evaluation **module** in procurement **data base**.	• Use rating system, NCs reports, and issues per visit.
	Time/stage of measuring supplier performance	• After each delivery and monthly.	• After completing 10% of the **PO**.	• Throughout the **PO**.
	Responsibility to measure supplier performance	• Procurement, project managers, and SQ committee.	• Procurement.	• Engineering, procurement**,** **logistics**, and SQS.
	Supplier performance and **future work**	• Yes. Based on **schedule**.	• Yes.	• Yes. **Formula** is used to calculate the effort of SQS.

Table 8: Set 3 and 4 of the interview questions

		Organizations with **least effective** SQM	Organizations with **moderately effective** SQM	Organizations with **highly effective** SQM
Set 4: Data	Supplier performance **tracking**	• Using reports.	• Using supplier evaluation **module**.	• **Using global data base**.
	Supplier performance **documents**	• Archived in inspection and audit reports.	• **Pulled from a data base**.	• Pulled from a **data base.**
	NCs documentation	• Corrective action program.	• Pulled from a **data base** monthly.	• Pulled from a **data base**.
	Supplier performance **data on SQ process map** (3.1 Release from shop, 3.2 Received at site, 3.3 Mechanical completion)	• Data only during release from shop and received at site.	• Data only during release from shop.	• Data during **all SQ stages except** mechanical completion which has different system.

Table 8 (Cont.): Set 3 and 4 of the interview questions

As presented in Table 8, the supplier performance measurement system is more advanced for organizations with highly effective SQM. These organizations measure the performance throughout the execution of the PO, and they evaluate supplier performance not only by the procurement function, but also by multiple disciplines including logistics and SQS (supplier quality surveillance). The performance measurement outcomes and metrics are used in a formula to calculate the level of SQS in future projects with the same supplier. For organizations with moderately effective SQM, they have initiatives to improve their SQM using a module within the procurement database to measure the supplier performance.

		Organizations with **least effective** SQM	Organizations with **moderately effective** SQM	Organizations with **highly effective** SQM
Set 5: Assessment	**Strengths**	• Risk identification. • Quality plans. • Well trained inspectors. • Inspection coverage. • Selecting suppliers.	• Developing project-specific procurement quality plan. • Consistency in using tools and practices. • **Internal data-base.**	• **Coordination**. • Inspection coverage. • **Measuring supplier performance**. • Consistency in using tools and practices. • Selecting and qualifying suppliers. • Developing project-specific procurement. • Well trained inspectors.

Table 9: Set 5, 6, and 7 of the interview questions

		Organizations with <u>least effective</u> SQM	Organizations with <u>moderately effective</u> SQM	Organizations with <u>highly effective</u> SQM
Set 5 (Cont.): Assessment	**Opportunities** for improvement	• Selecting and qualifying suppliers. • Measuring supplier performance. • Measuring inspector performance. • Consistency in using tools and practices. • Risk identification.	• Well trained inspectors. • Measuring supplier performance.	• Selecting and qualifying suppliers. • Well trained inspectors. • **Inspection coverage.** • Measuring inspector performance. • **Providing feedback to suppliers**.
	Challenges	• **Educate suppliers**. • **Defining the cost of quality**.	• Budget, well trained inspectors.	• Suppliers **don't read the contract in sufficient detail.** • **Cultural differences** for low cost supplier in emerging global markets.
Set 6: Documents	**Documents** for SQM	• Copies of documents were provided for analysis		
Set 7: Suppliers	**Sub-suppliers** quality assurance	• **Visit the sub-supplier**. • Assume **the suppliers are responsible**.	• **Use risk based approach**: If the job is complex, they will meet sub-suppliers.	• Treat **critical sub-suppliers same as suppliers**, and make sure the **requirements flow-down.**
	Number of active suppliers	• 60 -100. • Trend to **form partnership.**	• 2,000.	• 600-30,000.
	Tiers of suppliers	• 3	• 4	• 3

Table 9 (Cont.): Set 5, 6, and 7 of the interview questions

Table 9 summarizes the responses for set 5, 6, and 7 of the interview questions. The contractors interviewed were given a list including ten examples of strengths (such as coordination, measuring supplier performance, and risk identification) to choose from with the option to include additional ones if they wished. Table 9 shows that the strengths of organizations with highly effective SQM are coordination between the parties involved in the project, and the measurement of supplier performance in a consistent manner. These organizations are working to improve the inspector coverage, and the feedback process to the suppliers. Organizations with highly effective SQM still face problems with the contractors that do not properly read the contract in sufficient detail at the beginning of the project, and with the suppliers in the emerging global markets that have a different culture. In terms of managing the tiers of sub-suppliers, organizations with less effective SQM assume that the suppliers are responsible for the quality of their sub-suppliers. For organizations with highly effective SQM, they are proactive in terms of making sure that the information flow-down is clear for all the tiers of sub-suppliers, also they treat the critical sub-suppliers in the same way they treat their primary suppliers. Although these organizations have a large number of suppliers in their database, they tend to form partnerships with their strategic suppliers (strategic suppliers' base).

Step 4: Validation and Reporting

The validation of the research involves getting feedback from the informants and using two methods of triangulation, namely researchers' check and multiple instruments verification or cross analysis (Miles & Huberman, 1994).

In this research the SMEs (the informants) were involved in the analysis, offering their input for the research method and their insights for the interpretation of results found.

The first triangulation method that was used in this study is researchers' check. The researchers were involved to check the analysis steps for the SQM documents and structured interviews to identify any inconsistencies in the analysis. The second method that was used is cross analysis to verify the findings from the SQM documents, structured interviews, and the construction industry literature with regard to the effective practices of SQM. To implement this method, the SQM documents for organizations who reported themselves with highly effective SQM were re-examined to identify their effective practices in order to align them with the findings from the structured interviews and the literature. The cross analysis is described in the following sections.

Results Discussion

The SQM documents gathered from organizations with highly effective SQM were compared with the documents provided by organizations with least effective and moderately effective SQM. The effective practices for organizations with highly effective SQM that appeared different compared to the others include using percentages to indicate the work capacity of the suppliers during selection. These organizations assess how much of the supplier's capacity is tied up with other POs, i.e. a low percentage indicates that the supplier has low capacity due to a high number of other customer's orders that have to be fulfilled). Also, these organizations analyze the impact of NCs to the project cost and schedule and identify who is responsible for performing the corrective action using responsibilities charts.

The effective practices found from analyzing the SQM documents are aligned with the structured interview findings. In addition, these practices identified from the SQM documents and structured interviews are compared to what have been found in the construction industry literature. The effective practices are discussed according to the phases of the SQ process map in the following paragraphs:

1. Planning and selection: Organizations who reported themselves with highly effective SQM classify their suppliers into strategic (partnerships) and non-strategic. The analysis of the SQM documents for organizations with highly effective SQM shows that these organizations assess the supplier's workload to identify the total orders that have to be fulfilled for other customers. This assessment helps to determine the overall work capacity of the supplier.

The construction industry literature has indicated an emphasis on the supplier's planning and selection process. Songhori et al (2011) concluded that an effective supplier selection process directly impacts the supply chain performance, resulting in improved results to the organization. In addition, reducing the supplier base and forming strategic partnerships with the suppliers to achieve project success is also valuable (Peters, 1987). Arditi & Gunaydin (1998) also indicate that healthy partnerships with suppliers affect process quality in construction projects.

2. Execution: Organizations with highly effective SQM indicated in the structured interviews that they are proactive in terms of developing their suppliers and treating critical sub-suppliers the same as suppliers. The analysis of the SQM documents shows that these organizations ultimately determine the cost and quality impact of the NCs to the project and identify who is responsible for the correction and the due date for completion. Providing support to the supplier by utilizing proper SQM tools is important for a successful SQM (AlMaian et al., 2013).

2. Execution through 3.3 Mechanical completion: The organizations with highly effective SQMs maintain well-trained inspectors and use consistent tools to measure supplier performance as reported during the structured interview. Similar practices are found and/or recommended by the literature on construction supply chains.

Tommelein et al. (2003) found that organizations that perform systematic performance ratings of overall supplier processes create an added value to improve their projects' performance. Another study focusing on total quality management in the construction industry conducted by Arditi & Gunaydin (1997) suggested that organizations must be proactive and determine the root causes of poor quality and design training programs aimed at eliminating these causes. Along these lines, using consistent inspection procedures is paramount because their inconsistent use hinders the proper implementation of the quality management system in construction organizations (Lo, 2002).

1. Planning and selection through 3.3 Mechanical completion: The structured interviews with organizations with highly effective SQM reported that they involve top management (leadership) to improve the SQ system (set the vision, directions, and improvement initiatives), develop an internal database to track supplier performance and analyze future decisions, measure the supplier performance throughout the PO, evaluate the suppliers from multiple disciplines, and use a detailed formula to calculate the effort of SQS based on criticality of the items and previous supplier performance.

The literature also supports these findings as consistent management commitment, and the use of consistent quality management processes and quality metrics across the project life cycle form the foundation of effective quality management in the construction industry (Needy & Ries 2010). In a similar fashion, Chase (1993) described common elements of management roles used by construction organizations to ensure quality. The elements include top management involvement and commitment, the use of formalized process improvement techniques, helping suppliers and subcontractors improve, and thriving for continuous improvement. However, Ford et al. (2005) identified that many construction managers are making quick fixes to current problems rather than implementing long-term solutions for improving organizational performance. These quick fixes often do not resolve the underlying problem. Top management must commit to decisions resulting in long-term benefits for the organization.

Conclusions

This paper presented an integrated approach of grounded theory and qualitative data analysis process, as presented in Figure 5, to analyze data obtained from SQM documents and structured interviews. Throughout the research, SMEs were involved in the analysis process through face-to-face meetings to discuss the findings, and provide feedback during the analysis and validation phases. In total, 92 documents including 50 reports and 42 procedures provided by contractors and owners involved in EPC projects were analyzed. In addition, 6 structured interviews with construction contractors were conducted and their responses were analyzed.

In summary, organizations with highly effective SQM place importance on the planning and selection phase where they classify their suppliers into strategic and non-strategic, and they have higher involvement from top management throughout the project. Most of the organizations have proper documentation for their reports and procedures, however, organizations with highly effective SQM use databases to store their documentation. These databases are visible to all the parties involved in the project and company personnel can use the information stored in their database for future procurement decisions when choosing suppliers.

The future work of this research includes in-depth cross analysis of the results obtained from the qualitative data sources including the literature review of SQM effective practices inside and outside the construction industry, SQM documents, structured interviews, supplier focus groups, and the quantitative data sources including the purchase order (PO) survey instrument, and cost curves modeling.

The findings from this research will benefit academic researchers and professionals in design, construction, and management of projects by applying an integrated approach of grounded theory and qualitative data analysis process, as described in Figure 5. Within EPC project management in the construction industry, Civil and Construction professionals usually deal with several sources of information (data) that could be in qualitative forms such as inspection reports, suppliers' bids, and request for information reports. These data can be interpreted and presented to management using qualitative data analysis methods that help examining the relationships among the data so that conclusions can be easily drawn. This paper also examines current SQM practices by analyzing the structured interviews responses with the contractors and the SQM documents. The research also classifies these practices according to the effectiveness of SQM of the organizations sampled in order to identify what organizations with highly effective SQM are currently practicing. Construction organizations can adopt these practices to improve their current SQM systems. In this paper, the effective SQM practices are summarized within the phases of the SQ process in order to help construction organizations implement these effective practices within the EPC project life cycle.

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Appendix

			Company/organization type																				
			Owners							Contractors													
			O 1	O 2	O 3	O 4	O 5	O 6	O 7	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13	C 14
Document Type	Reports	Number of documents																					
		Report title																					
		Report type																					
		Location on SQ process map																					
		Site visit																					
		Construction task																					
		Action required for NCs																					
		Level of detail																					
	Procedures	Number of documents																					
		Procedure title																					
		Procedure type																					
		Location on SQ process map																					
		Scope																					
		Level of detail																					

Table A-1: A template for data analysis

	Category	Possible dimensions	Description (property)
1	Company type	Owner	Organization that manages and coordinates the functions and activities of a project and has the authority to make changes.
		Contractor	Organization responsible for the performance of a contract, including suppliers and subcontractors.
2	Report type	Inspection report	A report for "conformity evaluation by observation and judgment accompanied, as appropriate, by measurement, testing, or gauging." (The Quality Improvement Glossary, ASQ Quality Press 2004, P.117)
		Follow-up	A document to provide feedback from a previous inspection.
		Checklist/ progress report	A document with a checklist for evaluation or tracking the progress of a project. Usually used internally.

Table A-2: Open coding for reports (categories, dimensions, and properties)

	Category	Possible dimensions	Description (property)
3	Location on SQ process map (Figure 1)	Assessment of criticality	In this stage, purchase orders (POs), i.e. packages of products, to be purchased are assigned to a certain level of criticality (low, med, high) based on their impact to the project cost and schedule.
		Planning and selection	This stage involves supplier selection and qualification including the assessment of the supplier's financial and quality capabilities, as well as past performance.
		Execution	This stage includes developing supplier quality plan, observing supplier's work, and documenting observations.
		Release from shop	Final inspection of packages prior to shipping occurs in this stage.
		Received at site	In this stage, a recipient inspection occurs at site to accept or reject the shipped packages.
		Mechanical completion	The packages of products are installed in this stage and ready for use. Mechanical completion is the end stage for the purpose of this research.
4	Site visit	Yes	There was a site visit conducted
		No	No site visit was conducted
		N/A	• For progress report, follow-up report that includes a summary of findings after a site visit, or after items received at site, or • If not clear that the report was a summary of a site visit, or if the report was not filled (sample)
5	Construction task	Welding	The process of joining metal parts.
		Parts	This task includes: Pumps (water pumps),Grating, Injection umbilical, Coolers, heaters, Anodes, Valves, Drums, Gas filters, Blades Structural steel, Exchanger box, duct, Vessel, Electric components.
		Miscellaneous	A combination of two or more of the following construction tasks: • Welding • Parts • Coating • Drawings • Painting • Drilling • Waste water system
		N/A	The report provided is not filled (sample) or report contents are not clear.
7	Action required for NCs	Repair	"Action taken on nonconforming item so it will fulfill the intended usage requirements although it may not conform to the originally specified requirements." (The Quality Improvement Glossary, ASQ Quality Press 2004, P.208). That includes issues related to not following the agreed procedures.
		Rework	"Actions taken on a nonconforming item so it will fulfill the originally specified requirements." (The Quality Improvement Glossary, ASQ Quality Press 2004, P.21)
		Replace	Action to return the non-conformed item for replacement.
		Accept as is	A decision to use the item in its existing condition and acknowledge that it is within an acceptable level of quality (the item may not necessarily be within the exact quality requirement).
		Others	Includes: Missing parts or missing information.

Table A-2 (Cont.): Open coding for reports (categories, dimensions, and properties)

	Category	Possible dimensions	Description (property)
	Action required for NCs (Cont.)	N/A	• For some checklist/progress report • If report is not filled or contents are not clear (no section for NCs)
		No NCs	No non-conformances (NCs) were detected and corrective action was required.
8	Level of details	High	See Table 4 and 6.
		Med	See Table 4 and 6.
		Low	See Table 4 and 6.

Table A-2 (Cont.): Open coding for <u>reports</u> (categories, dimensions, and properties)

	Category	Possible dimensions	Description (property)
1	Company type	Owner	Organization that manages and coordinates the functions and activities of a project and has the authority to make changes.
		Contractor	Organization responsible for the performance of a contract, including suppliers and subcontractors.
2	Procedure type	Procedure	A detailed instructions describing a process
		Flowchart	A drawing that shows the flow of activities for a given process.
		Lesson	A document that reviewed a previous process and highlights the main lesson learned to be used for later similar projects to improve the process.
		Procedure and Flowchart	A document includes a detailed procedure and flowchart.
3	Location on SQ process map (Figure 1)	Assessment of criticality	See Table 2.
		Planning and selection	
		Execution	
		Release from shop	
		Received at site	
4	Scope	Inspection	A description of the inspection process that has to be undertaken by the contractor.
		SQS level according to criticality	A description of the supplier quality surveillance (SQS) effort according to material criticality that is being supplied.
		QA planning for equipment and material procurement	Quality assurance (QA) plans for suppliers
		Supplier qualification, selection, and quality planning	A description of activities for supplier assessment and prospective quality planning
5	Level of details	High	See Table 5 and 6.
		Med	See Table 5 and 6.
		Low	See Table 5 and 6.

Table A-3: Open coding for <u>procedures</u> (categories, dimensions, and properties)

4. ANALYZING SUPPLIER QUALITY MANAGEMENT PRACTICES IN THE CONSTRUCTION INDUSTRY USING PRINCIPAL COMPONENTS ANALYSIS

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Abstract

Supplier quality management (SQM) is an important function in the construction industry. Many construction organizations place high importance on using quantitative analyses to select the effective SQM practices that ensure that the materials, assemblies, and fabricated equipment for the construction project are within quality specifications. However, traditional quantitative analyses methods may be limited because the process of acquiring enough data to conduct the analyses is time consuming and costly. This paper discusses the use of principal components analysis (PCA) to analyze a number of SQM practices from construction organizations known for their effective SQM. PCA is useful as the data available for analysis is small in size and multivariate. SQM practices were discussed extensively and validated with the subject matter experts (SMEs) by using the analytic hierarchy process (AHP). This resulted in the discovery

that supplier's work observation, supplier performance rating, inspection effort tracking, and inspection and testing plans are important practices for SQM. The contributions of this research include proposing a quantitative method, PCA that can be used by quality engineers to analyze small sample size data. The research also describes how AHP, an analysis method based on expert judgment, can be used to validate and support the conclusions drawn from small sample size analyses. Identification of important SQM practices can benefit construction professionals with limited resources.

Keywords

Construction industry, Supplier Quality Management (SQM), Multivariate Data Analysis, Small Sample Size, Principal Components Analysis (PCA).

Introduction

The paper presents findings from research supported by the Construction Industry Institute (CII), and led by a research team composed of academic researchers, from industrial and civil/construction engineering, and subject matter experts (SMEs), representing CII member organizations as construction owners, contractors, and suppliers. The major research question under study was: "*What are the most effective processes and practices for ensuring that project materials and equipment are produced, manufactured, or fabricated in strict accordance with all applicable specifications, and that they are delivered to the project site without any need for rework?*

Data were collected from a range of quantitative and qualitative sources, including literature review, structured interviews, SQM documents, supplier focus groups, along with a data collection instrument to obtain quantitative information about SQM practices and performance for individual purchase orders (POs) data (PO instrument). The main data source that is the subject of this paper is the PO instrument. The PO instrument collected data about practices used for the selection of suppliers, tracking of purchase orders, communication with suppliers, installation of the products supplied in construction projects, and the resulting quality associated with these practices. The responses were drawn from actual data about specific POs (not from estimation), and each response represented data from a single PO. The PO instrument asked participants about the use of SQM practices using closed-ended questions such as observing and inspecting supplier's work, and projecting inspection costs to determine their effect on detecting non-conformances (NCs) per total PO value (NCs/$). Each question had a list of possible answers from which the respondents selected the answer that best described the situation. Table 1 summarizes the SQM practices examined within the PO instrument questions.

SQM practices	The closed-ended questions from the PO survey	Possible answers
Supplier's work observation	Did you have a person in the supplier's facility to observe the supplier's work?	• Full time • Part time • Occasionally • Final only • Not at all
Inspection effort tracking	Do you track hours, cost, or both, none?	• Hours • Cost and hours • None
Inspection and testing planning (ITP)	Was there a quality control plan/inspection and testing plan (ITP) used for this specific PO?	• Yes • No
Supplier's performance rating (after executing the work by the supplier)	Did you conduct a performance rating of the supplier after execution?	• Yes • No
Inspection cost projection	Did you project the cost of your inspection effort with this supplier for this PO?	• Yes • No

Table 1: Summary of the exploratory variables

In a separate effort, Neuman (2014) analyzed the PO instrument data and performed tests of hypotheses and correlation analyses. Neuman's analyses included cases in which data were parsed by material type and PO criticality. The PO data were also categorized according to the perceived effectiveness of the organizations' SQM systems. In this regard, a series of focus groups and structured interviews revealed a subset of construction organizations widely regarded as having highly effective SQM (Walsh, et al., forthcoming 2014). In general, the organizations with highly effective SQM perform an advanced process characterized by consistent use of a wide range of SQM practices, and were distinguished in the results variables by their ability to prevent, find, and correct NCs. The PO analysis effort permitted analysis to discover what the organizations with highly effective SQM are doing differently compared to the other organizations

Based on the PO instrument results, the following SQM practices were found to have significant impact on detecting NCs/$ (Neuman, 2014), as summarized below:

1. *Supplier's work observation*: Supervising the suppliers, full time or part time, to ensure that they are meeting the project quality requirements.
2. *Inspection effort tracking*: Using tracking measures to determine the effort spent in inspection, such as hours or dollars spent.
3. *Inspection and testing planning (ITP)*: Using plans developed in concert with suppliers for inspection and quality control at the beginning of each project.
4. *Supplier's performance rating* (after executing the work by the supplier): Evaluating the performance of the suppliers after fabricating the product.
5. *Inspection cost projection*: Estimating the costs associated with inspection visits.

The analysis of the PO instrument showed that organizations with highly effective SQM conduct these practices more frequently than the other organizations and detect NCs earlier in the project life cycle process. Also, these organizations perform more quality process meetings consistently with their suppliers, such as lessons learned meetings, to discuss quality issues.

The SQM practices were analyzed in this paper to select the most important SQM practices used by the construction industry by using a quantitative approach. The analysis can provide insights to construction organizations on how best to invest their limited resources on the most important SQM practices.

Research Motivation

Supplier quality management (SQM) in the construction industry is a system of processes and practices applied by the project organization to ensure that the quality of fabricated materials and equipment meet the project's requirements and specifications (Caldas et al., 2012). SQM in the construction industry is complex due to the irregular nature of every project in terms of its scope and life cycle. Also, improving SQM is challenging because of the constraints of limited resources of time, budget, and technical capabilities (AlMaian et al., 2013). The effectiveness of SQM within the construction industry varies from one organization to the other. Organizations with highly effective SQM use consistent practices for managing their suppliers (Walsh et al., forthcoming 2014). On the other hand, organizations with less effective SQM are still facing difficulties in defining, standardizing, and improving their practices. In this paper, we analyzed a number of SQM practices that have significant impact on quality based on research conducted by Neuman (2014). The aim is to determine the most important practices that help organizations improve their SQM. The identification of effective SQM practices is important in guiding organizations to focus efforts on practices that yield high return in terms of resources spent to achieve the best quality and avoid the waste associated with rework of any kind (re-designing components, accepting deviations, fixing mistakes, re-fabricating items). The practices discussed as part of this study can also be applied to other engineering fields such as aerospace and shipbuilding as they are not exclusive to the construction industry as supported by the literature review on SQM practices in other industries discussed by AlMaian et al. (2013).

In the context of construction organizations, the availability of data to analyze SQM practices is a challenge as organizations usually keep track of indicators related to cost and time, but keep details related to these and other SQM-related indicators scattered within different departments and within different data collection systems (Walsh et al., forthcoming 2014). This challenge is not unique to the construction industry, but is common for other industries as well where data is limited due to economic and time constraints to acquire more data such as from complicated quality tests and experiments. For example, Freeman (2011) used maximum likelihood estimators (MLEs) to study a small sample size of failure data. In another study, Khoo (2005) studied process dispersion monitoring in the manufacturing industry. The author analyzed the effectiveness of quality control charts based on experiments of small sample size. The research presented in this paper faces similar challenges with small sample size data. Generally within the construction industry, the phenomenon regarding data availability in the SQM sector is well known, due to time constraints and complexity to collect more data from several projects.

Research Methodology

The data under analysis is multivariate with small sample size. We have 31 data points and five exploratory variables representing the SQM practices, as described earlier in Table 1.

In order to select the appropriate data analysis approach, three main areas were considered: small sample size, categorical data analysis, and multivariate data analysis. Table 2 summarizes the findings from several key textbooks.

Literature area	Sources	Findings
Small sample size	Hoyle (1999); Maddala & Lahiri (2009)	The data analysis techniques found in these textbooks that treat the issue of small sample size were mainly for statistical analyses to identify the difference between groups of data.
Categorical data analysis	Agresti (1990); Bourque & Clark (1992)	Categorical variables can be coded using numbers, considering that these numbers are consistent for similar levels of different categories. For simplicity, we use numeric codes to represent the answers for survey questions appearing in Table 1. For example, a question with yes or no answers can be coded as 1 or 2 respectively.
Multivariate data analysis	Cliff (1987); Grimm & Yarnold (1995).	Based on examining the multivariate data analysis literature, we found that regression modeling techniques such as stepwise regression can be used as a variable selection method, along with PCA as a dimension reduction technique and variable selection method.

Table 2: The examined literature areas of data analysis

Scholarly academic journals were examined for articles that describe multivariate data techniques with small sample size. However, we found that their techniques are not within the scope of the paper, because they were mainly for identifying the difference between groups of data. For example, Bathke et al. (2008) and Harrar, & Bathke (2008) used statistical comparisons of multivariate data with small sample size. Saranadasa & Altan (1998) and Frömke, et al. (2008) used permutation algorithms to test the difference between multivariate treatments.

In summary, based on examining the three areas of literature in the textbooks and the scholarly journals, we found that regression modeling techniques and principal components analysis (PCA) could be possible approaches to analyze the SQM practices. However, upon further consideration, regression modeling requires a rule of thumb of having 15 to 20 observations for each exploratory variable (Siddiqui, 2013), which is impractical for our problem. With regard to the required number of observations for PCA, the PCA literature does not discuss the requirements for the minimum number of observations with respect to the number of studied variables. However, it does not recommend having the number of variables exceed the number of observations. Further details can be found in Dunteman (1989) and Jolliffe (2002). Thus, PCA was selected as an approach to analyze SQM practices.

PCA reduces the dimensionality of data by transforming data into a new set of principal components, which retain most of the variation present in all of the original variables (Jolliffe, 2002). The PCA literature contains diverse applications for using PCA to select a number of variables under analysis. For instance, Baciu & Parpucea (2011) studied the relationship between U.S. crime rates and variables such as age, education level, and unemployment rate. The authors performed PCA to determine which variable determines a higher crime rate. Previous applications of PCA as a variable selection method were also found in the *Quality Engineering* literature. For example, La Parra et al. (2004) applied PCA in a pharmaceutical study to detect the potential impurities (variables) that affect a certain drug substance. In another example, Ostyn et al. (2007) used PCA to find variables within multivariate control charts that help detect bad seals for food packaging. Das et al. (2008) also utilized PCA to find the most important customer preferences to improve product quality.

PCA Implementation

PCA can be performed on our exploratory variables, namely x_1: supplier's work observation, x_2: inspection effort tracking, x_3: ITP, x_4: supplier's performance rating, and x_5: inspection cost projection. As described earlier, PCA transforms the variables into a reduced set of components that represent most of the information in the original variables. Also, PCA can be used to select a number of variables based on some selection rules.

To describe PCA in a mathematical form, suppose the full dataset contains k variables, $x_1, x_2, \ldots, x_k$ measured on n observations. The set of these k variables, which can be characterized as a k-dimensional random vector $(x_1, x_2, \dots, x_k)$, can be linearly transformed into a principal component y. Any principal component for the full set of data is a linear combination of all the variables and can be written as:

$$y = a_1 x_1 + a_2 x_2 + \dots + a_k x_k$$

Where y is the principal component, a_i's are the weights (loadings) that maximize the variation of the linear composite or, equivalently, to maximize the sum of the squared correlations/ covariance of the calculated principal components with the original variables. PCA can be performed using either the correlation or covariance matrices between the variables from which the weight vectors (eigen vectors) are obtained. We used the correlation matrix because it is widely applied within PCA analysis (Jackson, 1991). Table 3 presents the correlation between the variables.

	x_1: Supplier's work observation	x_2: Inspection effort tracking	x_3: ITP	x_4: Supplier's performance rating	x_5: Inspection cost projection
x_1: Supplier's work observation	1	0.300	0.330	0.248	-0.114
x_2: Inspection effort tracking		1	0.373	0.311	0.691
x_3: ITP			1	-0.089	0.230
x_4: Supplier's performance rating				1	0.281
x_5: Inspection cost projection					1

Table 3: Correlation between the variables

It is necessary for an appropriate application of PCA that the correlation coefficient between the variables is not equal to zero Dunteman (1989) and Jolliffe (2002). As shown in Table 3, there is some degree of correlation between the variables. For example, there is a correlation of the value 0.373 between the inspection effort tracking and ITP indicating a positive relationship between these two variables.

PCA starts by constructing the correlation matrix, then the first principal component can be conducted, y_1, which is a linear combination of the k variables, $x_1, x_2, \dots, x_k$ (i.e., $y_1 = a_{11}x_1 + a_{12}x_2 + \ldots + a_{1k}x_k = \sum_{i=1}^{k} a_{1i}\, x_i$ such that the variance (eigenvalue) of y_1 is maximized, and the sum of squared correlations of y_1 with the original variables is also maximized. Then, the consecutive principal components are obtained (i.e., $y_m = \sum_{i=1}^{k} a_{mi}\, x_i$ for every component m) to find the weight vector ($a_{m1,}\, a_{m2}, \dots, a_{mk}$) such that the remaining variance is maximized. The important statistics obtained from the PCA are the weight (eigen) vector $(a_1, a_2, \dots., a_k)$ associated with each principal component and its associated variance (eigenvalue). Further details of the algebraic description of PCA, can be found in Dunteman (1989), Jackson (1991) and Jolliffe (2002).

Table 4 represents the summary of the PCA results for our dataset depicting five principal components (PCA produces principal components that are equal to the number of variables), their associated variance (eigenvalue), and proportion of variance explained. The proportion of the variance explained is calculated by dividing the variance of the principal component by the number of variables k, i.e., $k = 5$.

Variables	y_1	y_2	y_3	y_4	y_5
x_1: Supplier's work observation	0.301	-0.681	-0.393	-0.373	-0.389
x_2: Inspection effort tracking	0.621	0.099	0.094	-0.441	0.634
x_3: ITP	0.375	-0.489	0.485	0.617	0.066
x_4: Supplier's performance rating	0.340	0.219	-0.735	0.533	0.111
x_5: Inspection cost projection	0.517	0.489	0.248	-0.052	-0.656
Variance (eigenvalue)	2.116	1.195	1.058	0.437	0.194
Proportion of variance explained (%)	0.423	0.239	0.211	0.088	0.039
Cumulative	0.423	0.662	0.874	0.961	1.000

Table 4: PCA results

To select a subset of principal components (PCs), we used a common stopping rule in the PCA literature; the size of variances of principal components (Kaiser's rule). Kaiser's rule retains only the PCs whose variances (eigenvalues) are greater than unity. Looking at Table 4, we have three principal components to retain with a variance greater than 1: y_1, y_2, and y_3. These three principal components account for 87.4% of the total variance. The three principal components are:

$$y_1 = 0.301\, x_1 + \mathbf{0.621\, x_2} + 0.375\, x_3 + 0.340\, x_4 + 0.517\, x_5$$

$$y_2 = \mathbf{-0.681\, x_1} + 0.099\, x_2 - 0.489\, x_3 + 0.219\, x_4 + 0.489\, x_5$$

$$y_3 = -0.393\, x_1 + 0.094\, x_2 + 0.485\, x_3 \mathbf{- 0.735\, x_4} + 0.248\, x_5$$

To select a subset of variables from the retained PCs above, we chose the variable that has the highest absolute weight (loading), i.e., a_{mi} in each principal component y_m, as shown in bolded text in the above equations. As described in Jolliffe (2001), the selection of one variable that has the highest absolute weight from each retained PC preserves most of the information given by this particular PC. The details of variable selection method can be found in Jolliffe, 1972; Jolliffe, 1973; Jackson, 1991 and Al-Kandari & Jolliffe, 2001. Looking at Table 4 and the equations of the retained principal components, $x_2, x_1,\ and\ x_4$, respectively, inspection effort tracking, supplier's work observation, and supplier's performance rating are the selected variables from PCA.

Results Discussion

The SQM practices found from the PCA analysis were inspection effort tracking, supplier's work observation, and supplier's performance rating. To evaluate the robustness of the PCA to repeat the same results using a smaller number of data points (n), we selected randomly two-thirds of the data points, i.e., 21 data points. The summary of the PCA results is presented in Table 5.

Variables	y_1	y_2	y_3	y_4	y_5
x_1: Supplier's work observation	0.130	0.742	-0.309	-0.566	-0.125
x_2: Inspection effort tracking	0.638	-0.167	0.100	0.039	-0.744
x_3: ITP	0.502	0.475	0.074	0.618	0.366
x_4: Supplier's performance rating	0.069	-0.227	-0.943	0.234	-0.004
x_5: Inspection cost projection	0.564	-0.379	0.008	-0.492	0.544
Variance (eigenvalue)	2.243	1.416	1.0149	0.259	0.066
Proportion of variance explained (%)	0.449	0.283	0.203	0.052	0.013
Cumulative	0.449	0.732	0.935	0.987	1.000

Table 5: PCA results using 21 data points

As shown in Table 5, we have three principal components with a variance greater than 1; y_1, y_2, and y_3, which account for 93.5% of the total variability. Following the same rule to select a subset of variables as described earlier, we found that PCA produced the same variables that were found with the total 31 data points, namely supplier's work observation, inspection effort tracking, and supplier's performance rating.

In order to validate the findings from the PCA analysis, two SMEs representing organizations with highly effective SQM were interviewed to describe the importance of the SQM practices within construction projects. The SMEs were asked to determine the most important SQM practices described in Table 1 within the SQM systems of their organizations; the SMEs did not know the results obtained from the PCA analysis, so that they would not be influenced by the results. The SMEs reported that the importance of these practices differ from one project to the other depending on many factors including, but not limited to, whether the construction organizations select the suppliers for the first time or there was a past working relationships with these suppliers. In general, the SMEs reported that for every project ITP, supplier's work observation, and inspection effort tracking are the most important SQM practices. For learning purposes in consecutive projects dealing with the same supplier, the SMEs reported that supplier's performance rating is very important since this practice is usually used in future projects to determine the required amount of supplier surveillance.

To help the decision makers and practitioners in the construction industry understand the relative importance of the SQM practices in this research based on the SMEs judgment, we used the analytic hierarchy process (AHP) to further analyze these practices. AHP is widely used to structure a complex decision problem (Saaty, 1994), and it has diverse applications such as project planning, policies selection, and portfolios management. If the problem under analysis has a manageable number of alternatives (i.e., practices, policies, or any alternative courses of action) to compare, then AHP is an effective method, since it has a simple methodology to conduct the pairwise comparisons (Goodwin & Wright, 2009). To apply AHP in determining the relative importance of SQM practices based on the SMEs judgment, we used the numerical scale described in Saaty (1994) and Goodwin & Wright (2009). Table 6 describes this scale. For example, if the SQM practice (ITP) is weakly more important than the practice (supplier performance rating), the assigned preference number is 3.

Practice x is …… as (than) y	**Preference number assigned**
Equally important	1
Weakly more important	3
Strongly more important	5
Very strongly more important	7
Absolutely more important	9
Weakly worse	1/3
Strongly worse	1/5
Very strongly worse	1/7
Absolutely worse	1/9

Table 6: Numerical scale for pairwise comparisons in AHP

One SME with over 20 years of experience in the supplier quality field participated to perform pairwise comparisons on the SQM practices. This SME was one of the two SMEs that were initially interviewed to describe the importance of the SQM practices. The SME was provided with a matrix to enter the preference number for each practice as compared to the other. Table 7 presents the pairwise comparisons provided by the SME.

	x_1: Supplier's work observation	x_2: Inspection effort tracking	x_3: ITP	x_4:Supplier's performance rating	x_5:Inspection cost projection
x_1: Supplier's work observation	1.00	5.00	1.00	3.00	5.00
x_2: Inspection effort tracking	0.20	1.00	0.20	0.33	3.00
x_3: ITP	1.00	5.00	1.00	3.00	5.00
x_4:Supplier's performance rating	0.33	3.00	0.33	1.00	3.00
x_5:Inspection cost projection	0.20	0.33	0.20	0.33	1.00
Total	*2.73*	*14.33*	*2.73*	*7.67*	*17.00*

Table 7: Pairwise comparisons provided by the SME

As shown in Table 7, supplier's work observation is equally important as ITP. Also, these two practices are strongly more important than inspection cost projection. Following the AHP methodology to determine the priority weights for the practices which help to indicate the importance ranking for these practices, the preference numbers of each column in Table 7 should be normalized by dividing the value of each cell by the sum of the column. Table 8 shows the resulting values of normalizing the columns. Table 8 also shows the total sum for each row, and the average value, i.e., the priority weight for each SQM practice, which is the total row sum divided by the number of SQM practices.

	x_1:Supplier's work observation	x_2: Inspection effort tracking	x_3:ITP	x_4:Supplier's performance rating	x_5:Inspection cost projection	**Row total**	**Average= row total/ 5**
x_1:Supplier's work observation	0.366	0.349	0.366	0.391	0.294	**1.766**	**0.353**
x_2: Inspection effort tracking	0.073	0.070	0.073	0.043	0.176	**0.436**	**0.087**
x_3:ITP	0.366	0.349	0.366	0.391	0.294	**1.766**	**0.353**
x_4:Supplier's performance rating	0.122	0.209	0.122	0.130	0.176	**0.760**	**0.152**
x_5:Inspection cost projection	0.073	0.023	0.073	0.043	0.059	**0.272**	**0.054**
Total	*1*	*1*	*1*	*1*	*1*	*5*	*1*

Table 8: Resulting normalized pairwise comparisons and priority weights for SQM practices

Looking at Table 8, supplier's work observation, and ITP have the same highest priority with a value of 0.353, supplier's performance rating has the second highest priority with a value of 0.152, then inspection effort tracking with a value of 0.087. Inspection cost projection has the least priority with a value of 0.054.The SME reported that inspection cost projection is only an estimate and doesn't add value to the SQM process.

In summary, the PCA analysis identified supplier's work observation, inspection effort tracking, and supplier's performance rating as the most important SQM practices. The analysis of the SME judgment using AHP to determine the important SQM practices suggested that ITP is as important as supplier's work observation. Both analyses excluded inspection cost projection.

Conclusion and Future Work

Within the construction industry, there are many SQM practices to help improve the quality of the materials supplied to construction projects. However, the choice of one practice over the other using quantitative analysis techniques may not be easy due to limited data. This research aims to quantitatively identify important practices for SQM. First, we used principal components analysis (PCA) to select SQM practices that summarize main variability from data collected from organizations with highly effective SQM systems. Then, SMEs representing organizations with highly effective SQM were interviewed to provide a better understanding of the SQM practices as compared to each other.

The contribution of this paper includes proposing a quantitative approach, PCA, which can be used within quality engineering to analyze multivariate data with small sample size. In general, the results drawn from small sample size analysis should be carefully interpreted and validated to avoid inaccurate conclusions. Due to this limitation, the research includes discussion with SMEs from organizations with highly effective SQM systems to elicit their judgment with regard to the importance of the SQM practices under study, and to validate the results of PCA. The paper proposes the analytic hierarchy process (AHP) to be used by quality engineers and construction professionals to validate the results from small sample size quantitative approaches. Also, AHP can be used to determine and understand the relative importance of practices or any quality courses of actions by using expert knowledge judgment. In this research, both analyses, PCA and AHP, suggested that supplier's work observation, inspection effort tracking, and supplier's performance rating are important SQM practices.

The contribution of this research to the quality engineering field includes suggesting PCA to be used for small sample size analyses, and proposing AHP to strengthen the conclusions drawn from small sample size analysis, and to help the decision makers understand the relative importance of the studied practices (variables). The findings of this paper can benefit researchers and professionals in the construction industry by investing in the most important SQM practices and implementing them within construction projects. The analysis and discussion with the SMEs identified supplier's performance rating as an important practice because it provides suppliers with important information about previous performance to help them learn from mistakes that cause quality problems, and hence prevent these problems reoccurring in future projects. Observing supplier's work during execution will help construction organizations detect quality problems. As important as observing supplier's work, developing inspection and testing plans are collaborative efforts between the supplier and the contractor to understand what is required to produce a product with the required level of quality. Inspection effort tracking is also an important practice for SQM, because at the end of each project construction organizations can determine the required inspection effort for future projects dealing with the same suppliers.

This research is limited by a small sample size to determine important SQM practices. The study can be improved by collecting more data and involving more SMEs to determine the important SQM practices. The study is also limited to the investigation of SQM practices from construction organizations (contractors) performing mainly engineer-procure-construct (EPC) projects. The research findings might not be the same for other types of contractors in the construction industry. The research can be further improved with data from organizations with a different focus (e.g., commercial, residential, specialty contractors).

Suggestions for future work include synthesizing the effective SQM practices into a framework for implementation within construction projects, to guide construction organizations on how, and when to implement these practices within the project life cycle. These SQM practices can also be analyzed in terms of their impact on quality and ease of implementation to help construction organizations on selecting the important SQM practices that improve quality.

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5. USING THE BALANCED SCORECARD TO IMPLEMENT EFFECTIVE SUPPLIER QUALITY MANAGEMENT PRACTICES IN THE COSTRUCTION INDUSTRY

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Abstract

Construction organizations utilize supplier quality management (SQM) practices to ensure that the project materials and equipment are produced, manufactured, in accordance with the project specifications. This paper describes the development and validation of a balanced scorecard (BSC) framework used to organize SQM practices and help construction organizations effectively implement these practices within their projects. The proposed BSC provides a basis for implementing and measuring SQM practices to compare the performance across multiple projects and to provide opportunities for continuous improvement. Additionally, the paper addresses the validation of the BSC framework proposed for use by construction organizations as part of their SQM in each project. During the validation of the BSC framework, we found that

construction organizations anticipate using it in future projects within their organizations, and that the framework could allow them to focus on improving important areas of SQM other than financial, such as the internal process and innovation.

CE Focus Areas

Construction Industry, Construction Projects, Rework, Non-Conformances (NCs), Performance Measurement, Supplier Quality Management.

Keywords

Supplier Quality Management (SQM), SQM Practices, Supplier Quality (SQ) Process Map, Balanced Scorecard (BSC), Performance Measurement.

Introduction

The paper presents results from research performed by Research Team 308 (RT 308) Achieving Zero Rework through Effective Supplier Quality Practices supported by the Construction Industry Institute (CII). The team was composed of academic researchers from industrial and civil engineering and also included a group of subject matter experts (SMEs), representing member organizations in the CII as construction owners, contractors, and suppliers. Members from twenty one organizations contributed to this research project, and each team member brought multiple years of experience in local and global construction markets. The major research question under study: "*What are the most effective processes and practices for ensuring that project materials and equipment are produced, manufactured, or fabricated in strict accordance with all applicable specifications, and that they are delivered to the project site without any need for rework?*"

The objective of the paper is to suggest a framework for implementing SQM practices found to be effective, based on analyzing multiple data sources during the research. Figure 1 describes data sources used, classified as qualitative or quantitative.

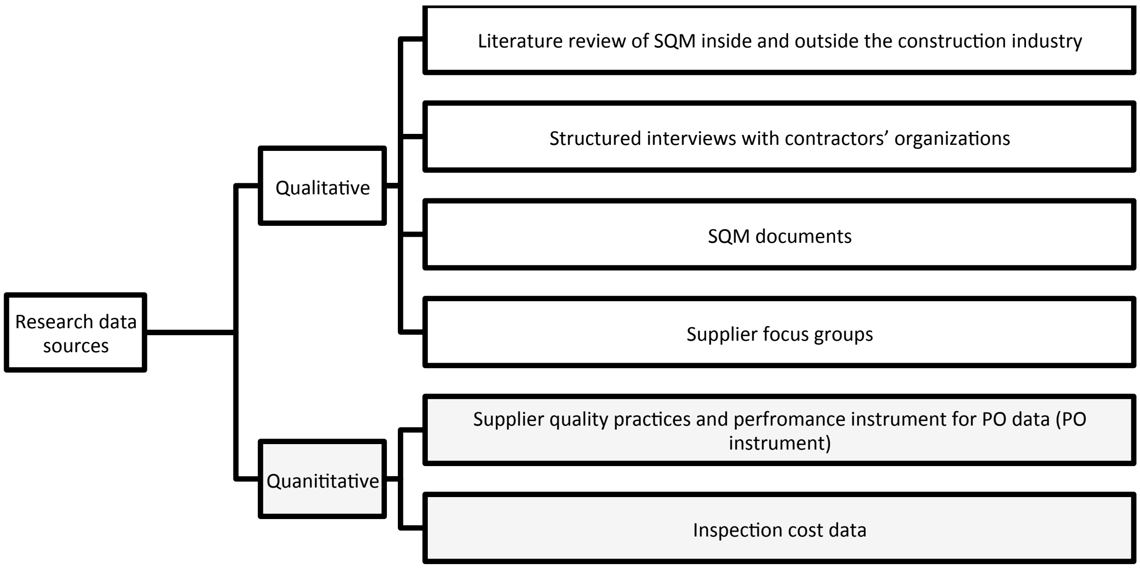

Figure 1: Data sources of the research

The paper begins with an overview of the research data sources and important SQM practices identified by analyzing the data sources. SQM practices are then mapped onto a process outline for supplier quality that was developed during the early stages of the research. Figure 2 depicts a high-level representation of the SQ process map described in detail by Alves et al. (2013). The map contains five major processes beginning with planning and selection of the suppliers. Next, comes execution (of the fabrication along with the development of a supplier quality plan) followed by release of completed purchase orders (POs) from the shop, i.e., packages of fabricated products. Finally, the map shows the receipt of those products at the construction site, and mechanical completion representing the stage when products are physically connected in place in the facility, which marks the end of the scope of analysis for the project. Feedback loops are embedded at each step within the process to indicate that occasionally information flows upstream to inform previous activities about their performance.

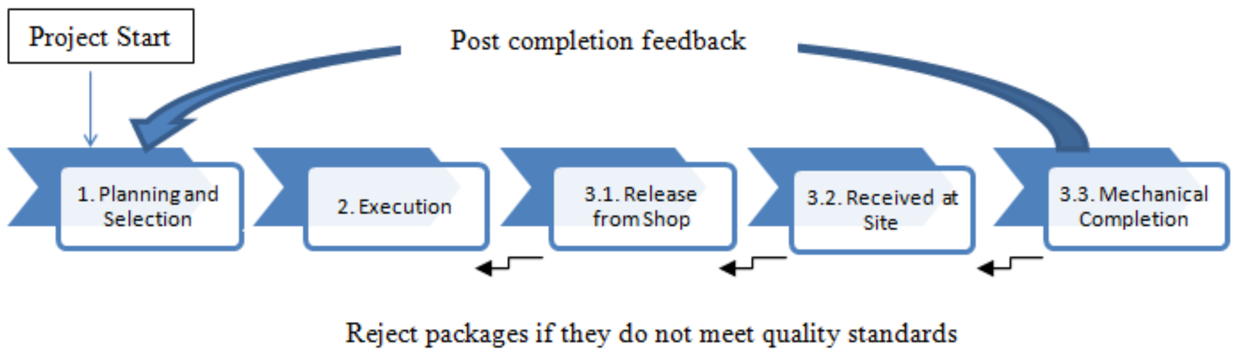

Figure 2. SQ Process Map. Adapted from Alves et al. (2013).

The SQ process map is used to define the main stages of the SQ process, cross analyze the SQM practices identified from the data sources linking them to the stages of the process map, and to describe when within the project life cycle these practices can be applied.

Finally, after identifying when these practices can be applied, we present the balanced scorecard (BSC) as a framework to be implemented during construction projects.

Research Motivation

Within the construction industry, supplier quality management (SQM) is a system of processes and practices applied by organizations to ensure that the quality of fabricated materials and equipment meet the project's requirements and specifications (Caldas et al., 2012). SQM in the construction industry is complex given the one-off nature of projects and the enormity of project size and life cycle, resulting in a continual challenge to ensure that project equipment, products and materials are produced without need for rework.

The motivation for selecting the balanced scorecard (BSC) as a framework for implementation of SQM practices is because of its well-known status in the literature and its diverse implementation in multiple types of businesses such as healthcare (Waal, 2003) and automobile manufacturing (Hoskisson et al. (2009). Since being introduced by Kaplan and Norton in 1992, the BSC has gained favorable support by academia and multiple industries (Kagioglou et al., 2001). The BSC allows managers to view the organization performance from four perspectives, financial, customer, internal business, and innovation and learning. The financial perspective indicates the success of organizations of its financial performance such as its profitability. Kaplan & Norton (1992) identified an example of how improvement in quality and product introduction will lead to higher profits and reduced expenses. The customer perspective considers customer satisfaction in terms of how the customers view the organization. The internal business perspective focuses on the efficiency of the operational activities of the organization. The innovation and learning perspective measures the organization performance toward improvement. Viewing the performance through four perspectives of the BSC helps prevent focusing on one aspect while sacrificing other important aspects (Kaplan & Norton, 1992). Within the construction industry, Kagioglou et al. (2001) indicated that most construction organizations still depend on financial performance measurements. In this paper, the BSC was also applied to propose a number of SQM performance measures within the four perspectives described above. Kagioglou et al. (2001) determined that supplier performance management in the project environment is poorly studied in the construction industry literature. Costa et al. (2006) found that there were no measures related to suppliers' performance and quality management based on their analysis of performance measures from the Construction Industry Institute Benchmarking and Metrics (CII BM&M), the National Benchmarking System for the Chilean Construction Industry (NBS-Chile), and the Construction and the Construction Best Practices Programme –UK (CBPP-UK). However, for all these performance measures to be compared, it is important that the measures be related to the whole project life cycle (Costa et al., 2006). Along the same lines, Needy & Ries (2010) found that the use of consistent quality management practices and quality metrics across the project life cycle form the foundation of effective quality management in the construction industry. In this paper, the SQM practices span the SQ process to provide an adequate focus for the whole project.

The proposed BSC is anticipated to be applied for each construction project as a framework for supplier quality management to provide a basis for implementing SQM practices and measuring performance of the SQM practices. Applying the BSC can help identify lessons learned and opportunities for improving future project performance. In addition, providing the BSC framework for implementation and performance measurement may help organizations compare their performance in multiple projects and benchmark – or assess- their performance against other organizations. Extending the assessment to the organizational level, allow additional useful lessons to be learned (Costa et al., 2006). Needy & Ries (2010) determined that obtaining quality performance metrics and tracking their effectiveness can help construction organizations promote continuous improvement and organizational learning.

Overview of Research Data Sources

As described in Figure 1, the data sources were quantitative or qualitative. A summary of the research methodology for each data source and the main findings is provided next. The research protocol was reviewed and approved by the institutional review board of the universities involved in the study.

Literature Review of SQM Inside and Outside the Construction Industry

The literature review was conducted based on an intensive examination of the scholarly literature and CII body of knowledge for SQM. The literature review also included an investigation of quality practices and methods outside the construction industry for companies and industries known for having effective SQM practices. The industries that were studied include healthcare, manufacturing, food and restaurant industries, aerospace, and shipbuilding. More details about the literature review can be found in AlMaian et al. (2013).

The literature review examination of SQM practices showed that the documented process in the construction industry is quite similar to those found outside of the construction industry. The primary lessons learned from the literature review with regard to improving SQM are to develop close relationships (partnerships) with suppliers, involve fewer and more dependable suppliers, implement a feedback system between the buyer and supplier with supplier improvement opportunities based on measurable objectives, develop a supplier selection process focusing on quality aspects, and ensure top management involvement and commitment with the SQM process.

Structured Interview with Contractors' Organizations

Interviews were conducted on a voluntary basis in a face-to-face setting, or via phone using a structured interview data protocol. The interview questions were grouped into seven sets, including: supplier quality organization, supplier quality system, metrics, data, assessment, supporting documents, and suppliers. In total six interviews were conducted with contractors' organizations. The structured interviews were used to learn in depth about the supplier quality process and compare the current practices among the organizations that have been interviewed.

The research methodology was based on an integrative approach of qualitative data analysis method using grounded theory as described in Strauss & Corbin (1998) and Schutt (2012). In grounded theory, the data analysis method depends on inductive analysis of data. The Grounded theory techniques that were used include detailed examination of the data contents (interview responses) and the development of coding schemes to compare the examined data and to build conclusions. By applying the techniques of grounded theory in examining the interview responses and developing coding schemes, several categories were built to compare the SQM of the interviewed organizations such as supplier performance metrics, strengths and opportunities assessment, and sub-suppliers quality assurance. A detailed description of the qualitative data analysis of this research can be found in AlMaian (2014 forthcoming).

The structured interview responses were sorted into three groups according to the self-reported SQM effectiveness level of the organizations interviewed. The three groupings are: organizations with highly effective SQM, organizations with moderately effective SQM, and organizations with least effective SQM. The three categories emerged from the analysis of interviews and from interviewees' assessment of their SQM systems when compared to that of other competing organizations in the same industry.

Findings from the structured interviews indicated that, when choosing suppliers, organizations with highly effective SQM place an importance on classifying suppliers as strategic or non-strategic. Also, they have higher involvement from top management throughout the project. These organizations use databases to store information about their suppliers, and use this information for supplier performance tracking and future supplier selection.

SQM Documents

The researchers asked participating organizations to provide a sample of documentation of their SQM processes and procedures. The SQM documents include reports and procedures used by construction organizations in their SQM systems. The SQM reports are written documents used to record quality issues and identified required corrective actions. The SQM procedures are written documents that define a specific process or describe a set of requirements that should be followed during the procurement, fabrication, and delivery of products/services. The SQM documents were used to analyze current SQM practices in construction. In total 92 SQM documents were analyzed including 50 reports and 42 procedures. The research method for analyzing the SQM documents was similar to the one used for the structured interview, namely, grounded theory.

Moreover, a second iteration of analysis was conducted for the sample SQM documents that were provided by the organizations reporting highly effective SQM, in the structured interviews. A few SQM practices for these organizations differed from other organizations in the assessment of the work capacity of the suppliers during selection, the analysis of the impact of poor quality on project cost and schedule, and the identification of who is responsible for performing corrective actions by using responsibilities charts.

Supplier Focus Groups

The researchers requested the participating organizations to refer supplier organizations that supply products and services to their local and global construction markets. The team received more than 30 suppliers' contact information; suppliers from this group were contacted and accepted/declined the invitation to participate in the focus groups. The names of the suppliers involved in the focus groups remained confidential, that is, those who provided the names do not know if they indicated participated in the focus groups. This was done to protect the free consent and anonymity of those participating. The purpose of the focus groups was to learn suppliers' perception about SQM and to identify practices that help suppliers achieve zero rework. Three focus group meetings were conducted, with 11 participants representing nine supplying companies (suppliers). These suppliers have been in the EPC industry for an average of 49 years supplying products such as structural steel, loading and combustion equipment, and industrial goods resembling filters and strainers.

The supplier focus group agenda included three categories: *current SQM practices* in which suppliers described existing SQM practices; *current effective SQM practices* in which suppliers provided examples of SQM practices, currently adopted by some of the construction organizations which suppliers believe are effective; and *practices that help suppliers achieve zero rework (desired SQM practices)* in which suppliers identified a number of practices that would help them achieve improved levels of quality. The compiled focus group notes were examined to identify main areas within each discussion category according to the suppliers had reported. Three main areas emerged from the analysis: quality management, project specifications, and feedback system. Table 1 summarizes the findings of the focus groups with respect to the three categories of focus groups discussion and the main areas of analysis.

Current SQM practices	Quality management	• Sending **inspection** staff that, sometimes, **do not have clear understanding of the inspection process.**
	Project specifications	• Receiving projects specifications from **different sources**, including project owners and contractors. Sometimes, received information **does not match**. • Quoting process **includes a lot of communication** about the project requirements.
	Feedback	• **Delaying** the process of **reporting non-conformances (NCs)** to the suppliers. Sometimes the NCs are only known to the supplier **after the product has been shipped.** • Sending, in some cases, combative inspectors. Most inspectors are helpful, but some inspectors **might be combative** and not immediately share with suppliers when problems are discovered. This results in **delaying** the process of correcting problems.
Current effective SQM practices	Quality management	• Use NCs as **learning opportunities** to develop and train suppliers. • Ensure **top management** involvement. • Establish strong supplier **partnerships** • Use examples from **other industries having effective SQM practices** such as automobile manufacturing to develop current practices. • Share **forecast plans with suppliers** that allow suppliers to plan. (What are your plans for increasing your capacity?) • Develop **central software** for repository of information and tracking/reporting data.
	Project specifications	• Provide relevant **standards and instructions** for each project.
	Feedback	(Suppliers have not provided examples of current effective practices for feedback.)
Desired SQM practices	Quality management	• Participate in up-front joint **quality planning** and establish **quarterly reviews with the goal of improving** "Get all players together in the same room to resolve problems."
	Project specifications	• Match the **purchase order (PO) to the request for quotation (RFQ)**. • Provide **exact and relevant specifications for each project.** "Sometimes we just get a **few drawings**" or "We get an **enormous amount** of information, 30-40% of which does not apply to what we do". • **Provide updated** specifications. "Some are more than **30 years old**!" • **Standardize** specifications and applications.
	Feedback	• Provide **feedback** to suppliers. • Notify suppliers **immediately** about NCs. "Sometimes there is a delay and the product has been shipped."

Table 1: Main findings from the supplier focus group meetings

The information gathered from the focus group meetings indicated that there is a need to improve the feedback process between suppliers and contractors, standardize and update project specifications, and perform joint quality planning with involvement from top management.

Supplier Quality Practices and Performance Instrument for Purchase Order Data (PO Instrument)

The PO instrument was designed according to the type of the supplied materials in construction projects, including tagged/engineered equipment, fabricated goods (structured steel), fabricated goods (pipe spools), and manufactured goods/bulk goods. The PO instrument collected data about practices used primarily in engineer-procure-construct (EPC) projects for the selection of suppliers, tracking of purchase orders from shop to site, communication with suppliers, installation of supplied products in construction projects, and resulting quality associated with these practices. The responses were based on actual data about specific POs not from estimation.

The team received 108 responses, each response represented data from a single PO. The PO instrument asked participants about the use of SQM practices such as observing and inspecting suppliers' work, and projecting inspection costs to determine their effect on detecting non-conformances (NCs) per total PO value (NCs/$). Tests of hypotheses and correlation analyses were used to draw the conclusions and the data were parsed by material type and PO criticality. The data were also studied in depth to identify what organizations with highly effective SQM are doing differently with respect to the studied practices. Details of the complete PO analysis and data interpretation can be found in Neuman (2014).

The main conclusions drawn from this study for organizations with highly effective SQM include: they detect more NCs/$; they find them earlier in the project; they have improved systems for observing suppliers' work and for inspection in terms of tracking the cost and hours of inspection. In addition, these organizations conduct more meetings with the suppliers and perform supplier ratings.

Inspection Cost Data

The researchers analyzed the effects of varying inspection and process capabilities with respect to cost parameters through simulation modeling. The model was developed to reflect the main stages of the SQ process map described in Figure 2. The researchers began by gathering cost data for correcting NCs from the SMEs to incorporate into the model to develop analysis scenarios. The objectives of the simulation model were to estimate the costs of identifying and correcting NCs at different stages of the project and to predict the performances of suppliers that have different initial costs and capabilities. It was found that the inspection capability (the ability of the inspection at a given point to detect and repair NCs) affects the outcome more significantly than process capability (the ability to fabricate the item correctly). Also, modeling cost curves indicate the higher quality the supplier, the less costs related to poor quality will be found at the end of the project. Details of the simulation modeling can be found in Ahmad (2014).

Cross Validation of the Research Findings

The SQM practices found from analyzing the quantitative and qualitative data sources can be summarized within the SQ process map to identify when they can be implemented during the project. Table 2 maps the SQM practices with respect to each stage of the SQ process.

SQ process map phases	SQM practices
1. Planning and selection	• Use a detailed formula to calculate the SQS efforts based on criticality of the items and previous supplier performance. • Estimate (project) the inspection cost. • Match PO with request for proposal/quotation (RFP) and update materials/equipment specifications. • Share forecasting plans of upcoming projects with suppliers. • Classify suppliers as strategic or non-strategic. • Focus on the planning and selection phase because it affects the whole SQ process. • Focus on quality (versus price and schedule). • Identify work capacity of the suppliers including other customers' POs. • Evaluate cultural barriers for global suppliers when doing supplier qualification assessment.
2. Execution	• Notify suppliers immediately regarding any NCs. • Send inspectors to supplier facilities who add value to the SQ process. • Observe suppliers' work at their facilities. • Ensure that sub-suppliers know quality requirements. • Derive supplier development and control from other industries, and shift from QC (inspection) to development and improvement (prevention). • Determine the cost and quality impact of NCs to the project.

Table 2: SQM practices onto the SQ process map

2. Execution *through* 3.3 Mechanical completion	• Avoid shortening schedules during the course of the PO. • Develop an integrated information platform with appropriate information access, i.e. have central software for repository of information, tracking/reporting data, and recording corrective actions. • Maintain well-trained inspectors. • Use consistent tools to measure supplier performance. • Track both cost and hours of the inspection effort.
1. Planning and selection *through* 3.3 Mechanical completion	• Build supplier partnership (alliance, training, and support). • Involve top management (leadership) to improve the SQ system (set visions, directions, and improvement initiatives). • Develop an internal database to track supplier performance and analyze future decisions. • Provide feedback to suppliers. • Hold a joint quality planning between contractors and suppliers. • Measure supplier performance throughout the PO.

Table 2 (Cont.): SQM practices onto the SQ process map

As can be seen in Table 2, the planning and selection stage includes practices such as estimating the cost and effort of inspection, and ensuring a proper quality focus by updating materials specifications and identifying work capacity of the suppliers. During the execution stage, the SQM practices include notifying suppliers of any NCs immediately and determining their impact on the project, also, ensuring that inspectors are helpful in improving the SQ process. The SQM practices that span the execution stage through mechanical completion are related to consistently using tools to measure supplier's performance and tracking inspection efforts, together with developing central software to store and retrieve project information. Important SQM practices that extend through the whole SQ process include building supplier partnerships with an involvement from top management to support SQM planning and improvement.

The validation of the research findings, i.e., SQM practices, involves verifying multiple data sources or cross analysis (Miles & Huberman, 1994). The findings from the multiple data sources were aligned to verify their convergence to the same conclusions. In the research, the SMEs were also closely involved in the analysis offering their interpretation of the results found. The SQM practices that were found to be effective based on analyzing the qualitative and quantitative data are organized by the phases of the SQ process map and described next.

1. Planning and selection The construction industry literature emphasizes on the supplier's planning and selection process, in terms of the importance of effective supplier selection (Songhori et al, 2011) and reducing the supplier base and forming strategic partnerships (Peters, 1987; Arditi & Gunaydin, 1998) to improve project outcomes. Similar findings were obtained by analyzing interviews and SQM documents of organization with highly effective SQM in terms of the importance of the planning process, i.e., partnership, classifying the suppliers as strategic or non-strategic, and using formulas to calculate the effort of inspection based on criticality of the items and previous supplier performance. Similar results were also obtained from the quantitative data in which modeling cost data present evidence that the higher quality the supplier (suppliers who have the capability to offer higher quality items), the less costs related to poor quality will be found at the end of the project. The results from the PO instrument show that developing quality plans and projecting the cost of inspection with the supplier improves supplier quality outcomes, because required resources to deliver the items in a PO will be known and planned accordingly at the beginning of the project.

2. Execution: From the qualitative analysis, we found that organizations with highly effective SQM, as indicated in the structured interviews, are proactive in developing their suppliers. The analysis of the SQM documents shows that these organizations ultimately determine the cost and quality impact of the NCs to the project. The results from the supplier focus group show that some organizations perform effective efforts to turn inspections into learning and education opportunities for their suppliers. The quantitative analysis, based on the PO instrument, shows that organizations with highly effective SQM perform more efforts observing the supplier work than those organizations with less effective SQM.

2. Execution through 3.3 Mechanical completion: Organizations with highly effective SQM maintain well-trained inspectors and use consistent tools to measure supplier performance as reported during the structured interviews. Within the construction industry literature, we found that performing systematic performance ratings of overall supplier processes (Tommelein et al., 2003), and using consistent inspection procedures (Lo, 2002) are important SQM approaches. The results of the quantitative analysis suggest that organizations with highly effective SQM have more elaborate systems for inspecting work of suppliers and tracking related inspection efforts.

1. Planning and selection through 3.3 Mechanical completion: Structured interviews with organizations having highly effective SQM reported they involve top management (leadership) to improve the SQ system, develop an internal database to track supplier performance and analyze future decisions, and measure and evaluate supplier performance from multiple disciplines. The findings from supplier focus groups revealed that top management involvement is an important aspect of SQM. Also, using central software to manage information exchange between the supplier and contractor is considered an effective practice. The literature also supports these findings. Chase (1993) described common elements of management roles used by construction organizations to ensure quality, such as top management involvement and commitment, the use of formalized process improvement techniques, helping suppliers to improve, and striving for continuous improvement. With regard to information exchange, the literature review shows that one of the effective SQM practices found outside the construction industry is to develop a product life cycle management (PLM) platform such as the one found in the shipbuilding industry. An example is Siemens PLM Software® (Siemens PLM software, 2013), that is used to clarify and show up-to-date project information and changes that occur during the project, and this information are accessible for all parties involved in the project.

The Balanced Scorecard (BSC) Framework for SQM Practices

Once effective SQM practices are identified and validated through cross analysis, the next step is to develop an implementation framework. SQM practices identified were matched to the four perspectives of the BSC, namely, financial, customer, internal business, and innovation and learning. The matching criterion for SQM practices to the perspectives was based on setting a goal for each perspective and then aligning the practices that fulfilled the stated goal if they were successfully implemented as part of the SQM. The goals were defined as suggested by Kaplan & Norton (1992), and customized to properly describe the SQM. The proposed BSC is portrayed in Figure 3.

Financial Perspective

Goal: Reduce the cost of rework by practicing proper supplier quality management.

Practices:

1. Use a detailed formula to calculate the effort of SQS based on criticality of the items and previous supplier performance.
2. Estimate (project) inspection cost.
3. Determine the cost and quality impact of the NCs to the project.
4. Track both cost and hours of inspection efforts.

Customer (Supplier) Perspective

Goal: Achieve a successful relationship with suppliers to improve the outcomes of the construction project and reduce rework tasks.

Practices:

1. Match PO with request for proposal/quotation (RFP), i.e. send exact specifications to the supplier so that the bid can be more accurate.
2. Update materials/equipment specifications.
3. Share forecasting plans of upcoming projects with suppliers to allow them to plan. (What are the plans for increasing suppliers' capacities?)
4. Notify suppliers immediately regarding any NCs.
5. Send inspectors to supplier facilities who add value to the SQ process.
6. Avoid shortening schedules during the course of PO.
7. Observe suppliers' work at their facilities.

The Balanced Scorecard

Internal Business Perspective

Goal: Ensure internal quality of work in the organization (contractor) in order to improve external (supplier) quality.

Practices:

1. Classify suppliers as strategic or non-strategic.
2. Focus on the planning and selection phase.
3. Focus on quality (versus price and schedule).
4. Identify the work capacity of the suppliers including the other customers' POs.
5. Maintain well-trained inspectors.
6. Use consistent tools to measure supplier performance.
7. Involve top management (leadership) to improve the SQ system (set visions, directions, and improvement initiatives).
8. Measure supplier performance throughout the PO.
9. Evaluate cultural barriers for global suppliers and adapt the SQ process in each country.
10. Develop an internal database to track supplier performance and analyze future decisions.

Innovation and Learning Perspective

Goal: Build a continuous improvement environment to develop the organization's (contractor's staff) and supplier's knowledge and skills.

Practices:

1. Ensure that sub-suppliers (tiers of suppliers) know quality requirements.
2. Derive supplier development and control from other industries, and shift from QC (inspection) to more development and improvement (prevention).
3. Build supplier partnerships (alliance, training, and support).
4. Develop an integrated information platform with appropriate information access, i.e. have central software for use as repository for information, tracking/reporting data, and recording corrective action.
5. Hold joint quality planning between contractors and suppliers.
6. Provide feedback (performance ratings, and meetings) to suppliers.

Figure 3: SQM practices within the balanced scorecard

After aligning SQM practices with the BSC, performance metrics were suggested for each practice within each perspective to help organizations implement the BSC. These performance metrics were obtained from the construction industry literature and the multiple data sources from the research project. The sources of the performance metrics are described in Table 3.

Source of evidence	Description
AS: Alarcón & Serpell (1996)	Alarcón & Serpell (1996) proposed a project performance measurement system for construction companies including metrics such as cost per rework claim.
HB: Harper & Bernold (2005)	Harper & Bernold (2005) provided performance measures to assess the performance of suppliers, such as past working relationships with suppliers, based on surveying a number of contractors.
Yu: Yu et al. (2007)	Yu et al. (2007) developed a performance measurement framework to assess the performance of construction companies, based on surveying a number of companies. He found important metrics like training investment and knowledge management.
PO: PO instrument	The PO instrument of this research includes a number of metrics such as NCs/PO, hours and $ of inspection, that can be used within the BSC.
SQMD: SQM documents	SQM documents provided by organizations with highly effective SQM were examined to find relative metrics that could be used within the BSC. We found several metrics from multiple documents, example of the titles of these documents: quality surveillance report, quality plan, corrective action report, vendor inspection pre-fabrication checklist, assessment survey, and initial visit quality report
SI: Structured interviews	Structured interview responses were examined to find relative metrics that could be used within the BSC. We found that contractors that were interviewed identified a number of metrics within their answers such as, number of inspectors and active suppliers.
SF: Supplier focus groups	Based on supplier focus groups, suppliers reported a number of practices with examples of relative metrics, e.g., supplier feedback frequency, that can be used within BSC.

Table 3: Sources of performance metrics

The proposed metrics can that can be used to track performance of the SQM practices in each project are described in Tables 4 to 7.

Practice	Approximately Similar Metrics found in Literature and/or data sources	Units for Measurement
1	Ratio: Supplied item criticality (PO) / Past working relationships with the supplier (HB)	Scale: (high, med, or low criticality)/ (excellent, good, bad performance)
	Surveillance level (SQMD)	Numeric Scale: 1 to 4 (1: low, 4: high surveillance)
2	Projected cost of surveillance or inspection (SQMD), (PO)	$
3	Cost per rework claim (AS)	Rework Man-Hour/ Total Man-Hour
	Rework impact on quality (SQMD)	Scale: Potential, indirect
4	Number of hours and relative cost per inspection visit (SQMD)	Total Hours and $

Table 4: Financial perspective

Practice	Approximately Similar Metrics found in Literature and/or data sources	Units for Measurement
1	Verification of receiving correct and applicable project specification by the supplier (SQMD)	Yes, No
2	System to update project specifications and quality documentation (SQMD)	Rating: 0-4 (0:no system, 4: good with continuous improvement)
3	Initiatives to share forecasting plans (SF)	Yes, No
4	Time between NC detection and NC notification (delay time) (SF)	Days
5	Collaboration effort by the inspector to improve supplier quality (SF)	Yes, No

Table 5: Customer (supplier) perspective

Practice	Approximately Similar Metrics found in Literature and/or data sources	Units for Measurement
6	Schedule variation[(AS)]	Days
7	Supplier's work observation [(PO)]	Scale: Not at all, full time observation

Table 5 (Cont.): Customer (supplier) perspective

Practice	Approximately Similar Metrics found in Literature and/or data sources	Units for Measurement
1	Strategic suppliers/total number of active suppliers [(SI)]	%
2	Planning meetings [SQMD)]	Number of meetings
	Inspection and testing plans (ITP) [(PO)]	Yes, No
3	Supplier evaluation when making sourcing decisions (supplier's ability to contribute to new product, supplier's continuous improvement effort) [(SQMD)]	Rating scale: 0-4 (0: no consistent planning system, 4: good with continuous improvement)
4	Estimate of current working capacity of the supplier [(SQMD)]	%
5	Experienced inspectors [(SI)]	Number of inspectors
6	Consistency of measuring inspection or testing processes [(SQMD)]	Rating scale: 0-4 (0:no consistent system, 4: good with continuous improvement)
7	Senior management responsibility for improvement [(SQMD)]	Rating scale: 0 to 4 (0: no improvement system or culture, 4: good with proven continuous improvement)
8	Control of non-conformances (NCs) throughout the project [(SQMD)]	Rating scale: 0 to 4 (0: no control system, 4: good with proven continuous improvement)
	Number of NCs detected [(PO)]	Number of NCs/ PO
9	Initiatives to evaluate cultural (communication) barriers for global suppliers [(SF)]	Yes/ No
10	Supplier performance traceability [(SQMD)]	Rating scale: 0-4 (0: no system, 4: good with continuous improvement)

Table 6: Internal business perspective

Practice	Approximately Similar Metrics found in Literature and/or data sources	Units for Measurement
1	Plans for sub-supplier auditing and quality control [(SQMD)]	Rating scale: 0-4 (0: no consistent planning system, 4: good with continuous improvement)
2	Knowledge gained from other industries [(SF)]	Numeric scale: 1 to 5 (1: no knowledge management system, 5: good)
	Knowledge management [(Yu)]	
3	Training investment [(Yu)]	$
4	Information and communication system [(Yu)]	Scale :high to low i.e. high integration (central software), low integration (emails)
5	Number of planning meetings /project [(SQMD)]	Meetings
	Development of quality control plans/inspection and testing plans (ITP) [(PO)]	Yes, No
6	Frequency to provide supplier feedback [(SF)]	Scale: Always, frequently, rarely, never
	Meetings with suppliers to discuss quality issues and provide feedback [(PO)]	Number and types of meetings
	Supplier performance rating after executing the work [(PO)]	Yes, No

Table 7: Innovation and learning perspective

Validating the Balanced Scorecard (BSC)

To validate the proposed BSC framework and the relative metrics described in Tables 4 to 7, the SMEs were involved to provide insights and comments for the applicability of the BSC framework and the correctness of aligning practices and metrics within each perspective. Six validation interviews were conducted with construction organizations representing owners, contractors, and suppliers. The suppliers were included in the validation interviews because they can implement the BSC framework since they work with multiple tiers of suppliers that provide them with materials and products. For each perspective within the BSC, the SMEs were asked to determine whether the SQM practices with relative metrics are correctly viewed to belong to a particular perspective. Four SMEs strongly agreed that these practices and metrics are correctly placed within each perspective. Two SMEs agreed that these practices and metrics are correctly viewed because they believe that there must be some modifications in order to be applicable within each project. For example, for the financial perspective (Table 4), the metrics of practices 2, 3, and 4, need to be measured for each equipment/material in order to be more accurate. For the internal business perspective (Table 6), the metric of practice 5, i.e. number of experienced inspectors, has to be clarified to include the levels of the inspectors experience in order to reflect what is being generally practiced in the construction industry. In other words, level I represents the entry level inspectors, level III represents the highest experienced inspectors.

The SMEs were also asked if they anticipate suggesting the BSC framework be used in future projects at their organizations. All the SMEs were willing to implement this framework. In general, the SMEs reported that all of the financial SQM practices are currently implemented. In fact in most cases, they have more advanced systems to measure the financial perspective of SQM. However, the practices in the other perspectives of the BSC are not currently well implemented within their organizations and they indicated that organizations would benefit from paying more attention to these areas. The SMEs believed that the practices of the internal business and innovation and learning are the most critical to improve the SQM in their organizations.

Conclusions

This research summarized the most effective SQM practices identified by multiple sources of quantitative and qualitative data. These SQM practices were mapped onto a process outline, SQ process map, to determine when they should be implemented during the project. Also, these practices were matched within the balanced scorecard (BSC) to be used as an implementation framework for SQM within construction projects.

The most important contribution of the research to civil and construction engineering management is recommending the BSC framework for implementing the effective SQM practices during construction projects. The BSC usually incorporates a goal for each perspective with relative metrics to help track and measure the performance. In this study, we aligned effective SQM within each perspective with applicable metrics to guide organizations in performing required actions (practices) to achieve the goal of each perspective. The proposed framework is beneficial in assisting organizations in improving their current SQM. At the end of each project, the practices within each perspective can be assessed based on how well the goal was achieved given the utilization of these practices. In general, this paper drew upon a research effort to propose a framework that, if used for each construction project, would allow a comparison of the performance across multiple projects, thus suggesting areas of improvement.

Research Limitations and Future Work

This paper has a number of limitations. First, it does not address the required resources (e.g., budget, staffing and data collection efforts) for organizations to effectively utilize the BSC. It is important for construction organizations to develop their internal capabilities to effectively implement the framework. For example, Costa et al. (2006) identified the necessity to develop technical support for the data collection process within construction organizations to implement performance management systems. Second, with regard to the available data (metrics) for performance measurement, any performance measurement system must incorporate a database to store, retrieve, and handle the needed information for developing the measurement system (Costa et al., 2006; Alarcon & Serpell, 1996). The paper does not address the challenges of not having an advanced database for storing and retrieving information needed for the BSC. Third, having many practices within each perspective may add complexity to effectively measure and track their performance during each project. Moreover, not all practices are easy to implement or have similar impacts on improving quality. Suggestions for future work include further analysis of each practice within each perspective of the BSC in terms of their ease of implementation and impact on quality by using the appropriate analysis methods.

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6. ANALYZING EFFECTIVE SUPPLIER QUALITY MANAGEMENT PRACTICES USING SIMPLE MULTI-ATTRIBUTE RATING TECHNIQUE (SMART) AND VALUE FOCUSED THINKING (VFT)

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Abstract

Supplier quality management (SQM) practices are important to ensure that supplied project materials are within quality specifications. However not all SQM practices have similar impact on quality or are easy to perform within construction projects. This research describes applying simple mutli-attribute rating technique (SMART) to analyze a number of SQM practices aligned within the balanced scorecard (BSC) perspectives, namely, financial, customer (supplier), internal business, and innovation and learning. Each SQM practice is assessed in terms of its ease of implementation and impact on quality. In addition, the research describes important leadership principles that were found in the literature, and utilizes the value focused thinking

(VFT) method to derive important leadership objectives and practices for SQM. The SMART analysis identified SQM practices that are most important within each perspective, such as the practice of holding joint quality planning within the innovation and learning perspective of the BSC. The results of applying VFT show having a quality director who establishes and supports the culture of SQM is the most important leadership practice. The research findings can benefit construction organizations wishing to improve their existing SQM by identifying practices that are easy to implement with high impact on quality, and by sharing such organizations leadership objectives and practices necessary to develop strategic leadership and successfully implement SQM practices within construction projects.

Keywords

Construction industry, Supplier Quality Management (SQM), Balanced Scorecard (BSC), Simple Multi-Attribute Rating Technique (SMART), Value Focused Thinking (VFT), Leadership Principles, Strategic Leadership.

Introduction

The paper presents results from a research study supported by the Construction Industry Institute (CII), and led by academic researchers from industrial and civil engineering with a group of subject matter experts (SMEs) representing their member organizations in the CII as construction owners, contractors, and suppliers. The major research question under study was as follows: "*What are the most effective processes and practices for ensuring that project materials and equipment are produced, manufactured, or fabricated in strict accordance with all applicable specifications, and that they are delivered to the project site without any need for rework?*"

The objectives of this paper are to analyze a number of supplier quality management (SQM) practices that were found to be effective based on analyzing multiple data sources, and to describe important leadership practices that help in developing strategic leadership for SQM in construction organizations.

Within scope of this study, the balanced scorecard (BSC) was previously developed as a framework to align SQM practices with their performance metrics to assist construction organizations measure project performance. The practices were aligned within the four BSC perspectives: financial, customer (supplier), internal business, and innovation and learning. Each perspective has a goal with related practices, in which if these practices aer successfully implemented, the goal will be achieved. The details of the BSC framework can be found in AlMaian (forthcoming 2014). Table 1 describes the BSC.

BSC perspective	SQM goals and practices
Financial	***Goal:*** *Reduce the cost of rework by practicing proper supplier quality management.* **Practices:** 1. Use a detailed formula to calculate the effort of supplier quality surveillance (SQS) based on criticality of the items and previous supplier performance. 2. Estimate (project) the inspection cost. 3. Determine the cost and quality impact of the non conformances (NCs) to the project. 4. Track both cost and hours of the inspection efforts.
Customer (supplier)	***Goal:*** *Achieve a successful relationship with suppliers to improve the outcomes of the construction project and reduce rework tasks.* **Practices:** 1. Match purchase order (PO) with request for proposal/quotation (RFP), i.e. send exact specifications to supplier so that the bid can be more accurate. 2. Update materials/equipment specifications. 3. Share forecasting plans of upcoming projects with suppliers that allow them to plan. (What are the plans for increasing suppliers' capacities?) 4. Notify suppliers immediately regarding any NCs. 5. Send inspectors to supplier's facility who add value to the SQ process. 6. Avoid shortening schedules during the course of the PO. 7. Observe suppliers' work at their facilities.

Table 1: The SQM goals and practices within the balanced scorecard. Adapted from AlMaian (2014 forthcoming)

BSC perspective	SQM goals and practices
Internal business	***Goal:*** *Ensure internal quality of work in the organization (contractor) in order to improve external (supplier) quality.* **Practices:** 1. Classify suppliers as strategic or non-strategic. 2. Focus on the planning and selection phase. 3. Focus on quality (versus price and schedule). 4. Identify work capacity of suppliers including the other customers' POs. 5. Maintain well-trained inspectors. 6. Use consistent tools to measure supplier performance. 7. Involve top management (leadership) to improve the SQ system (set visions, directions, and improvement initiatives). 8. Measure supplier performance throughout the PO. 9. Evaluate cultural barriers for global suppliers and adapt the SQ process in each country. 10. Develop an internal database to Track supplier performance and analyze future decisions.
Innovation and learning	***Goal:*** *Build a continuous improvement environment to develop the organization's (contractor's staff) and supplier's knowledge and skills.* **Practices:** 1. Ensure that sub-suppliers (tiers of suppliers) know quality requirements. 2. Derive supplier development and control from other industries, and shift from QC (inspection) to development and improvement (prevention). 3. Build supplier partnerships (alliance, training, and support). 4. Develop an integrated information platform with appropriate information access, i.e. have central software as a repository for information, tracking/reporting data, and recording corrective actions. 5. Hold joint quality planning between contractors and suppliers. 6. Provide feedback to suppliers.

Table 1 (Cont.): The SQM goals and practices within the balanced scorecard. Adapted from AlMaian (2014 forthcoming)

Building on the aforementioned work about SQM practices organized in the BSC, this paper analyzes the SQM practices within each BSC perspective by considering their impact on quality and ease of implementation using a decision analysis technique, namely Simple Multi-Attribute Rating Technique (SMART). This analysis can help construction organizations identify the most effective SQM practices for their business. The paper also presents important leadership principles identified by analyzing the literature. The principles support the development of strategic leadership for SQM. They can be used to define SQM leadership objectives. The principles are further analyzed using value focused thinking (VFT) method to develop practices that might support long-term development and effective implementation of SQM.

The paper begins with description of the research motivation and research methods, namely, SMART, leadership literature taxonomy, and VFT. Next, the research methodology and its implementation are described. Finally, conclusions are drawn based on the research findings.

Research Motivation

Construction organizations apply supplier quality management (SQM) within their projects. SQM is a system of processes and practices applied by the organization to ensure that the quality of the fabricated materials and equipment meet the project's requirements and specifications (Caldas et al., 2012). SQM in the construction industry is challenging due to the uniqueness of each construction project in terms of its scope, size, and life cycle. It is desirable for construction organizations to define SQM practices that can be implemented in every project so that quality outcomes can be consistent and delivered as planned or improved. A previous study by AlMaian (2014 forthcoming), analyzed SQM practices that span the project life cycle and incorporated them in the balanced scorecard (BSC), shown in Figure 1, to help construction organizations implement these practices and compare their performance among multiple projects. However, the number of practices within each perspective is considered large, adding complexity for organizations trying to implement this framework for the first time. Furthermore, proper data inquiry efforts within the organizations seeking to implement it are required to collect, store, and retrieve performance measures for the practices. Kaplan & Norton (1992) emphasized the number of performance measures within the BSC should be manageable to avoid information overload and to focus on the most critical measures. To simplify implementing the BSC framework within construction projects, the practices were assessed within each perspective in terms of their ease of implementation, i.e., the practice is easy to implement when the resources to implement this practice are already available. Also, the practices were assessed in terms of their impact on quality, i.e., the practice has a high impact on quality when it helps in improving supplier quality. The assessment of SQM practices can help construction organizations focus on key SQM practices within the BSC framework, and provide a basis for selecting consistent SQM practices across the construction projects that have high impact on quality and are simple to implement. Needy & Ries (2010) observed the use of consistent quality management practices and quality metrics across the project life cycle form the foundation of effective quality management in the construction industry.

This paper also includes a description and analysis of leadership principles and practices. The necessity to discuss leadership within the scope of the study is to inform organizations about important principles and practices necessary to develop strategic leadership for SQM, and hence successfully implement efficient SQM practices across the construction industry. Strategic leadership is crucial for achieving and maintaining continuous improvement (Vera, & Crossan, 2004). Strategic leadership includes the process of forming a vision for the future, communicating it to subordinates, motivating followers, and engaging in strategy-supportive activities with subordinates (Elenkov et al., 2005). A preliminary review of the strategic leadership literature indicates that leadership practices should be adjusted to reflect the challenges of the global economy of the 21st century (Saee, 2005). A study by Ireland & Hitt (2005) concluded that developing technological knowledge; building partnerships and alliances; and sharing leadership influence are important strategic leadership skills. Within the construction industry, Isik, et al. (2010) noted leadership strategic decisions and plans have direct influence on the company's performance and project success. However, the subject of leadership has received limited focus within the construction literature, and researchers have focused mainly on technical features of construction projects (Toor & Ofori, 2008). The lack of focus on leadership in the construction industry applies to both academic research and industry practice (Chan & Chan, 2005). Toor & Ofori (2008) suggested that leadership studies need to be improved in terms of the methodological approach, and development of leadership perspective within the construction industry. In our research, important leadership principles were derived based on examining two sources: the construction industry leadership literature, and the general leadership literature. The derived leadership principles were used to identify important leadership objectives necessary to successfully implement SQM practices, and effectively develop strategic leadership for SQM within construction organizations.

The findings from the assessment and discussion of both SQM practices within the BSC and strategic leadership for SQM can benefit construction organizations by improving the existing SQM systems. Hoskisson et al. (2009) indicated effective strategic leadership in any organization must use control systems such as the BSC so that leaders can assess organization performance. Also, effective strategic leadership must select and asses practices that add value to the organization and promote improvements (Hoskisson et al., 2009). In summary, managers should be able to identify effective practices that are relatively easy for their organizations to implement and yield the highest impact on quality; the analysis of SQM practices with the BSC supports this process. In addition, the discussion of strategic leadership can promote long-term improvements for SQM in construction organizations.

Research Methodology

The research methodology used consists of three parts: an assessment of the SQM practices within each perspective of the BSC using SMART, an examination of leadership principles in the construction industry and general leadership literature using a taxonomy based on the literature review and a qualitative comparative analysis, and a consideration of SQM leadership objectives and creation of SQM leadership practices using value focused thinking (VFT). A detailed description of the research methods is follows.

Simple Multi-Attribute Rating Technique (SMART)

The simple multi-attribute rating technique (SMART) is a decision analysis method based on rating alternatives with respect to a defined set of attributes. In this research, we have a number of practices identified, i.e., alternative courses of action, within each perspective of the BSC. Assuming that the BSC perspectives are of equal importance, we used SMART to analyze the practices within each perspective based on two attributes: ease of implementation and impact on quality. SMART was selected for this research, because it has been widely used by decision makers from various backgrounds due to its relative simplicity (Goodwin & Wright, 2009). The analytic hierarch process (AHP) was also considered as a means of evaluating SQM practices. However, SMART was selected over AHP due to its simplicity in considering a large number of practices. In our study, the use of AHP would have resulted in over one hundred pairwise comparisons, which was impractical for this application. More details describing the simplicity of SMART as compared to AHP can be found in Goodwin & Wright (2009) and Pöyhönen & Hämäläinen (2001).

In our research, the assessment of alternatives (SQM practices) and attribute weightings were elicited from two SMEs having extensive knowledge and experience of SQM within organizations with highly effective SQM systems. Collectively, their experience spanned 50 years in supplier quality. These SMEs were also subsequently interviewed to gain additional insight and understanding of their assessment.

Methodology of Leadership Literature review

Cooper's (1988) taxonomy of literature review was utilized to classify the literature according to: *focus, goal, coverage, and organization*. The *focus* of the literature review can be on research outcomes (findings), research methods, theories, or practices and applications. In this study, the focus of literature review is on information analysis and synthesis of findings from construction leadership literature, and the general leadership literature.

The *goal* of the literature review can be integration, criticism, and identification of central issues. In this study, the goal of the review is to integrate and generalize findings across two fields of literature, and to bridge the common leadership principles between these two areas.

The *coverage (inclusion criteria)* of the literature can be exhaustive, exhaustive with selective citation, representative, or central. In this study the coverage was exhaustive with selective citation. As described by Cooper (1998), this criterion of coverage is to find a manageable number of sources to examine.

To review the leadership literature in the construction industry, we conducted a search on a number of databases, and limited our search to peer-reviewed scholarly journals. The exclusion criteria were for articles that discuss professional issues for leadership education and research, and leadership career development. We obtained 23 articles. After examining their abstracts to determine their relevancy, a total of four articles were selected for further examination.

The inclusion criteria for the leadership literature were based on a select group of books known for their impact on the leadership field. Nine books were selected and studied in-depth as depicted in Table 2.

Author(s) citation	Book title
Phillips, 1992	*Lincoln on Leadership: Executive Strategies for Tough Times*
Kouzes & Posner, 1995	*The Leadership Challenge: How to Keep Getting Extraordinary Things Done in Organizations*
Machiavelli, 1994	*The Prince*
Maxwell, 2007	*The 21 Irrefutable Laws of Leadership: Follow them and the People will Follow You*
Heifetz & Linsky, 2002	*Leadership on the Line: Staying Alive through the Dangers of Leading*
Sun Tzu, 1963	*The Art of War*
Heifetz, 1994	*Leadership without Easy Answers*
Sample, 2002	*The Contrarian's Guide to Leadership*
Kolp & Rea, 2006	*Leading with Integrity: Character based Leadership*

Table 2: Leadership books used for literature review

For *organization*, the most common choice of the formats in which to organize the review are historical format, conceptual format, and the methodological format. The conceptual format was used to find the common leadership concepts (principles) between the two areas of literature that we examined. Also, we adopted the qualitative comparative analysis described in Schutt (2012), in which the contents of data collected from multiple sources are compared to find common concepts. In this study, two sources of literature fields were examined to identify the combination of factors that are present across these multiple sources.

Value Focused Thinking (VFT)

Value focused thinking (VFT) is a decision analysis method that differs from alternative-focused thinking methods, such as SMART and AHP, in terms of its focus on the values or objectives that are required to be achieved through the decision analysis. VFT relies on the principle that values are better achieved if they are stated and understood prior to thinking of alternatives (Keeney, 1992; Keeney, 1993). Within decision making contexts, recognizing the need for objectives (values) is a fundamental step for any strategic approach (Keeney, 1996). In general, VFT seeks to gain in-depth understanding of the objectives, leading to creative alternatives (practices) that are strongly related to these objectives. Therefore, we started with the objectives and then developed alternatives by utilizing the VFT method to identify leadership practices for effective SQM. First we designed objectives (values) based on examining the leadership literature as described earlier, then these objectives were weighted and their relative practices (alternatives) were developed.

An assessment of these alternatives was performed by SMEs to select the practices that influence strategic leadership for SQM. Information required to utilize VFT was collected via interviews with the same SMEs that were involved with the SMART analysis.

Research Methodology Implementation

As described earlier, the research used SMART to analyze the practices within each perspective of the BSC, and then used VFT to discuss the leadership principles obtained from the leadership literature taxonomy. The details of implementing the research methodology and the results are obtained and discussed next.

SMART

The SMEs were asked to consider each BSC perspective and provide their assessment accordingly. The two attributes used for analysis were ease of implementation and impact on quality. To implement SMART, the practices within each perspective should be weighted with respect to each attribute, and also the attributes within each perspective should be weighted. There are multiple weighting methods for the alternatives, i.e., practices and attributes within the multi-criteria decision analysis (MCDA) literature, such as swing, direct, and relative importance. Details can be found, for example, in Daniels et al. (2001), Pöyhönen & Hämäläinen (2001), and Goodwin & Wright (2009). For SMART, swing weighting is commonly used for the attributes and the relative importance weighting for the alternatives (practices). For swing weighting, the attribute weight is based on the SMEs perception of how important the attribute's swing in values (from worst to best) is relative to the swings in values for the other attributes under consideration. Usually, swing weight is illustrated considering a hypothetical alternative in which all the attributes are at their worst level. For SQM, a hypothetical alternative can be for a practice that has no impact on quality and is very difficult to implement. The SMEs were asked to pick the attribute that moves the practice from its worst to be ranked first. For example, if ease of implementation was picked and ranked first, then a swing from worst to best impact on quality for a practice can be considered to be, for example 80%, as important as a swing from worst to best level of ease of implementation.

For relative importance weighting, the practice weight is based on the SMEs perception of how important the practice is relative to other practices under consideration.

The weighting methods were explained to the SMEs prior to the interview. Then, within each perspective of the BSC, the SMEs were asked to rank the practices by their ease of implementation and impact on quality. Assuming higher values are better, the practices that were ranked first were given a value of 100 and those that were ranked last were given a value of zero. A value of 100 describes a practice that is very easy to implement, and a value of zero describes a practice that is very difficult to implement. Weighting of the impact on quality is done similarly, i.e., zero for practice that has no impact on quality, and 100 for a practice that has significant impact on quality. Relative values were given to the remaining practices. The weighting values were then normalized, so that the total summation of values is equal to 100.

The SMEs were then asked to evaluate the two attributes within each perspective using swing weights. The values of swing weights were normalized so that that the total summation of values for the two attributes is equal to 1. Once the weights were determined, the overall value for each practice within each perspective was calculated as follows:

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i) \qquad (1)$$

Where,

$v(x)$ = practice's value

i = the attribute number from 1 to n (in our case i is equal 1 or 2)

w_i= weight of the attribute i (normalized weight, i.e., summation of w_i is equal to 1)

$v_i(x_i)$ = rating/score of alternative x for attribute i (normalized rating, i.e., summation of $v_i(x_i)$ is equal to 100)

Table 3 describes the practices' ratings for the financial and customer (supplier) perspectives.

	Attributes			
	Ease of implementation		Impact on quality	
SQM practices (financial)	Original rating	Normalized rating	Original rating	Normalized rating
1. Use a **detailed formula** to calculate the effort of SQS based on criticality of the items and previous supplier performance.	50	28.57	70	30.43
2. **Estimate** (project) the **inspection cost**.	45	25.71	50	21.74
3. **Determine the cost and quality impact** of the NCs to the project.	10	5.71	70	30.43
4. **Track** both cost and hours of **inspection efforts**.	70	40	40	17.39
Total	*175*	*100*	*230*	100
SQM practices (supplier)	Original rating	Normalized rating	Original rating	Normalized rating
1. **Match PO with** request for proposal/quotation **(RFP)**.	50	13.70	100	19.34

Table 3: Ratings for practices of the financial and customer perspectives

SQM practices (supplier) (Cont.)	Attributes: Ease of implementation – Original rating	Ease of implementation – Normalized rating	Impact on quality – Original rating	Impact on quality – Normalized rating
2. **Update materials**/equipment specifications.	100	27.40	95	18.38
3. **Share forecasting plans** of upcoming projects with suppliers that allow them to plan.	0	0.00	20	3.87
4. **Notify** suppliers **immediately** regarding **any NCs**.	40	10.96	80	15.47
5. **Send inspectors** to supplier's facility who **add value** to the SQ process.	80	21.92	82	15.86
6. **Avoid shortening schedules** during the course of the PO.	25	6.85	50	9.67
7. **Observe suppliers' work** at their facilities.	70	19.18	90	17.41
Total	*365*	*100*	*517*	*100*

Table 3 (Cont.): Ratings for practices of the financial and customer perspectives

Figures 1 and 2 depict how the practices are spread according to the original rating of ease of implementation and impact on quality from financial and customer perspectives. As shown in Figure 1and Table 3 for financial practices, there is no SQM practice that is easy to implement with high impact on quality. Practice 3 (financial), determine cost and quality impact of NCs, has high impact on quality, but is very difficult to implement.

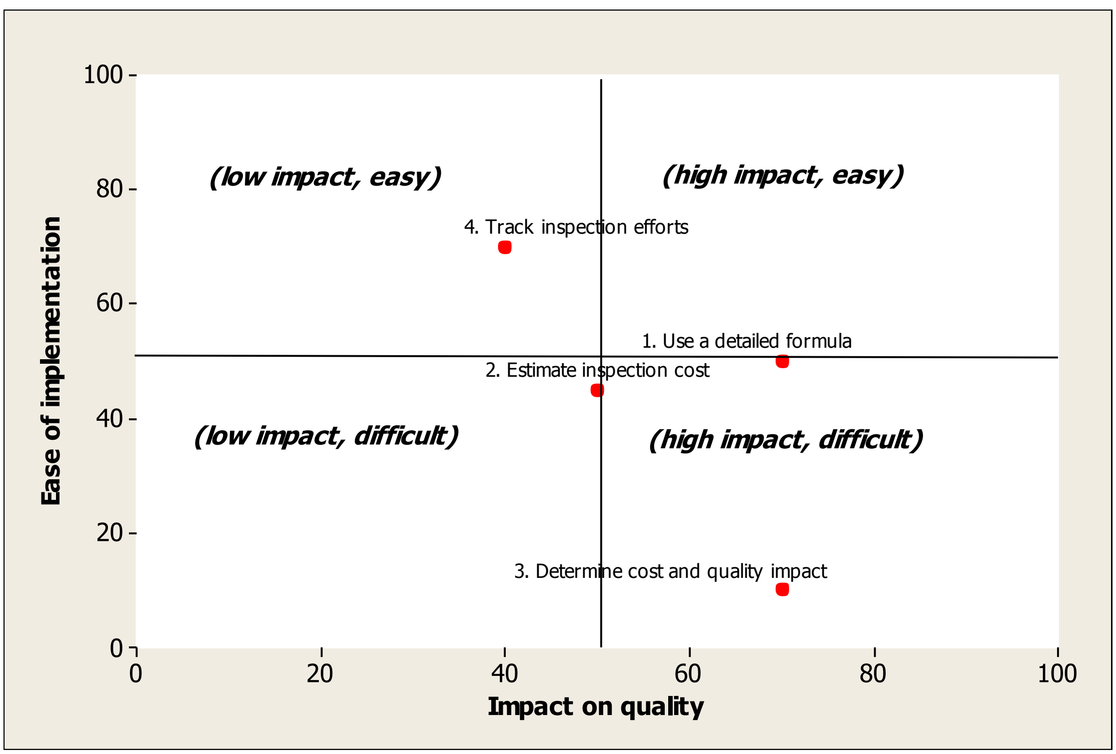

Figure 1: SQM practices in the financial perspective

For SQM practices within the customer perspective, as shown in Figure 2, most of practices were considered relatively easy to implement. Only sharing forecasting plans with suppliers is difficult to implement with low impact on quality.

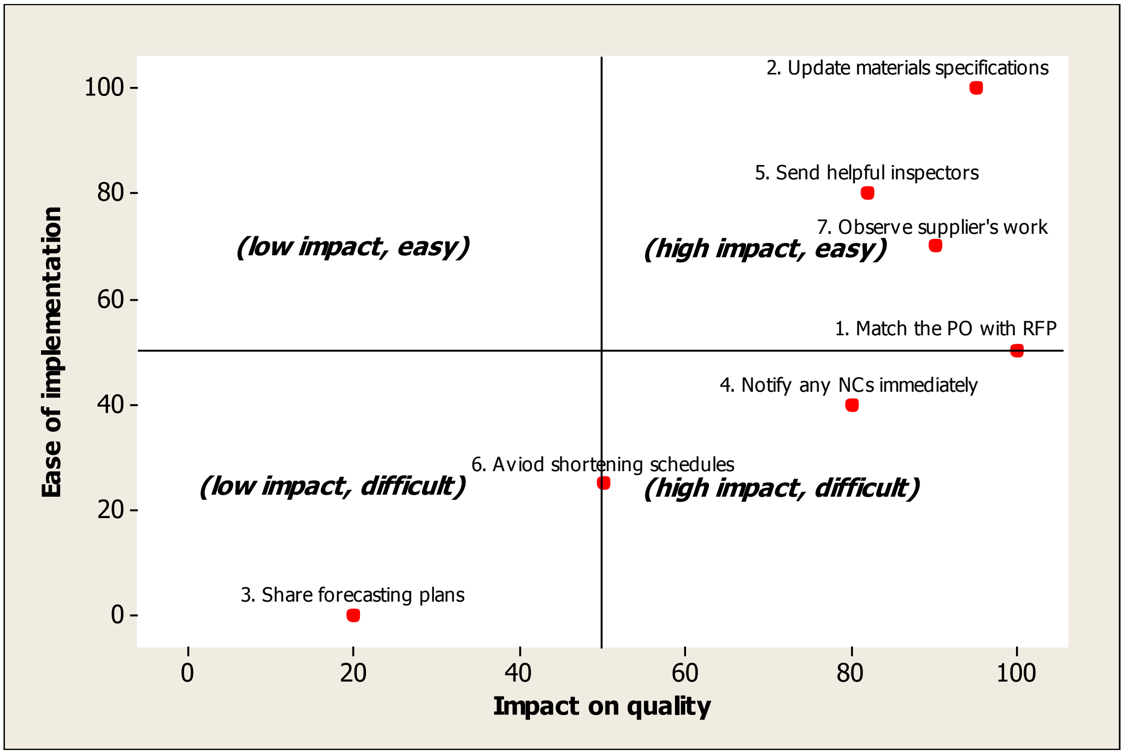

Figure 2: SQM practices in the customer (supplier) perspective

Table 4 describes the practices' ratings for the internal business and innovation and learning perspectives.

	Attributes			
	Ease of implementation		Impact on quality	
SQM practices (internal business)	Original rating	Normalized rating	Original rating	Normalized rating
1. **Classify suppliers** as strategic or non-strategic.	100	28.57	75	9.18
2. **Focus on the planning** and selection phase.	12	3.43	85	10.40
3. **Focus on quality** (versus price and schedule).	98	28.00	99	12.12
4. **Identify work capacity** of the suppliers including the other customers' POs.	10	2.86	70	8.57
5. **Maintain well-trained** inspectors.	15	4.29	98	12.00
6. **Use consistent tools** to measure supplier performance.	20	5.71	80	9.79

Table 4: Ratings for practices of the internal business, and innovation perspectives

	Attributes			
	Ease of implementation		Impact on quality	
SQM practices (internal business) (Cont.)	Original rating	Normalized rating	Original rating	Normalized rating
7. **Involve top management** (leadership) to improve the SQ system (set visions, directions, and improvement initiatives).	5	1.43	100	12.24
8. **Measure supplier performance** throughout the PO.	40	11.43	95	11.63
9. **Evaluate cultural barriers** for global suppliers and adapt the SQ process in each country.	0	0.00	25	3.06
10. **Develop an internal database** to track supplier performance and analyze future decisions.	50	14.29	90	11.02
Total	*350*	*100*	*817*	*100*
SQM practices (innovation and learning)	Original rating	Normalized rating	Original rating	Normalized rating
1. **Ensure** that **sub-suppliers** (tiers of suppliers) **know quality** requirements.	80	23.74	100	22.99
2. **Derive supplier development** and control **from other industries**, and shift from QC (inspection) to development and improvement (prevention).	0	0.00	25	5.75
3. **Build supplier partnerships** (alliance, training, and support).	40	11.87	50	11.49
4. **Develop an integrated information platform** with appropriate information access.	20	5.93	75	17.24
5. **Hold joint quality planning** between contractors and suppliers.	100	29.67	95	21.84
6. **Provide feedback** to suppliers.	97	28.78	90	20.69
Total	*337*	*100*	*435*	*100*

Table 4 (Cont.): Ratings for practices of the internal business, and innovation perspectives

Figure 3 portrays the SQM practices in the internal business perspective presented in Table 4. As shown in Figure 3 and described in Table 4, practices 2 and 4 through 7 have high impact on quality, but are relatively difficult to implement.

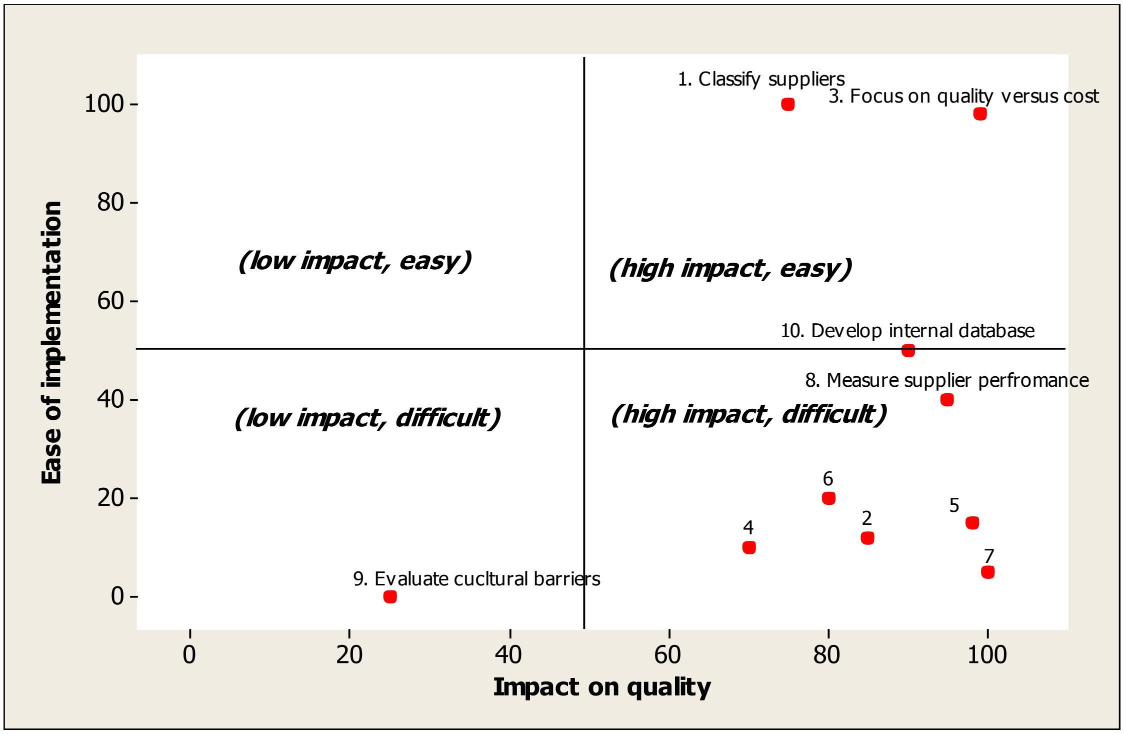

Figure 3: SQM practices in the internal business perspective

Figure 4 is for SQM practices in the innovation and learning perspective.

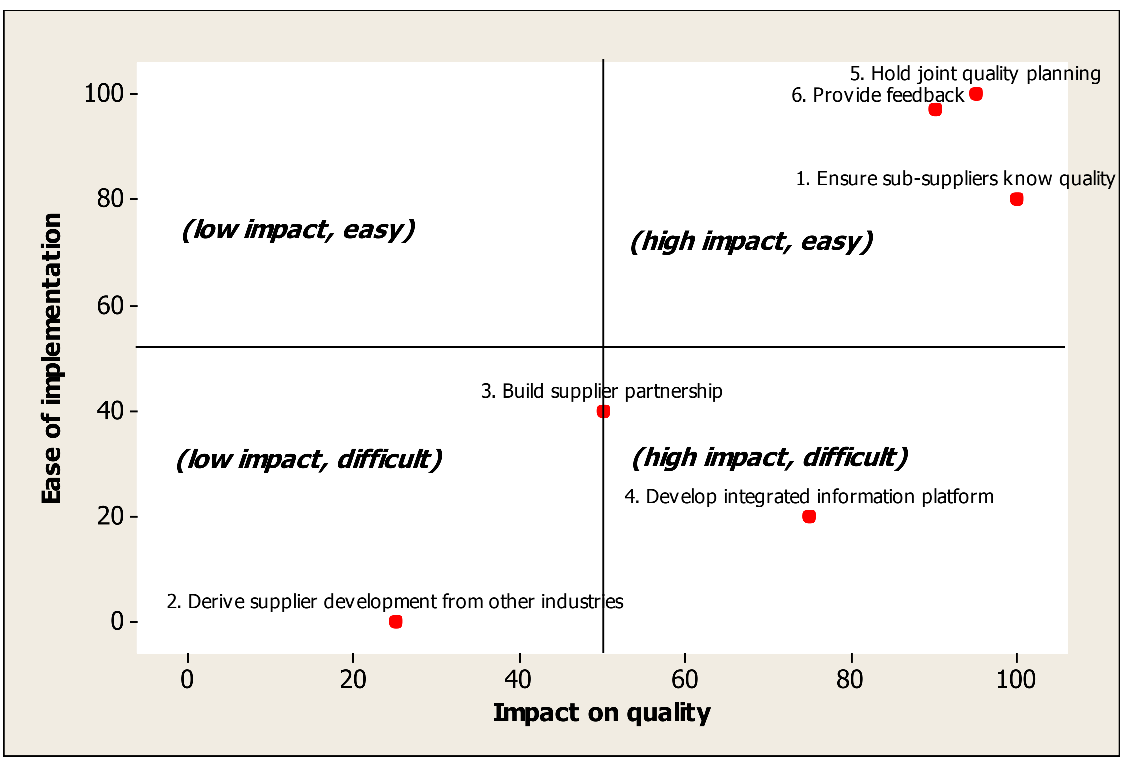

Figure 4: SQM practices in the innovation and learning perspective

From Figure 5, holding joint quality planning, providing feedback to the supplier, and ensuring sub-suppliers know quality requirements are the most important practices in terms of their high impact on quality and ease of implementation.

As described earlier, the attributes within each perspective were evaluated by SMEs using swing weight. The weightings for attributes within each perspective are summarized in Table 6.

	Financial		**Customer (supplier)**		**Internal business**		**Innovation and learning**	
	Weight	Normalized weight	Weight	Normalized weight	Weight	Normalized weight	Weight	Normalized weight
Ease of implementation	75	0.43	25	0.20	90	0.47	100	0.56
Impact on quality	100	0.57	100	0.80	100	0.53	80	0.44
Total	*175*	*1*	*125*	*1*	*190*	*1*	*180*	*1*

Table 5: Attributes weighting for each perspective

As shown in Table 5, the financial, customer (supplier), and internal business perspectives have higher weights for the impact on quality. SMEs viewed impact on quality for the practices within these perspectives to be more important than their simplicity of implementation because they can work on improving the processes within their organizations to make these practices easier. The weight for the ease of implementation for the supplier perspective is relatively smaller compared to the weight of impact on quality because most of the practices are done routinely and their simple implementation will not substantially improve the quality. For innovation and learning, SMEs believed that building continuous improvement for SQM should involve easy practices in order to improve quality.

Once ratings of practices and weights for the attributes were obtained, equation (1) can be applied for practices within each perspective. The detailed calculations are shown in APPENDIX I. We found that within the financial perspective, practice1 (use a detailed formula to calculate the effort of SQS) has the highest value of 29.64. Practice 4 (track the inspection efforts) has the second highest value of 27.08. Practice 3 (determine the impact of NCs) has the lowest score with a value 19.84.

For the customer (supplier) perspective, practice 2 (update materials/equipment specifications) has the highest score with a value of 20.18, practice1 (match the PO with RFP) has the second highest score with a value of 18.2. Practice 3 (share forecasting plans with suppliers) has the lowest score, with a value of 3.09.

For the internal business, practice 3 (focus on quality) has the highest value of 19.64. Practice 1 (classify suppliers as strategic or non-strategic) has the second highest value of 18.37. The practice that has the lowest value is practice 9 (evaluate cultural barriers for global suppliers) with a value of 1.61.

The practice that has the highest score within the innovation and learning perspective was number 5 (hold a joint quality planning) with a value of 26.19, practice 6 (provide feedback to suppliers), and has the second highest score with a value of 25.19. Practice 2 (derive supplier development from other industries) has the lowest value of 2.55.

Based on the results suggested by SMART, the reduced BSC with the important SQM practices in each perspective is depicted in Table 6.

Financial perspective ***Goal:*** *Reduce the cost of rework by practicing proper supplier quality management.* **Practices:** • Use a detailed formula to calculate the effort of supplier quality surveillance (SQS) based on criticality of the items and previous supplier performance. • Track both cost and hours of the inspection efforts.
Customer (supplier) perspective ***Goal:*** *Achieve a successful relationship with suppliers to improve the outcomes of the construction project and reduce rework tasks.* **Practices:** • Update materials/equipment specifications. • Match the purchase order (PO) with request for proposal/quotation (RFP), i.e. send exact specifications to supplier so that the bid can be more accurate.
Internal business perspective ***Goal:*** *Ensure internal quality of work in the organization (contractor) in order to improve external (supplier) quality.* **Practices:** • Focus on the planning and selection phase. • Classify suppliers as strategic or non-strategic.
Innovation and learning perspective ***Goal:*** *Build a continuous improvement environment to develop the organization's (contractor's staff) and supplier's knowledge and skills.* **Practices:** • Hold joint quality planning between contractors and suppliers. • Provide feedback to suppliers.

Table 6: The balanced scorecard with important SQM practices

Sensitivity analysis was performed for each BSC perspective to determine how robust the choice of a practice is to the changes in the attributes' weights used in the analysis. In general, the recommendation is to invest in practices that have the highest scores from SMART analysis. However, sensitivity analysis can provide important information for decision makers in terms of viewing the changes of practices' values with respect to modifications in attribute's weights. To perform sensitivity analysis, the weight of an attribute was varied from 0 to 1 using 0.1 increments. The detailed calculations of sensitivity analysis are provided in APPENDIX II. Figure 5 depicts how a change in the weight of ease of implementation affects the practices' values within the financial perspective. The vertical dashed line represent the original weight, i.e., $w_{(ease\ of\ impl.)} = 0.43$ and $w_{(impact\ on\ quality)} = 1 - w_{(ease\ of\ impl.)} = 0.57$. Recall the summation of the attributes' weights is equal to 1. As shown in Figure 5, the line of practice 1 is the most horizontal (with a slope closest to zero) and retains almost the same value over the changes of attributes weight from 0 to 1. This indicates that this practice is the most robust in terms of attributes' weights variation. The sensitivity analysis in Figure 5 also shows that practices 3 and 4 are the most sensitive to changes in attributes' weights. It can be seen for weights of ease of implementation over 0.5, practice 4 has the highest value among the other practices. This indicates that if the decision maker would assign higher weights for ease of implementation, then practice 4 would be the best practice and practice 3 would be the worst practice, in terms of their values.

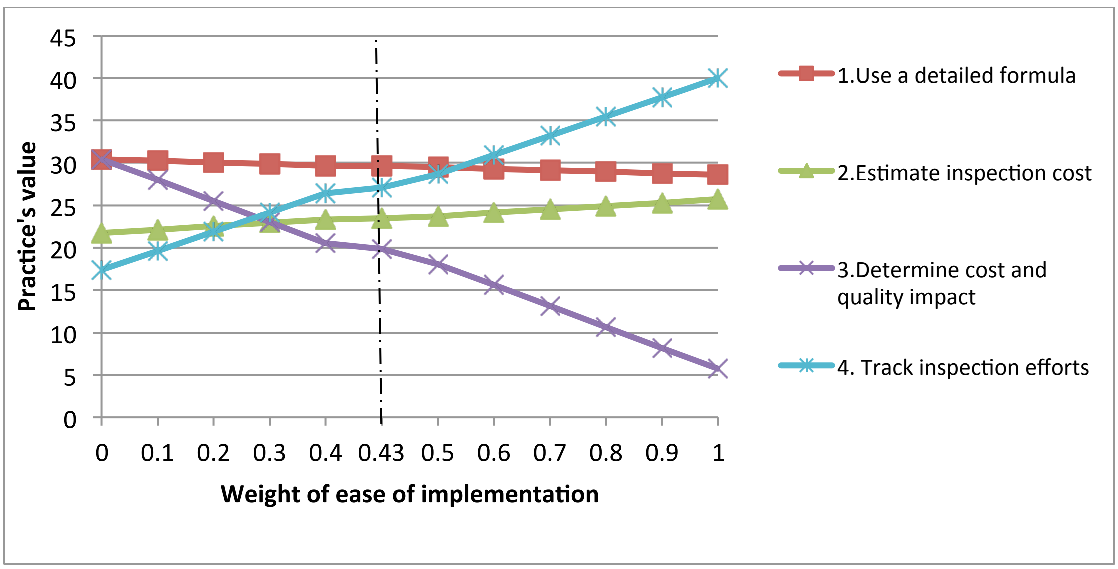

Figure 5: Sensitivity analysis for the financial perspective practices

Figure 6 shows that practice 7 in the customer perspective, observe the supplier's work, is the most robust practice to the changes in ease of implementation and impact on quality. However, practice 2 has the highest value across all the weights of ease of implementation. This indicates that the choice of practice 2 is the most favorable because it results in the best outcome regardless of the assigned value of preference for the attributes' weights.

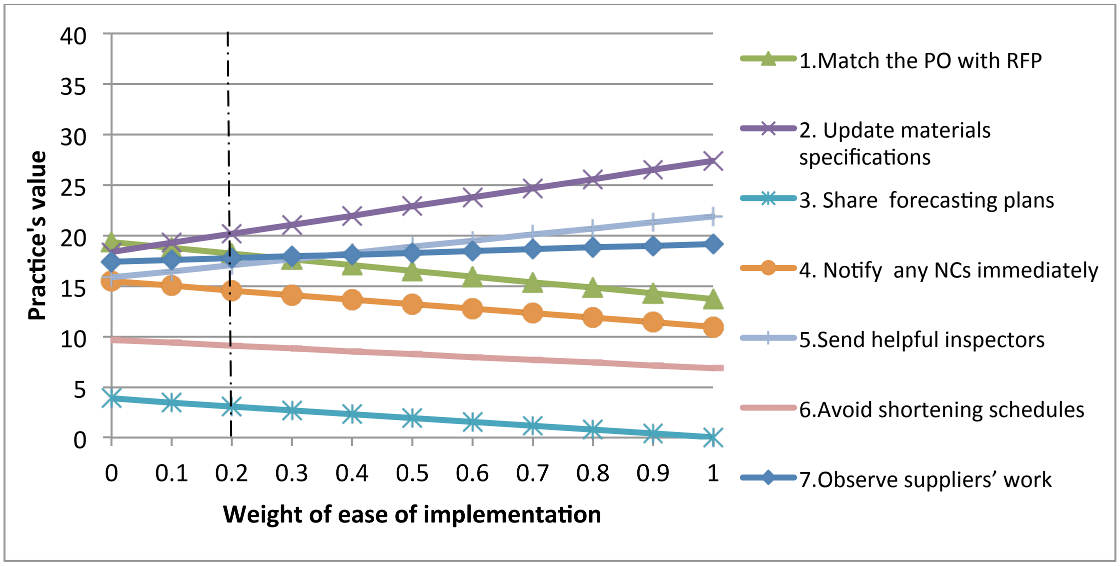

Figure 6: Sensitivity analysis for the customer perspective practices

Figure 7 depicts the sensitivity analysis for the practices within the internal business perspective. As can be seen, practice 8 is the least sensitive to the changes of ease of implementation weight. Practice 3 has the highest value for any weight of ease of implementation. In general, the practices within this perspective are sensitive to changes in attribute's weights, as can be seen from the slope of their lines in the graph.

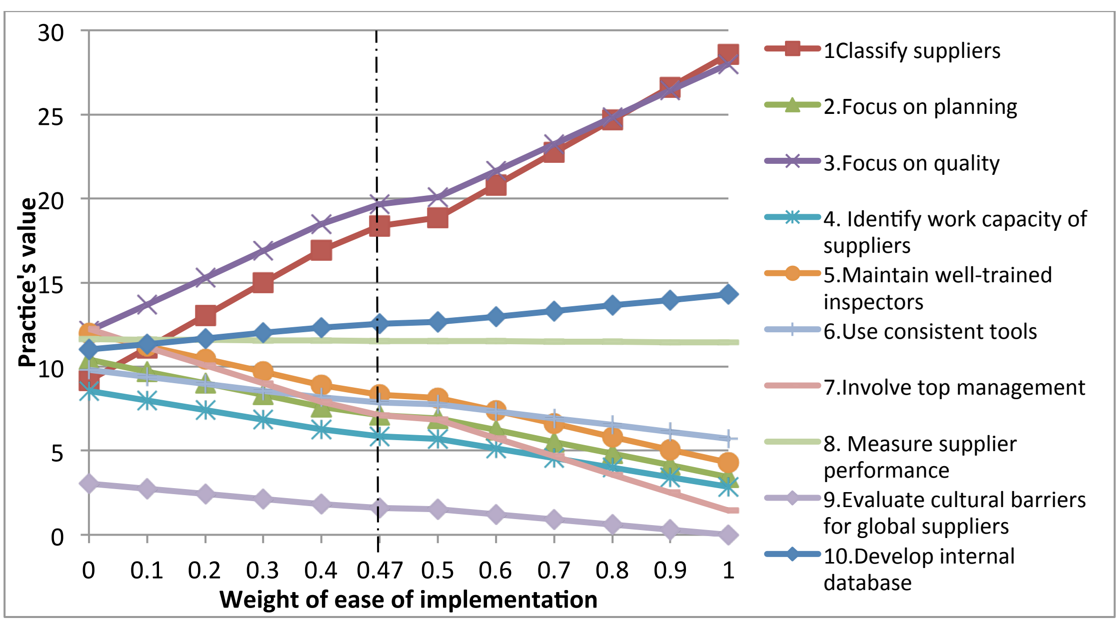

Figure 7: Sensitivity analysis for the internal business practices

Figure 8 represents the sensitivity analysis for the innovation and learning. It shows that practices 1 and 3 are the most robust practices and practice 5 has the highest value for all weights. It is also noted that practice 4 is the most sensitive.

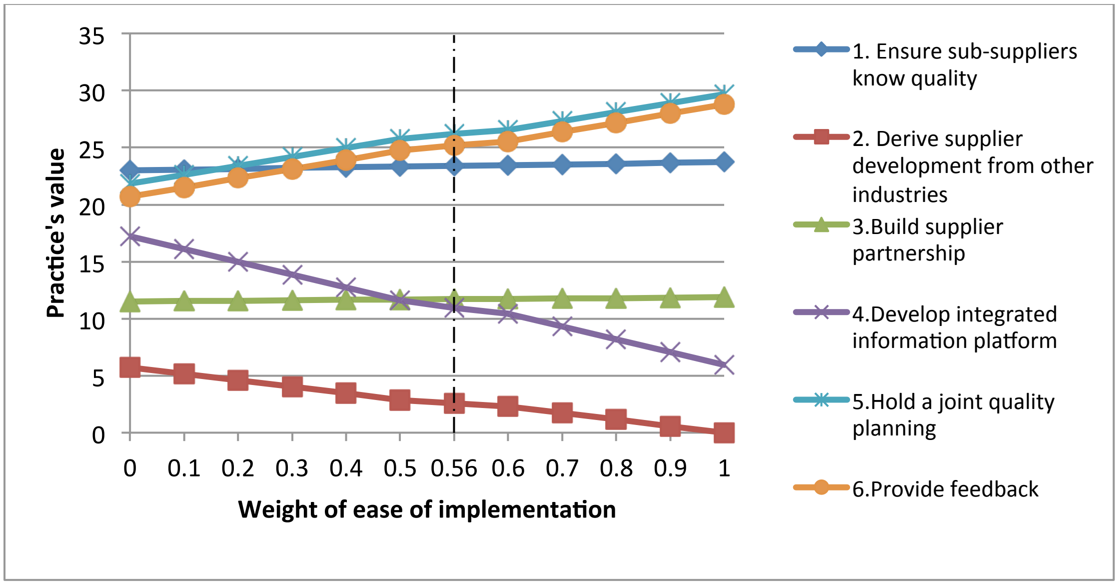

Figure 8: Sensitivity analysis for the innovation and learning perspective

The sensitivity analysis shows that updating materials specifications, focusing on quality, and holding joint quality planning have the highest values when the weights vary, i.e., changes in weights preference will still result in these practices have the highest scores. The sensitivity analysis also shows that using a detailed formula, observing supplier's work, measuring supplier's performance, building partnerships, and ensuring sub-suppliers know quality requirements are the least sensitive to the variations in the attributes' weights in all BSC perspectives. The analysis of robustness of practices allows construction decision makers to understand which practices are least affected by the ease of implementation and impact on quality when applied in real projects.

Leadership Literature Taxonomy

Six common leadership principles were found when implementing the leadership literature taxonomy between the construction industry leadership and general leadership literatures. These principles are: trust, partnerships and alliances, assessing internal capabilities, effective communication, innovation and learning, and influence. Table 7 describes these principles and the relevant findings from the literature.

Leadership principle	**Findings from the construction industry leadership literature**	**Findings from the general leadership literature**
1. Trust	Building **mutual-trust** relationship with project stakeholders is important for project success (Liu et al., 2003; Skipper & Bell, 2006; Sunindijo, 2012).	**Trust** is the foundation for **successful relationship** (Phillips, 1992), the **foundation** of leadership (Maxwell, 2007), and a **requirement** for leadership (Sample, 2002). Also, trust is very difficult to restore, once lost (Machiavelli, 1994; Kolp & Rea, 2006). • Remark: Trust is mentioned in almost all of the examined books.
2. Partnership and alliances	**Partnership and alliances** with project stakeholders are important in achieving project objectives (Sunindijo, 2012).	Recent studies in the field of leadership recognize the **need for building strong relationships and alliances** (Phillips, 1992; Hiefetz, 1994; Heifetz & Linsky, 2002).
3. Assessing internal capabilities	**Evaluating and assessing** the internal capabilities and **seeking** self-improvement are important to improve the organization's performance (Gharehbaghi & McManus, 2003).	The ability to assess leadership effectiveness is important (Maxwell, 2007), i.e. leaders must have **self-confidence** of their **strengths** (Phillips, 1992), must **know their weaknesses,** i.e. know yourself **(**Sun Tzu, 1963), and seek new challenges (Kouzes & Posner, 1995).
4. Effective communication	Developing **effective communication** skills (Gharehbaghi & McManus, 2003), and ensuring clear communication are key factors for successful relationships in construction projects (Sunindijo, 2012).	Leadership theory requires **effective skills and ways of communication** (Phillips, 1992; Kouzes & Posner, 1995; Sample, 2002).
5. Innovation and learning	Learning to **increase the knowledge** and skills of the team is an important leadership skill (Gharehbaghi & McManus, 2003; Skipper & Bell, 2006).	Leadership must include **innovation encouragement** (Phillips, 1992; Kouzes & Posner, 1995), **training** (Sun Tzu, 1963), and **learning and educative** strategy (Heifetz,1994).
6. Influence	Leadership is about **motivation and influence to followers** (Liu et al., 2003), and it is important that project managers influence and inspire the team to achieve project success and gain respect and trust from the team (Sunindijo, 2012).	An important factor in leadership is the **ability to influence and inspire** subordinates (Phillips, 1992; Kouzes & Posner, 1995; Sample, 2002). Influence is considered to be the true measure of leadership (Maxwell, 2007). • Remark: Influence is mentioned in almost all of the examined books.

Table 7: The common leadership principles found from the two literatures

After identifying leadership principles, the SMEs were involved in developing objectives based on these principles to reflect strategic leadership for SQM in the construction industry. The objectives that were developed are:

- Maximizing **mutual trust** between the construction organization and suppliers.
- Maximizing benefits of **developing successful partnerships and alliances** with suppliers.
- Maximizing **effective communication** between construction organization and suppliers.
- Maximizing the efforts to **assess internal capabilities** of the construction organization to achieve improvements.
- Maximizing **educative and learning culture of quality** within the construction organization.
- Maximizing **quality influence** of top management on all levels of the construction organization.

These objectives were then used for VFT as described next.

Value Focused Thinking (VFT)

The aforementioned objectives can be classified into internal and external leadership objectives. The internal objectives are those that can be achieved and controlled internally within the organization, such as maximizing the quality influence and the educative and learning culture of quality. The external objectives are those that involve relationships between the construction organization and suppliers, such as maximizing mutual trust and partnerships between the construction organization and the supplier. Based on this classification of the objectives, the value hierarchy, i.e., a graphical representation of the objectives, of the VFT can be constructed.

The hierarchy is organized with a fundamental objective at the top, with subsequent tiers of supporting objectives (Keeney, 1992). Figure 9 depicts the value hierarchy.

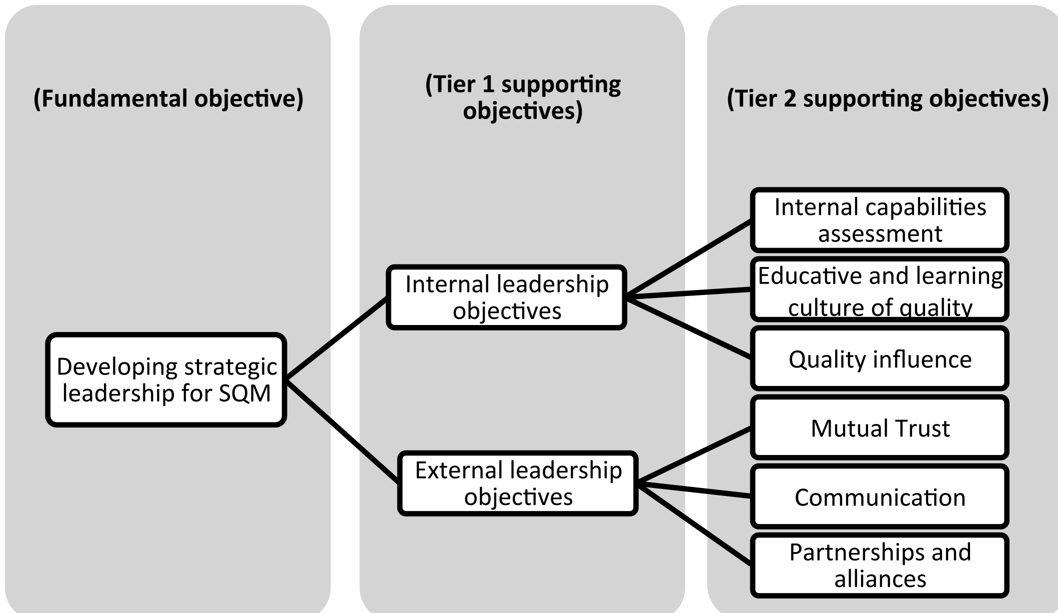

Figure 9: Value hierarchy for the SQM leadership objectives

As shown in Figure 9, the fundamental objective is to develop strategic leadership for SQM in construction organizations. Tier 1 supporting objectives are the internal and external leadership objectives, followed by tier 2 supporting objectives.

Once the hierarchy is constructed, the next step in VFT is to develop evaluation measures. In our case, the aim is to create practices and then evaluate these practices accordingly. So, we developed a constructed measure (described in Table 8) because the natural measure recommended by Keeny (1992), using quantifiable metrics, is not easy within the context of leadership for SQM. Following Keeny (1992) and Parnell et al. (2011) guidance for developing a constructed measure, we developed three levels of evaluation scores: low, medium, and high, with an interval of numerical values to describe the possible value scores for each level. Table 8 presents the constructed measure used.

Evaluation scores	Description	Possible value score
Low	The practice is **least important** to SQM leadership	0-25
Med	The practice is **moderately important** to SQM leadership	26-75
High	The practice is **highly important** to SQM leadership	76-100

Table 8: The constructed measure for the practices

After constructing the value hierarchy and the evaluation measures, the SMEs were asked to provide scores (weights) on a scale from 0 (least important) to 100 (very important) for tier 1 and tier 2 in the value hierarchy shown in Figure 9. We used the relative importance weighting for the value hierarchy. The SMEs were asked to rank tier 1 objectives and provide a relative importance weight. Tier 2 objectives within both the internal and external objectives were then ranked and weighted. This process leads to developing local and global weights. Local weights present the weight for each objective under the higher level objective in the hierarchy. The local weights are used to build global weights by taking the product of the local weights along the tiers of the hierarchy. The local weights under the same objective should sum to 1. Similarly, the global weights in the lowest tier of the hierarchy should sum to 1. Table 9 presents the local and global weights for the value hierarchy.

Tier 1 supporting objectives			Tier 2 supporting objectives			
Objective	**Local weight**	**Normalized local weight**	**Objective**	**Local weight**	**Normalized local weight**	**Global weight**
Internal leadership	100	0.54	Internal capabilities assessment	88	0.31	0.54 * 0.31= 0.17
			Educative and learning culture of quality	95	0.34	0.54 * 0.34= 0.18
			Quality influence	100	0.35	0.54 * 0.35= 0.19
			∑ (normalized local weight) = 1			
External leadership	85	0.46	Mutual trust	80	0.33	0.46 * 0.33= 0.15
			Communication	90	0.37	0.46 * 0.37= 0.17
			Partnerships and alliances	75	0.31	0.46 * 0.31= 0.14
∑ (normalized local weight) = 1			∑ (normalized local weight) = 1			∑ (global weight) = 1

Table 9: Local and global weights for the value hierarchy

As shown in Table 9, internal leadership has higher weight. The SMEs revealed that it is important to ensure the internal leadership of the organization first. The quality influence has the highest global weight, because the SMEs believe that the overall quality can't be achieved without an influence.

The SMEs were then asked to develop practices that help to achieve the internal and external objectives. This approach of generating practices is called the design tactic, in which the alternatives, i.e., practices, are custom-made to stress innovation (Parnell et al., 2011). The SMEs reported the following three practices:

1. Have a **quality director** (leader in the top level) that helps create and oversee a quality culture for SQM.
2. Establish **relationships with strategic suppliers** with frequent joint quality meetings to assess and derive improvements for both the supplier and contractor.
3. Perform **internal reviews of the SQM practices** and get a buy-in from the stakeholders (quality director, SQS personnel, inspectors, procurement, and suppliers, etc.).

The developed practices were then scored/weighted with respect to each supporting objective in order to determine the overall value for each practice. Equation (1): $v(x) = \sum_{i=1}^{n} w_i v_i(x_i)$, can be used. Using equation (1) for VFT, $v(x)$ represents the practice's score, i is the number of objectives, w_i represents the weight of the i^{th} objective, x_i represents the evaluation score for the practice with respect to objective i, and $v_i(x_i)$ represents the numeric value score of x_i. Table 10 presents the evaluation scores for the objectives and practices.

	Supporting objectives												$v(x)$
	Internal capabilities assessment		Educative and learning culture of quality		Quality influence		Mutual trust		Communication		Partnerships and alliances		
w_i	0.17		0.18		0.19		0.15		0.17		0.14		
Practice	x_i	$v_i(x_i)$	x_i	$v_i(x_i)$	x_i	$v_i(x_i)$	x_i	$v_i(x_i)$	x_i	$v_i(x_i)$	x_i	$v_i(x_i)$	
1. Quality director	High	100	High	100	High	100	High	85	Med	70	High	80	**89.8**
2. Relationship	Med	30	Med	70	Med	50	High	95	High	90	High	100	**70.8**
3. Internal review	High	100	High	95	High	80	High	90	Med	75	Low	30	**79.7**

Table 10: Evaluation scores for the objectives and practices

As shown in Table 10, practice 1, having a quality director, has the highest score. This result shows the importance of having a person leading the efforts and overseeing the work to make the people accountable for their jobs to strategically lead SQM within construction organizations.

Conclusions

The research yielded findings that can help construction organizations successfully implement SQM practices within their projects. The paper also provides leadership principles and practices that are critical for developing strategic leadership for SQM. The research utilized three research methods: SMART, leadership literature taxonomy, and VFT. The SMART analysis identified using a detailed formula to calculate the efforts of supplier surveillance, updating materials specifications, focusing on quality versus price or schedule, and holding joint quality planning to be the most important SQM practices with the highest scores within each of the four perspectives of the BSC. Sensitivity analysis was also performed to provide construction decision makers and professionals with the information regarding the fluctuation of the practices' values (analysis output) over the variation of attributes' weights (analysis input). The analysis provided important insights when applying the SQM practices in real projects with different attributes' weights.

In this research, SMART was used to analyze SQM practices that are important in every construction project. In order to describe the required long-term strategy for SQM, it was important to consider the importance of leadership and its impact on SQM. The leadership taxonomy and VFT were utilized for this purpose. The leadership literature taxonomy produced six common leadership principles that were used to formulate objectives for the VFT analysis. The VFT analysis revealed that the internal leadership objectives are more important than the external because it is essential for construction organizations to focus on managing their internal objectives prior to managing the external ones. The analysis also identified maximizing quality influence as the most important objective for SQM leadership. Three leadership practices were created for VFT: having a quality director to create a quality culture; establishing relationships and joint quality meetings with strategic suppliers; and performing internal reviews of SQM practices. The assessment of these practices shows that having a quality director is the most important practice in developing strategic leadership for SQM.

The contributions of this research to the construction and management engineering include analyzing SQM practices within the BSC framework that can provide a basis for construction organizations to assess their existing SQM practices given their current capabilities to perform the practices and their effect on the SQM quality. The findings from this analysis can help construction leaders identify SQM practices that have high impact on quality and are easy to implement across construction projects. The research also identifies key leadership objectives and practices that will help create an effective environment for applying SQM practices within construction organizations and support the achievement of strategic leadership for SQM.

This study is limited in that only two attributes were used with SMART for rating the SQM practices: ease of implementation and impact on quality. Other attributes can be beneficial to be included within the analysis such as cost and risk associated with implementing the practices. The study is also limited by using data obtained from construction organizations performing mainly engineer-procure-construct (EPC) projects, the results might not be the same for other types of contractors in the construction industry. Suggestions for future work include conducting SMART analysis for the SQM practices for organizations with least effective SQM in order to assess their internal capabilities. Also, future work could include investigating the barriers for SQM improvement. Other suggestions for future work to improve the research may include involving more SMEs from organizations with a different focus (e.g., commercial, residential, specialty contracting).

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APPENDIX I: SMART calculations for SQM practices

	Attributes				
	Ease of implementation		Impact on quality		
	Weight	Normalized weight wi	Weight	Normalized weight wi	
	75	**0.43**	100	**0.57**	
1. Financial perspective practices	Rating	Normalized rating vi(xi)	Rating	Normalized rating vi(xi)	Total v(x)
1. Use a detailed formula to calculate the effort of SQS.	50	**28.57**	70	**30.43**	29.64
2. Estimate (project) the inspection cost.	45	**25.71**	50	**21.74**	23.44
3. Determine the cost and quality impact of the NCs to the project.	10	**5.71**	70	**30.43**	19.84
4. Track both cost and hours of the inspection efforts.	70	**40.00**	40	**17.39**	27.08
Total	***175***	***100***	***230***	***100***	

	Attributes				
	Ease of implementation		Impact on quality		
	Weight	Normalized weight wi	Weight	Normalized weight wi	
	25	**0.2**	100	**0.8**	
2. Customer (Supplier) perspective practices	Rating	Normalized rating vi(xi)	Rating	Normalized rating vi(xi)	Total v(x)
1. Match the PO with request for proposal/quotation (RFP)	50	**13.70**	100	**19.34**	18.21
2. Update the materials/ equipment specifications.	100	**27.40**	95	**18.38**	20.18
3. Share forecasting plans of upcoming projects with suppliers.	0	**0.00**	20	**3.87**	3.09
4. Notify suppliers immediately regarding any NCs.	40	**10.96**	80	**15.47**	14.57
5. Send inspectors to the supplier's facility who add value to the SQ process.	80	**21.92**	82	**15.86**	7.56
6. Avoid shortening schedules during the course of the PO.	25	**6.85**	50	**9.67**	9.11
7. Observe the suppliers' work at their facilities.	70	**19.18**	90	**17.41**	17.76
Total	***365***	***100***	***517***	***100***	

	Attributes				
	Ease of implementation		Impact on quality		
	Weight	Normalized weight wi	Weight	Normalized weight wi	
	90	**0.47**	100	**0.53**	
3. Internal business perspective practices	Rating	Normalized rating	Rating	Normalized rating vi(xi)	Total v(x)
1. Classify suppliers as strategic or non-strategic.	100	**28.57**	75	**9.18**	18.37
2. Focus on the planning and selection phase.	12	**3.43**	85	**10.40**	7.10
3. Focus on quality (versus price and schedule).	98	**28.00**	99	**12.12**	19.64
4. Identify work capacity of suppliers including the other customers' POs.	10	**2.86**	70	**8.57**	5.86
5. Maintain well-trained inspectors.	15	**4.29**	98	**12.00**	8.34
6. Use consistent tools to measure supplier performance.	20	**5.71**	80	**9.79**	7.86
7. Involve top management (leadership) to improve the SQ system.	5	**1.43**	100	**12.24**	7.12
8. Measure supplier performance throughout the PO.	40	**11.43**	95	**11.63**	11.53
9. Evaluate cultural barriers for global suppliers and adapt the SQ process in each country.	0	**0.00**	25	**3.06**	1.61
10. Develop an internal database to Track supplier performance and analyze future decisions.	50	**14.29**	90	**11.02**	12.56
Total	***350***	***100***	***817***	***100***	

	Attributes				
	Ease of implementation		Impact on quality		
	Weight	Normalized weight wi	Weight	Normalized weight wi	
	100	**0.56**	80	**0.44**	
4.Innovation and learning practices	Rating	Normalized rating	Rating	Normalized rating vi(xi)	Total v(x)
1. Ensure that sub-suppliers (tiers of suppliers) know the quality requirements.	80	**23.74**	100	**22.99**	23.41
2. Derive supplier development and control from other industries, and shift from QC (inspection) to more into development and improvement (prevention).	0	**0.00**	25	**5.75**	2.55
3. Build supplier partnership (alliance, training, and support).	40	**11.87**	50	**11.49**	11.70
4. Develop an integrated information platform with appropriate information access.	20	**5.93**	75	**17.24**	10.96
5. Hold a joint quality planning between contractors and suppliers.	100	**29.67**	95	**21.84**	26.19
6. Provide feedback to the suppliers.	97	**28.78**	90	**20.69**	25.19
Total	***337***	***100***	***435***	***100***	

*— Example for calculating total value of practice 3 (determine the cost and quality impact of NCs) in the finanacial perspective : Total v(x)= 0.43*5.71 + 0.57*30.43 = 19.84*

—Highlighted rows represent practices that have the highest scores within each perspective of the balanced scorecard (BSC).

APPENDIX II: Sensitivity analysis for SMART calculations

1. Financial practices

Change in ease of implmentation weight	v(x)			
	1.Use a detailed formula	2.Estimate inspection cost	3.Determine cost and quality impact	4. Track inspection efforts
0	30.4347826	21.73913043	30.43478261	17.39130435
0.1	30.2484472	22.13664596	27.96273292	19.65217391
0.2	30.0621118	22.53416149	25.49068323	21.91304348
0.3	29.8757764	22.93167702	23.01863354	24.17391304
0.4	29.689441	23.32919255	20.54658385	26.43478261
0.43	29.6362023	23.44276841	19.84028394	27.08074534
0.5	29.5031056	23.72670807	18.07453416	28.69565217
0.6	29.3167702	24.1242236	15.60248447	30.95652174
0.7	29.1304348	24.52173913	13.13043478	33.2173913
0.8	28.9440994	24.91925466	10.65838509	35.47826087
0.9	28.757764	25.31677019	8.186335404	37.73913043
1	28.5714286	25.71428571	5.714285714	40

2. Customer (Supplier) practices

Change in ease of implmentation weight	v(x)						
	1. Match PO with RFP	2. Update materials specifications	3. Share forecasting plans	4. Notify of any NCs immediately	5.Send helpful inspectors	6.Avoid shortening schedules	7.Observe suppliers' work
0	19.3423598	18.37524178	3.868471954	15.47388781	15.860735	9.671179884	17.40812379
0.1	18.7779868	19.27744363	3.481624758	15.02238944	16.466442	9.388993402	17.58511963
0.2	18.2136138	20.17964548	3.094777563	14.57089107	17.07215	9.106806921	17.76211547
0.3	17.6492409	21.08184733	2.707930368	14.1193927	17.677857	8.824620439	17.93911131
0.4	17.0848679	21.98404918	2.321083172	13.66789433	18.283564	8.542433958	18.11610715
0.5	16.520495	22.88625103	1.934235977	13.21639596	18.889272	8.260247476	18.29310299
0.6	15.956122	23.78845288	1.547388781	12.76489759	19.494979	7.978060995	18.47009883
0.7	15.391749	24.69065473	1.160541586	12.31339922	20.100686	7.695874513	18.64709467
0.8	14.8273761	25.59285658	0.773694391	11.86190085	20.706394	7.413688032	18.82409051
0.9	14.2630031	26.49505842	0.386847195	11.41040248	21.312101	7.13150155	19.00108635
1	13.6986301	27.39726027	0	10.95890411	21.917808	6.849315068	19.17808219

3. Internal business practices

Change in ease of implmentation weight	v(x)									
	1. Classify suppliers	2.Focus on planning	3.Focus on quality	4. Identify work capacity of suppliers	5.Maintain well-trained inspectors	6.Use consistent tools	7.Involve top management	8. Measure supplier performance	9.Evaluate cultural barriers for global suppliers	10. Develop internal database
0	9.17992656	10.40391677	12.11750306	8.567931457	11.995104	9.791921665	12.23990208	11.62790698	3.05997552	11.0159119
0.1	11.1190768	9.706382235	13.70575275	7.996852597	11.224165	9.38415807	11.15876902	11.60797342	2.753977968	11.3428921
0.2	13.058227	9.008847701	15.29400245	7.425773737	10.453226	8.976394475	10.07763595	11.58803987	2.447980416	11.6698724
0.3	14.9973772	8.311313167	16.88225214	6.854694877	9.6822871	8.56863088	8.996502885	11.56810631	2.141982864	11.9968526
0.4	16.9365274	7.613778633	18.47050184	6.283616017	8.9113481	8.160867284	7.91536982	11.54817276	1.835985312	12.3238328
0.47	18.3653749	7.099805818	19.64079108	5.862821067	8.3432878	7.860409899	7.118745456	11.53348487	1.610513432	12.5647656
0.5	18.8756776	6.916244099	20.05875153	5.712537157	8.1404092	7.753103689	6.834236755	11.5282392	1.52998776	12.6508131
0.6	20.8148278	6.218709565	21.64700122	5.141458297	7.3694702	7.345340094	5.753103689	11.50830565	1.223990208	12.9777933
0.7	22.753978	5.521175031	23.23525092	4.570379437	6.5985312	6.937576499	4.671970624	11.48837209	0.917992656	13.3047736
0.8	24.6931282	4.823640497	24.82350061	3.999300577	5.8275922	6.529812904	3.590837559	11.46843854	0.611995104	13.6317538
0.9	26.6322784	4.126105963	26.41175031	3.428221717	5.0566533	6.122049309	2.509704494	11.44850498	0.305997552	13.958734
1	28.5714286	3.428571429	28	2.857142857	4.2857143	5.714285714	1.428571429	11.42857143	0	14.2857143

4. Innovation and learning practices

Change in ease of implmentation weight	v(x)					
	1. Ensure sub-suppliers know quality requirements	2. Derive supplier development from other industries	3.Build supplier partnerships	4. Develop integrated information platform	5. Hold joint quality planning	6. Provide feedback
0	22.9885057	5.747126437	11.49425287	17.24137931	21.83908	20.68965517
0.1	23.0635424	5.172413793	11.53177121	16.11071319	22.622531	21.49902793
0.2	23.1385791	4.597701149	11.56928954	14.98004707	23.405982	22.3084007
0.3	23.2136157	4.022988506	11.60680787	13.84938095	24.189433	23.11777346
0.4	23.2886524	3.448275862	11.6443262	12.71871483	24.972884	23.92714622
0.5	23.3636891	2.873563218	11.68184454	11.58804871	25.756335	24.73651898
0.56	23.4053761	2.554278416	11.70268806	10.95990086	26.191586	25.18617052
0.6	23.4387257	2.298850575	11.71936287	10.45738258	26.539786	25.54589174
0.7	23.5137624	1.724137931	11.7568812	9.326716464	27.323237	26.3552645
0.8	23.5887991	1.149425287	11.79439954	8.196050343	28.106688	27.16463727
0.9	23.6638357	0.574712644	11.83191787	7.065384222	28.890139	27.97401003
1	23.7388724	0	11.8694362	5.934718101	29.673591	28.78338279

—Highlighted rows represent calculations of the base (original) value for the attributes' weights provided by subject matter experts (SMEs).

7. CONCLUSION

This dissertation employs a strategic approach to effectively manage supplier quality within the construction industry. This strategic approach involves examining SQM practices from the construction industry and from multiple industries found in the literature to identify practices that could be used by the construction industry to improve SQM. The research also investigates the current SQM practices within the construction industry from multiple data sources, such as structured interviews and supplier focus groups to identify effective SQM practices that help improve the existing SQM. Effective SQM practices identified in the investigation are validated (cross analyzed) to verify that the findings from multiple data sources yield same conclusions. Effective SQM practices identified in the research are presented in multiple views, including the SQ process map and the balanced scorecard (BSC), to help construction management adopt these practices within construction projects. The SQ process map indicates when SQM practices are best implemented within the project life cycle. The BSC organizes SQM practices along four perspectives: financial, customer (supplier), internal business, and innovation and learning. Performance metrics were then formulated for each practice within each perspective of the BSC to help managers measure and compare performance of multiple projects. In general, the BSC is an effective framework for leaders who use in assessing the organization performance to achieve effective strategic leadership (Hoskisson et al., 2009). The research effort also includes an assessment of SQM practices aligned within the BSC framework to help construction organizations focus on key SQM practices within this framework. In order to promote strategic leadership for SQM and enable an effective implementation of SQM practices, the research identifies important leadership practices for construction organizations. In general, leadership provides conditions for motivation, commitment, and support for any project (Cleland & Ireland, 2006).

The research includes three objectives to effectively manage supplier quality within the construction industry. The first objective is to describe and assess the process of assuring supplier quality inside and outside the construction industry. The second objective is to develop a framework for the supplier quality process based on the collection of SQM practices from multiple data sources. The third objective is to assess the SQM practices within the developed framework of supplier quality process, and to discuss the development of strategic leadership for SQM.

The research efforts to achieve the dissertation objectives include an investigation of SQM practices inside and outside the construction industry; and for the current SQM practices applied by construction organizations, to identify the effective practices that ensure the quality of the supplied products. The research efforts also involve recommending a framework for implementing the identified effective SQM practices and measuring the performance of multiple projects. The dissertation also contains an assessment of those effective SQM practices within the proposed framework to simplify the implementation process and to focus on the most important practices. Finally, the research includes an examination of important leadership principles and practices that help in achieving strategic leadership for SQM within the construction industry.

Research Findings

The research has identified several findings related to the effective management of supplier quality within the construction industry through the dissertation contributions (publishable papers). The first contribution, presented in Chapter 2, identifies the importance of the strategic supplier partnership and development for SQM, along with management commitment for improvement, and proper feedback system implementation. The first contribution shows that SQM approaches inside and outside the construction industry are quite similar. However, the current SQM within the construction industry requires consistent implementation.

Chapter 3 presents the second contribution. This contribution identifies that organizations with highly effective SQM place higher importance during the planning and selection phase of construction projects, and are more consistent in measuring and developing supplier performance as compared to other organizations with least and moderate effective SQM.

The third contribution, discussed in Chapter 4, describes the use of quantitative methods to analyze the SQM practices and to determine the most important practices for SQM. The analysis results and the discussion with the SMEs show supplier's performance rating is an important practice because it helps suppliers learn from their mistakes that caused quality problems. Observing supplier's work helps construction organizations detect quality problems during execution. As important as observing supplier's work, developing inspection and testing plans help to understand what is required to produce a product with the required level of quality. Inspection effort tracking is also an important practice for SQM, because at the end of each project, construction organizations can determine the required inspection effort for future projects.

In Chapter 5, the fourth contribution shows the alignment of effective SQM practices across multiple data sources and determines the importance of proposing the BSC as an implementation framework for consistent application and continuous improvement for SQM. The discussion with the SMEs show that the construction organizations anticipate using the BSC framework in future projects, and that the BSC could allow them to consider improving important areas of SQM other than financial, such as internal business and innovation.

Chapter 6 describes the fifth contribution which identifies that using financial formulas for supplier surveillance, updating project materials specifications, focusing on quality as opposed to cost, and holding joint quality planning with suppliers are important SQM practices for construction organizations because of their high impact on quality and ease of implementation. The fifth contribution also shows effective SQM implementation within construction organizations require strategic leadership for SQM by having a quality director who inspires the culture of quality.

In this dissertation, SQM practices identified to be effective were found based on analyzing multiple data sources. The data sources include literature review, SQM documents, structured interviews, supplier focus groups, PO instrument, and inspection cost data. Table 1 summarizes all SQM practices identified throughout the research and marks from which data source the SQM practice was shown to be effective.

	Data source					
SQM practice	Literature review	SQM documents	Structured interviews	Supplier focus groups	PO instrument	Inspection cost data
1. Use a detailed formula to calculate the effort of SQS based on criticality of the items and previous supplier performance.		✓	✓			✓
2. Estimate (project) inspection cost.					✓	
3. Determine the cost and quality impact of the NCs to the project.		✓				
4. Track both cost and hours of inspection efforts.		✓	✓		✓	
5. Match PO with request for proposal/quotation (RFP).				✓		
6. Update materials/equipment specifications.				✓		

Table 1: Summary of effective SQM practices and the data sources

SQM practice	Data source					
	Literature review	SQM documents	Structured interviews	Supplier focus groups	PO instrument	Inspection cost data
7. Share forecasting plans of upcoming projects with suppliers to allow them to plan.				✓		
8. Notify suppliers immediately regarding any NCs.				✓		
9. Send inspectors to supplier's facility who add value to the SQ process.				✓		
10. Avoid shortening schedules during the course of PO.				✓		
11. Observe suppliers' work at their facilities.	✓				✓	
12. Classify suppliers as strategic or non-strategic.	✓		✓			
13. Focus on the planning and selection phase.			✓	✓		
14. Identify work capacity of suppliers including the other customers' POs.	✓	✓				
15. Focus on quality (versus price and schedule).	✓		✓	✓		✓
16. Maintain well-trained inspectors.			✓			
17. Use consistent tools to measure supplier performance.	✓		✓	✓		
18. Involve top management (leadership) to improve the SQ system (set visions, directions, and improvement initiatives).	✓		✓	✓		
19. Measure supplier performance throughout the PO.					✓	
20. Evaluate cultural barriers for global suppliers and adapt the SQ process in each country.	✓		✓	✓		
21. Develop an internal database to track supplier performance and analyze future decisions.			✓			
22. Ensure that sub-suppliers (tiers of suppliers) know quality requirements.	✓		✓	✓		
23. Derive supplier development and control from other industries, and shift from QC (inspection) to development and improvement (prevention).	✓			✓		
24. Build supplier partnerships (alliance, training, and support).	✓		✓	✓		
25. Develop an integrated information platform with appropriate information access.	✓			✓		
26. Hold joint quality planning between contractors and suppliers.	✓		✓	✓	✓	
27. Provide feedback (performance ratings, and meetings) to suppliers.	✓		✓	✓	✓	

Table 1(Cont.): Summary of effective SQM practices and the data sources

The practices highlighted in Table 1 are for those found to be effective from analyzing four data sources. The analysis of literature review, structured interviews, supplier focus groups, and inspection cost data suggested practice 15 (focus on quality) to be effective. Practices 26 (hold joint quality planning) and 27 (provide feedback to suppliers) were identified to be effective based on analyzing the literature, structured interviews, supplier focus groups, and PO instrument.

Several research methods were used in this dissertation to analyze the data and to draw conclusions about the effective SQM practices including: literature review taxonomy for SQM practices inside and outside construction industry, grounded theory, principal components analysis (PCA), and analytic hierarchy process (AHP). SQM practices that were identified to be effective were aligned in the BSC framework, and evaluated using simple multi-attribute rating technique (SMART). Leadership practices were also discussed as part of this dissertation and evaluated using value focused thinking (VFT). Table 2 presents a summary of SQM practices recommended based on consensus among several research methods findings.

SQM practice	Cross analysis remarks
Practice 1: Use a detailed formula to calculate the effort of SQS based on criticality of the items and previous supplier performance.	This practice was selected as an effective practice based on the analysis of grounded theory, also SMART analysis determined this practice to have the highest score value within financial perspective of the BSC.
Practice 4: Track both cost and hours of inspection efforts.	The analysis using grounded theory suggested this practice as one of the effective practices for organizations with highly effective SQM. PCA and AHP identified this practice as an important SQM practice. SMART analysis suggested this practice to have the second highest score within financial perspective of the BSC.
Practice 6: Update materials/equipment specifications.	SMART analysis determined this practice to have the highest score within customer perspective of the BSC. Also, as reported by suppliers in the supplier focus groups, this practice is critical for SQM improvement.
Practice 11: Observe suppliers' work at their facilities.	The literature review for SQM practices inside and outside the construction industry by using literature review taxonomy recommended this practice as an effective SQM practice. Also, PCA and AHP identified this practice as an important SQM practice.
Practices 12: Classify suppliers as strategic or non-strategic.	The literature review for SQM practices inside and outside the construction industry by using literature review taxonomy and grounded theory analysis recommend this practice as an effective SQM practice. Also, SMART analysis suggested this practice to have the second highest score in internal business of the BSC.

Table 2: Summary of cross analysis for the SQM practices

SQM practice	Cross analysis remarks
Practice 15: Focus on quality (versus price and schedule).	The literature review for SQM practices inside and outside the construction industry by using literature review taxonomy and grounded theory analysis recommended this practice as an effective SQM practice. Also, SMART analysis suggested this practice to have the highest score in internal business of the BSC.
Practice 18: Involve top management (leadership) to improve the SQ system (set visions, directions, and improvement initiatives).	The literature review for SQM practices inside and outside the construction industry by using literature review taxonomy, grounded theory analysis, and VFT recommend this practice as an effective SQM practice. SMART analysis showed this practice to have a significant impact on improving quality, however it is very difficult to implement.
Practice 26: Hold joint quality planning between contractors and suppliers.	The literature review for SQM practices inside and outside the construction industry by using literature review taxonomy, grounded theory analysis, AHP, and SMART suggested this practice as an effective SQM practice.
Practice 27: Provide feedback (performance ratings, and meetings) to suppliers.	The literature review for SQM practices inside and outside the construction industry by using literature review taxonomy, grounded theory analysis, PCA and AHP, as well as SMART (second highest score in innovation perspective of the BSC) suggested this practice as an effective SQM practice.

Table 2 (Cont.): Summary of cross analysis for the SQM practices

Synthesizing the findings summarized in Tables 1 and 2, we conclude that observing suppliers at their facilities, using detailed formulas to calculate the efforts (cost and hours) of supplier surveillance, and also tracking those efforts are important practices as supported by the consensus among several data and research methods used in this dissertation. Also, the cross analysis of findings showed that updating materials specifications provided to suppliers and focusing on quality as opposed to cost are effective SQM practices for improving current SQM systems. Not surprisingly, many research methods used for analyzing the dissertation data sources noted the importance of management support for SQM. In addition, classification of suppliers as strategic or non-strategic and proper joint planning and feedback systems were also found to be effective SQM practices.

Research Limitations

The research involves a number of limitations. SQM practices identified from literature examination inside and outside the construction industry is limited to the focus of the literature review (integrative review) and to what was found in the examined sources. Other practices can be effective for SQM but might not be discussed in the first publishable paper of the dissertation presented in Chapter 2. The discussion of effectiveness of SQM is limited to the sampled data from construction organizations conducting mainly engineer-procure-construct (EPC) projects, also limited to what the interviewed contractors have reported regarding the level of SQM effectiveness in their organizations. The classifications and findings of effectiveness for SQM might not necessarily be similar to other construction organizations with different focus other than EPC. The third publishable paper, presented in Chapter 4, is limited by the use of a small data set to analyze and derive conclusions about practices conducted by organizations with highly effective SQM within EPC projects. The findings identified in Chapter 4 might not represent a large number of organizations conducting different types of projects within the construction industry. The developed BSC framework could have included other important SQM practices; however, the development of the BSC is based on SQM practices collected from multiple data sources that are limited to the focus of the research. In addition, the findings of the fifth publishable paper described in Chapter 6 are based on expert judgment and preference from two SMEs in organizations with highly effective SQM who have collectively over 50 years of experience in the construction industry and primarily in EPC projects, resulting in nearly similar judgments. The SMEs' judgments might not have similar consensus if the research involved a large group of SMEs from the construction industry. In such cases of disagreement, the research may include a detailed methodology for group decision making to address the lack of consensus. The focus of this dissertation in terms of describing and evaluating existing SQM practices in construction industry requires the utilization of ordinal data such as the self-reported level of SQM effectiveness from construction organizations (highly effective, moderately effective, and least effective) and the expert judgment of SQM practices. The conclusions based on ordinal data from this research might not necessarily be generalized for the whole construction industry. Despite these limitations, this research has made a significant contribution to the body of knowledge. The findings can be used by stakeholders in the construction industry to improve SQM within their organizations, and can also benefit researchers who wish to better understand SQM practices within the construction industry.

Future Work

This dissertation can provide several opportunities to expand the discussion of SQM in future work. Suggestions for future work are described next.

Analyzing SQM Effectiveness and Suppliers' Products

The research can be expanded to include more organizations reflecting diverse levels of SQM effectiveness so that further areas of comparisons among these organizations can be examined. Another area for future work may include analyzing and comparing SQM practices with respect to the products and services being supplied. For example, practices for managing the quality of supplied materials and equipment may differ from the practices used for managing the supplied services at a construction site such as welding and drilling.

Analyzing SQM Practices from Construction Organizations with Different Focus

This dissertation focuses on SQM practices from construction organizations performing mainly EPC projects. The suggested future work for the dissertation may include analyzing SQM from construction organizations with different focus other than EPC such as commercial, residential, or specialty contracting. Although, the identified SQM practices of this dissertation may not only be restricted for EPC projects, it is beneficial to analyze and compare the SQM practices from diverse construction organizations with different focus. Also, future work may include exploring and investigating supplier development practices, and predicting their impact to project outcomes.

Analyzing the SQM Practices in terms of Detecting and Preventing Non-Conformances

The SQM practices within the proposed balanced scorecard (BSC), shown in Figure 3 of Chapter 5, can be analyzed by their ability to detect and prevent non-quality problems, i.e., non-conformances. Detecting non-conformances measures the ability of a given practice to help in discovering quality problems during the project. Preventing non-conformances describes the ability of a practice to avoid non-conformances from occurring.

Studying the Barriers for Improving SQM

Implementing effective SQM practices within construction projects may be hindered by a number of barriers and risks. Future work may include analyzing barriers and risks associated with SQM implementation. Examples of the barriers and risks may include:

- Lack of commitment by the supplier to the relationship and performance expectations.
- Lack of support from management to choose a supplier that has long-term benefits for the organization.
- Unforeseen supplier tiers that could lead to complexities in communication, management, and legal consequences.

- Uncertainty of future conflicting interests of the suppliers that could not be obvious during the selection process.
- Supplier's environment risk such as operating and political risks.

The barriers and risks can also be classified into within control and out of control, as well as internal and external barriers and risks.

Improving the Quality Culture and Supplier Data Management

The discussion with the SMEs revealed important suggestions for future work such as identifying the initiatives necessary to build an integrated culture of quality within organization given the challenges of staffing, recruitment, and retention. Also, based on the SMEs discussion future work may include how to effectively manage supplier data in terms of collecting, consolidating, and analyzing in order to help improving SQM. Another suggestion for future work for assisting construction organizations in improving their SQM systems is to provide them with a user-friendly tool, such as an Excel spreadsheet, for SQM evaluation. The evaluation methodology described in Chapter 6 of the dissertation can be more useful for application if a user-friendly tool is developed for construction organizations to let them customize the level of preference for ranking and weighting the SQM practices allowing them to better manage their SQM data.

References

Cleland, D. I., & Ireland, L., R. (2006). *Project management: Strategic design and implementation*. New York: McGraw-Hill.

Hoskisson, R., Hitt, M., Ireland, R. D., & Harrison, J. (2009). *Competing for advantage*. Mason, OH: Cengage Learning.

APPENDIX I: Structured Interview

Data Collection Protocol
RT 308 – Achieving Zero Rework through Effective Supplier Quality Practices

- Companies will be invited to participate on a volunteer basis according to the guidelines provided by CII (GuidelinesForMeetingsAndConferences-CII.pdf) and the informed consent letter.
- Data will be collected via interview face-to-face or via conference call based on the following set of questions:

1. Supplier Quality Organization
   1.1. Provide an organization chart depicting the Supplier Quality Organization relative to other units within the organization.
   1.2. What role does top management play with respect to supplier quality management?
   1.3. How many people are employed in the Supplier Quality Organization? What titles do they hold? Are they salaried or hourly? Are the full-time or part-time? Are they employed by the company or contracted?
   1.4. List the location of personnel in the Supplier Quality Organization, i.e., domestic/abroad, office/project site.
   1.5. What is the range of education of Supplier Quality personnel? On average, how much experience do they have? Do they typically hold Supplier Quality Certification? What Supplier Quality training do they take? What kinds of "levels of Supplier Quality education" ("training") does your company offer?
   1.6. What is the ratio of agency (temporary labor) to direct hired (staff) people?

2. Supplier Quality System
   2.1. Who makes decisions to choose suppliers?
   2.2. How are suppliers selected/qualified for use?
   2.3. How frequently are suppliers re-qualified for use?
   2.4. What triggers a supplier to be removed from your bidders list?
   2.5. Do you use supplier quality surveillance to try to ensure supplier quality? Tell us about the system.
   2.6. What other tools do you use to ensure supplier quality?

3. Metrics
   3.1. Which metrics do you use to measure supplier performance?
   3.2. When do you measure supplier performance?
   3.3. Who is responsible for measuring supplier performance?
   3.4. Do you use supplier performance in consideration for future work or maintenance of bidders list?

4. Data
   4.1. Describe the method for tracking supplier performance?
   4.2. What documents are generated by your organization to document supplier performance?
   4.3. How are non-conformances documented and managed within your organization?

4.4. Could you provide supplier performance data? [phases: release from inspection, received on site acceptable, and mechanical completion acceptable]

5. Assessment
   5.1. What are the strengths of your supplier quality system?
      5.1.1. Selecting and qualifying suppliers
      5.1.2. Risk identification
      5.1.3. Developing project-specific procurement quality plan
      5.1.4. Coordination
      5.1.5. Well trained inspectors
      5.1.6. Inspection coverage
      5.1.7. Measuring supplier performance
      5.1.8. Measuring inspector performance
      5.1.9. Consistency in using tools and practices
      5.1.10. Continuous improvement
      5.1.11. Other

   5.2. What are the opportunities for improvement in your supplier quality system?
      5.2.1. Selecting and qualifying suppliers
      5.2.2. Risk identification
      5.2.3. Developing project-specific procurement quality plan
      5.2.4. Coordination
      5.2.5. Well trained inspectors
      5.2.6. Inspection coverage
      5.2.7. Measuring supplier performance
      5.2.8. Measuring inspector performance
      5.2.9. Consistency in using tools and practices
      5.2.10. Other

   5.3. What is the biggest challenge you face as an organization with respect to supplier quality?
   5.4. Would you consider the supplier quality system at your company to be highly mature?

6. Supporting documents
   6.1. Which documents do you use to keep track of data related to quality of products and services? Can we obtain copies of these documents?
   6.2. Which procedures or guidelines are used as part of your quality system? Can we obtain copies of these documents?

7. Suppliers
   7.1. How do you assure that your sub-suppliers are complying with your requirements?
   7.2. How many active suppliers do you have?
   7.3. How many levels and/or tiers are typically in your supply chain?

APPENDIX II: PO Instrument

Data Collection Instrument

Purchase Order Data – Supplier Quality Practices and Performance

RT 308 – Achieving Zero Rework through Effective Supplier Quality Practices

The following questions are to be answered for a GIVEN PURCHASE ORDER for a project. It is helpful to obtain data from more than one P.O. for a given project, across a range of different types of purchases (levels of criticality, spend, etc.), and also to look for different projects. Please select P.O.'s representative of all criticality levels, however, not by "cherry-picking" the best (or worst) P.O.'s in recent experience. Select P.O.'s were equipment was installed and not for storage. Ideally, P.O.'s selected for this process should have been completed within the last THREE years.

Please assign a reference number for purposes of this instrument. This number should be different than your internal P.O. number, but please keep a record of which answers go with which of your internal P.O.'s. That way, if there were to be any follow up questions, you could find the same P.O. easily.

IMPORTANT: PLEASE COMPLETE THIS INSTRUMENT BY extracting data from P.O.'s and other archived data sources, and not by estimating or based on your impressions/memories about the project, unless otherwise noted in the question. You will likely need to confer with others to complete this instrument. The instrument is likely to take less than ½ hour to fill out, but it will likely take 1-3 hours to compile the data needed for each P.O. (including time to coordinate with others within your organization).

This instrument may be used for <u>only one P.O. at a time</u> for either:

1) *Tagged/engineered equipment*
2) *Fabricated goods* (only for structural steel and pipe spools)
3) *Manufactured/bulk* goods (only for non-engineered/bulk valves)

P.O.'s for any other type of purchase should not be considered for this study.

This instrument is intended for anonymous data collection. Please make sure no individually identifying information is included among your answers. All data provided to CII in support of research activities by participating organizations are to be considered confidential information. 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 any analyses based on these data that are shared with others or published will represent summaries of data from multiple participating organizations that have been aggregated in a way that will preclude identification of proprietary data and the specific performance of individual organizations.

Reports, presentations, and proceedings containing statistical summaries of aggregated company data may be used to support team findings. To protect the confidentiality of companies submitting data, all data published and/or presented must reflect the aggregate of no less than 10 P.O.'s, where project level data are collected, and must have been submitted by at least three (3) separate companies. In cases where a disproportionate amount of the data are provided by a single company, the research team will suppress publication of results until the data set is sufficiently large to mitigate confidentiality and bias concerns.

Should you have any questions about this request please contact any or all the project investigators: Dr. Kenneth Walsh, Dr. Kim Needy, and Dr. Thais Alves. Alternatively you might contact the Institutional Review Board at San Diego State University at irb@mail.sdsu.edu or 619-594-6622 for any questions or concerns about this project.

1. Contact information for follow up questions:

   The following information will ONLY be used for follow up questions and will NOT be associated with the rest of the questions in the final database used for analysis.

   Title: ________

   Name: __________

   Company: ________

   Phone: (Include **area code** and **country code** if outside USA or Canada) ________

   Email: __________

   Verify Email: ______

PROJECT DATA

For this section, please provide your answers while trying to leave out as much individually identifying information as possible. Items 2 and 3 are for internal use by the academics only, and will not be shared in any publications or with any industry members of the research team, but are requested only to support follow-up questions (if any), general understanding of the project, and linking P.O.s on the same project.

2. Project Name:
   ____

3. Brief description of project for which this P.O. was initiated:
   ____

4. Project location (Country if outside U.S., State if inside U.S.):
   ____

5. Project size (estimated total installed cost, should be an order of magnitude value, is it more like e.g. $1M, $10M, $100M) Including engineer, procure, and construct price to the owner: ______________________________________
6. Indicate your role on this project (contractor, owner, supplier): ______________________________

P.O. BASIC DATA

7. P.O. Number (note, this is a reference you should apply only to this response, that should be different from your internal P.O. number): ____
8. Total value of P.O. (US $): ____
9. Brief description of what was purchased: ____
10. Primary location of supplier's facility (not headquarters, but rather where the bulk of the supplied material for this P.O. came from): ____
11. Did the supplier subcontract a significant portion of the work for this P.O.? (As compared to other purchases) Yes/No
12. **If <u>Yes</u> for Question 11,** was this expected at the time the supplier was selected? Yes/No
13. **If <u>No</u> for Question 12,** when did it become clear that the work was going to be subcontracted? ____
14. P.O. Award Date: ____
15. Date of *release to ship* from the supplier's facility. For P.O's that had multiple deliveries, use the *first* release to ship date. If the release date is not known, please provide the ship date from the supplier's facility: ____
16. Date material received on the site. For P.O's that had multiple deliveries, use the date of the *first* arrival at the site: ____
17. Estimated *date of mechanical completion* for supplied material. Throughout this instrument, "mechanical completion" refers to the physical installation of the item into the facility, onto foundation, piped, wired, with fluids added as appropriate. For P.O.s with multiple deliveries, use the date of the *last* installation. An estimate of this date is acceptable: ___________________________________
18. Was the supplier selected from your activities, or was the selection driven by some other criterion: (e.g. In-country manufacturing requirement of contract, Direction to use owner-selected supplier)

____

19. What was the criticality level assigned to this P.O. (low, medium, high, critical)? ________________

PRACTICES

Please answer the following questions in regards to the relationship with this particular supplier, for this particular P.O.

20. Did you have a person in the supplier's facility to observe the supplier's work?

    ____Not at all

    ____Full time (resident)

    ____Part time (_____ % time)

    ____ Occasionally, Randomly, or Periodically (specify below _____# days)

    ____Final only

    _____Neither

21. Do you track hours, cost, or both, none?
22. If available, how many hours were used for inspection on this P.O (this would include hours spent in item 20): ______
23. If available, estimated cost for inspection on this P.O. (this would include cost spent in item 20): ______
24. Were your inspection personnel contract, staff personnel or both?
25. Was there a Quality Control Plan/Inspection and Testing Plan (ITP) used for this specific P.O.? Yes/No
26. **If Yes for Question 25**, were all steps in the above plan followed? Yes/No
27. **If No for Question 26,** Explain why not?
    ____
28. **If No for Question 26**, what percentage of inspections/tests on the ITP ended up NOT being conducted: ____________%
29. Was the Inspection and Testing Plan (ITP) revised due to issues that arose during execution? Yes/No
30. Did you conduct meetings with the supplier to discuss quality processes that should be conducted? (Check all that apply)

    ____ Pre-award meetings related to the quality function

    ____ Post-award, pre-execution related to the quality function

    ____ Pre-inspection meetings

    ____ Meetings during execution related to the quality function

    ____ Lessons learned meetings after execution to discuss quality outcomes and potential improvements

31. Did you conduct a performance rating of the supplier after execution? Yes/No
32. Did you include ratings of *prior* performance in determining whether or not to select this supplier for this specific P.O.? Yes/No

33. **If Yes for Question 32**, what characteristics of the prior performance did you consider? (Give a list) ____(Open-ended in Survey Select)
34. Did you project the cost of your inspection effort with this supplier for this P.O.? Yes/No
35. **If Yes for Question 34**, was the final actual cost of that effort measured? Yes/No
36. **If Yes for Question 35**, how did it compare to the estimate? (% Higher, negative number for lower than expected cost): ____
37. Did the supplier have a registered/certified Quality Management System (QMS) in place at the time the P.O. was issued? Yes/No
38. **If Yes for Question 37**, please list all relevant or important registrations/certifications held: ____(Open-ended in Survey Select)
39. Do you prefer to select suppliers with a registration/certification? Yes/No
40. What OTHER PRACTICES that you believe are CRITICAL to your procurement quality process were not identified or recognized by questions 20-39? Explain?

____

____

41. TO CONTINUE, CHOOSE ONE OF THE OPTIONS BELOW:

(Note: In order to match the numbering scheme in Survey Select, these pointers must be kept as "Question 41" but there is no real question to be answered here)

- If P.O. Was for *Tagged/engineered equipment* skip to question # 42.
- If P.O. Was for *Fabricated goods;*

  For structural steel, skip to question # 48.

  For pipe spools, skip to question # 55.
- If P.O. Was for *Manufactured/bulk* goods (only for non-engineered/bulk valves) skip to question # 61.

OUTCOMES

FOR TAGGED/ENGINEERED EQUIPMENT

42. Total number of items for this P.O. ____
43. Did you identify any discrepancies or non-conformances during execution in the shop, prior to release to ship? Yes/No
44. If available, Total number of discrepancies and non-conformances noted during execution in the shop ____________________
45. Total number of items identified as unacceptable at release to ship from shop? If no final inspection was performed, answer N/A. ____

46. Total number of items identified as unacceptable when received on site? If no inspection was performed, answer N/A.

    ____

47. Total number of items identified as unacceptable at mechanical completion at the site? If no inspection was performed, answer N/A.

    ____

FOR FABRICATED GOODS - STRUCTURAL STEEL

48. Total number of tons (ton=2,000lb) of structural steel for this P.O.

    ____

49. If available, approximate number of pieces of steel represented by the answer to Question 45: ____

50. Did you identify any non-conformances during execution in the shop prior to release to ship? Yes/No
51. If available, total number of pieces of steel for which discrepancies and non-conformances were noted during execution in the shop_______________________________________
52. Total number of pieces of steel which were identified as unacceptable at release to ship from shop? If no final inspection was performed, answer N/A.

    ____

53. Total number of pieces of steel which were identified as unacceptable when received on site? If no inspection was performed, answer N/A.

    ____

54. Total number of pieces of steel which were identified as unacceptable at mechanical completion? If no inspection was performed, answer N/A.

    ____

FOR FABRICATED GOODS - PIPE SPOOLS

55. Total number of pipe spools for this P.O.

    ____

56. Did you identify any non-conformances during execution in the shop prior to release to ship? Yes/No
57. If available, total number of pipe spools for which discrepancies and non-conformances were noted during execution in the shop: ____
58. Total number of pipe spools identified as unacceptable at release to ship from shop? If no final inspection was performed, answer N/A.

    ____

59. Total number of pipe spools identified as unacceptable when received on site? If no inspection was performed, answer N/A.

    ____

60. Total number of pipe spools identified as unacceptable during installation at the site? If no inspection was performed, answer N/A.

    ____

FOR MANUFACTURED/BULK GOODS - NON-ENGINEERED/BULK VALVES

61. Total number of non-engineered valves for this P.O. ______________
62. Did you identify any non-conformances during execution in the shop prior to release to ship? Yes/No
63. If available, total number of valves for which discrepancies and non-conformances were noted during execution in the shop: ____
64. Total number of valves identified as unacceptable at release to ship from shop? If no final inspection was performed, answer N/A.
    ____
65. Total number of valves identified as unacceptable when received on site? If no inspection was performed, answer N/A.
    ____
66. Total number of valves identified as unacceptable at mechanical completion? If no inspection was performed, answer N/A.
    ____

End of Survey

Thank you for volunteering your time to help RT-308 survey and improve supplier quality surveillance practices! Your help is greatly appreciated.

APPENDIX III: IRB Approval

UNIVERSITY OF
ARKANSAS

Office of Research Compliance
Institutional Review Board

October 3, 2012

MEMORANDUM

TO:	Kim LaScola Needy Rufaidah Alamaian Austin Strickland Kenneth Walsh Thais da C.L. Alves
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Approval
IRB Protocol #:	12-08-072
Protocol Title:	*Proactive Processes and Practices to Assure Procured Materials and Equipment Meet Applicable Requirements*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Approved Project Period:	Start Date: 10/03/2012 Expiration Date: 09/05/2013

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (http://vpred.uark.edu/210.php). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

This protocol has been approved for 40 participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 210 Administration Building, 5-2208, or irb@uark.edu.

210 Administration Building • 1 University of Arkansas • Fayetteville, AR 72701
Voice (479) 575-2208 • Fax (479) 575-3846 • Email irb@uark.edu

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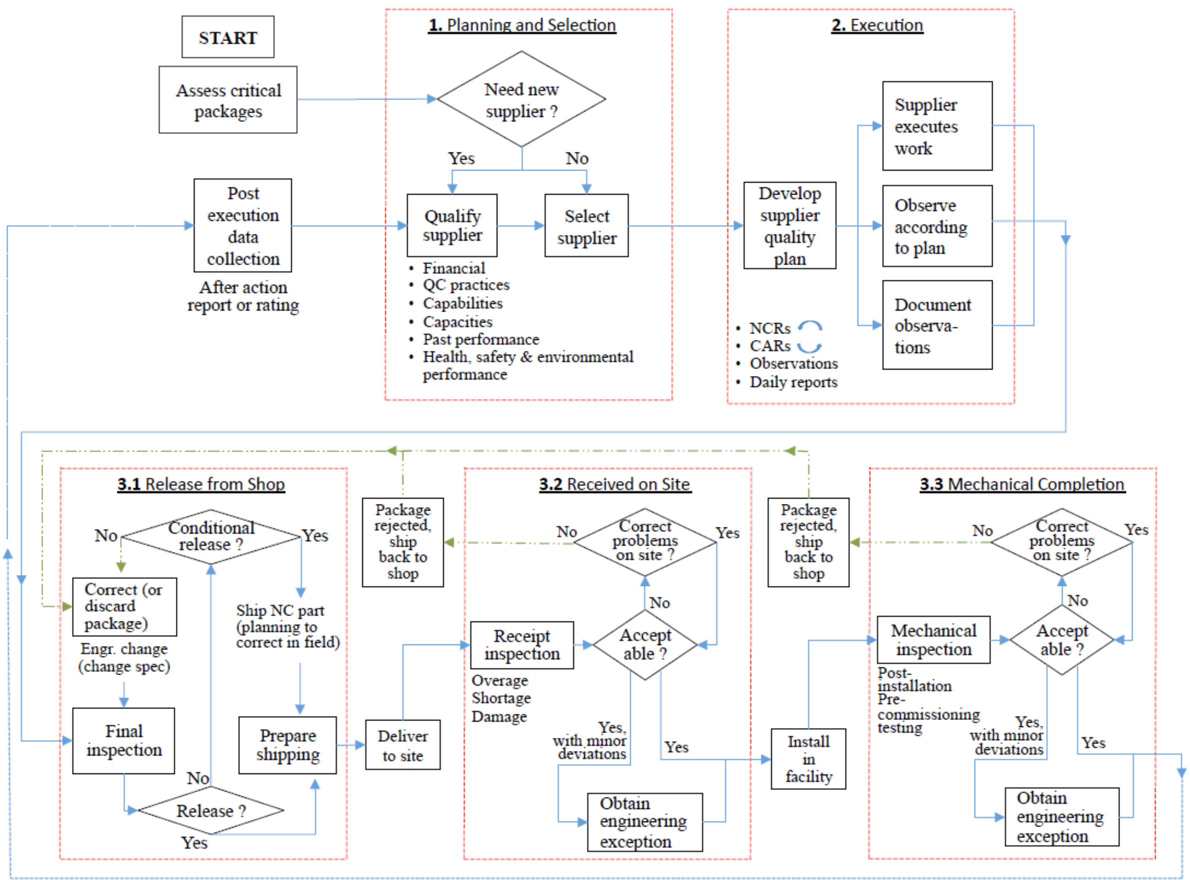
APPENDIX IV: Supplier Quality Process Map (Detailed)



Supplier Quality Process Map. From Alves et al. (2013)*

*Alves, T., Walsh, K., Neuman, Y., Needy, K., & AlMaian, R. (2013). Supplier quality surveillance practices in construction. *21st Annual Conference of the International Group for Lean Construction* – IGLC 21 – Fortaleza, Brazil, 833-842.

APPENDIX V: Multi-Author Documentation

UNIVERSITY of ARKANSAS

4207 Bell Engineering Center • Fayetteville, Arkansas 72701 • 479-575-3156 • 479-575-8431 (FAX)

College of Engineering
Department of Industrial Engineering

August 18, 2014

Graduate School and International Education
University of Arkansas
Fayetteville, AR 72701

Dear Graduate School and International Education:

I certify that Rufaidah AlMaian is the first author on the five publishable papers listed below and that she has completed at least 51% of the work for each of these papers.

Chapter 2
AlMaian, R. Y., Needy, K. L., Walsh, K. D., & Alves, T. (2014). Suppler quality management inside and outside the construction industry. Submitted to *The Engineering Management Journal* (under second review).

Chapter 3
AlMaian, R. Y., Needy, K. L., Walsh, K. D., & Alves, T. (2014). A Qualitative data analysis for supplier quality management practices in the construction industry. Submitted to *The Journal of Construction Engineering and Management* (Received a decision to revise for re-review).

Chapter 4
AlMaian, R. Y., Needy, K. L.,Walsh, K. D., & Alves, T. (2014). Analyzing supplier quality management practices in the construction industry using principal components analysis. In preparation for submission to *The Quality Engineering Journal.*

Chapter 5
AlMaian, R. Y., Needy, K. L., Alves, T., & Walsh, K. D. (2014).Using the balanced scorecard to implement effective supplier quality management practices in the construction industry. Submitted to *The Journal of Management in Engineering* (under review).

Chapter 6
AlMaian, R. Y., Needy, K. L., Alves, T., & Walsh, K. D. (2014). Analyzing effective supplier quality management practices using Simple Multi-Attribute Rating Technique (SMART) and Value Focused Thinking (VFT). Submitted to *The Journal of Management in Engineering* (under review).

Respectfully yours,

Kim LaScola Needy, Ph.D., P.E., CFPIM, PEM
Professor, Department of Industrial Engineering
University of Arkansas